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Disentangling shell middens: Exploring the complexities of deposit formation and transformation using amino acid racemisation

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I certify that any help received in the preparing of this thesis, and all sources used, have been acknowledged herein.

I certify that the substance of this thesis has not already been submitted for any degree, and is not currently being submitted for any other degree or qualification

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ABSTRACT

The archaeological record is a time-averaged palimpsest of material variably influenced by post-depositional processes. The aim of archaeology is to elucidate and inform on past human behaviour, however, the palimpsest nature of the archaeological record limits the potential for events on the scale of the individual and day-to-day life to be preserved. While some perceive this lack of temporal resolution as a hindrance, it rather presents an opportunity to investigate environmental and behavioural processes at a larger, broader scale. The delimiting and constraining of palimpsests to access this spectrum of temporal scales poses methodological and conceptual complications. It is this challenge that forms the focus of this thesis.

Shell middens, in many ways, magnify the effects of the palimpsest nature of the archaeological record through aspects such as their porosity and frequent lack of clearly visible stratigraphic differentiation. Complex and variable formation processes blur the spatial and temporal relationships of the material contained within a midden deposit. The vertical displacement of midden shell, the time-averaging of previously temporally distinct layers, as well as the muddying of the depositional patterning behind midden formation are all issues that complicate behavioural and palaeoenvironmental interpretations. The midden within the Brremangurey rockshelter, located in the Kimberley region of Western Australia's far north, embodies this conundrum. During excavation and analysis of the midden, clues were identified that pointed towards a far more complex formation and transformation history than initially thought. Precisely to what extent, though, would be problematic to determine using conventional techniques.

The typical approach to refining the formation processes of shell middens relies on radiocarbon dating. Greater number of samples provide enhanced resolution, but at a considerable cost. Amino acid racemisation (AAR) is a low-cost relative dating technique that has not been widely

incorporated into archaeological investigation. In the context of shell midden archaeology, the potential of AAR in resolving issues of site formation and transformation comes from the ability to analyse a large number of samples to establish a high resolution relative chronological sequence of a midden deposit. Recent refinements to the AAR method improve the technique's accuracy and precision, making it more amenable to the temporal scales at play within these specific archaeological contexts. To test the applicability of this novel use of AAR, this approach was applied to the material excavated from the Brremangurey rockshelter.

The use of AAR dating to establish a high resolution relative chronology of the Brremangurey midden deposit managed to address a range of problems commonly encountered in shell midden archaeology. The temporality and spatial origins of vertically displaced shell could be recognised allowing the integration of *ex situ* material to the archaeological interpretations. A time-averaged layer was disentangled, and the relative contributions of each phase of deposition to be identified, adding more detail to the formation history of the midden deposit. Most importantly, the application of AAR and 'Temporal Packaging' presented a detailed picture of the depositional patterning of the Brremangurey midden deposit.

A complicating aspect of the archaeological record is that the scales of temporal resolution recorded within a palimpsest are hidden. This denies the investigator the opportunity to appropriately adjust their scale of investigation to the scale of evidence the archaeological record can support. Not only were AAR and Temporal Packaging able to refine the chronology of a midden deposit, but also allowed the previously inaccessible temporal resolution contained within a deposit to be defined.

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TABLE OF CONTENTS

Appendix 1

Print version of: **Koppel, B.**, Szabó, K., Moore, M.W. and Morwood, M.J. 2016. Untangling time-averaging: Defining temporal units using amino acid racemisation. *Journal of Archaeological Science: Reports*. 7: 741-750.

Appendix 2

Print version of: **Koppel, B.**, Szabó, K., Moore, M.W. and Morwood, M.J. 2017. Isolating downward displacement: The solutions and challenges of amino acid racemisation in shell midden archaeology. *Quaternary International.* 427: 21-30.

Appendix 3

Print version of: Szabó, K., **Koppel, B.**, Moore, M., Young, I., Tighe, M. and Morwood, M.J. 2015. The Brremangurey pearl: A 2000 year old archaeological find from the coastal Kimberley, Western Australia. *Australian Archaeology*. 80: 112-115.

LIST OF FIGURES

LIST OF TABLES

Chapter 1 – Shell middens and the nature of the archaeological record

Introduction

In 2011, in the northern Kimberley region of Western Australia, a shell midden located at a site called Brremangurey was excavated. During the examination of the Brremangurey midden, it became clear that the deposit as a whole formed through a complex and multiphase series of formation processes. These already complex patterns were obscured through the influence of post-depositional movement of material within the deposit, and further exacerbated by the decision to excavate the site in arbitrary levels, or spits.

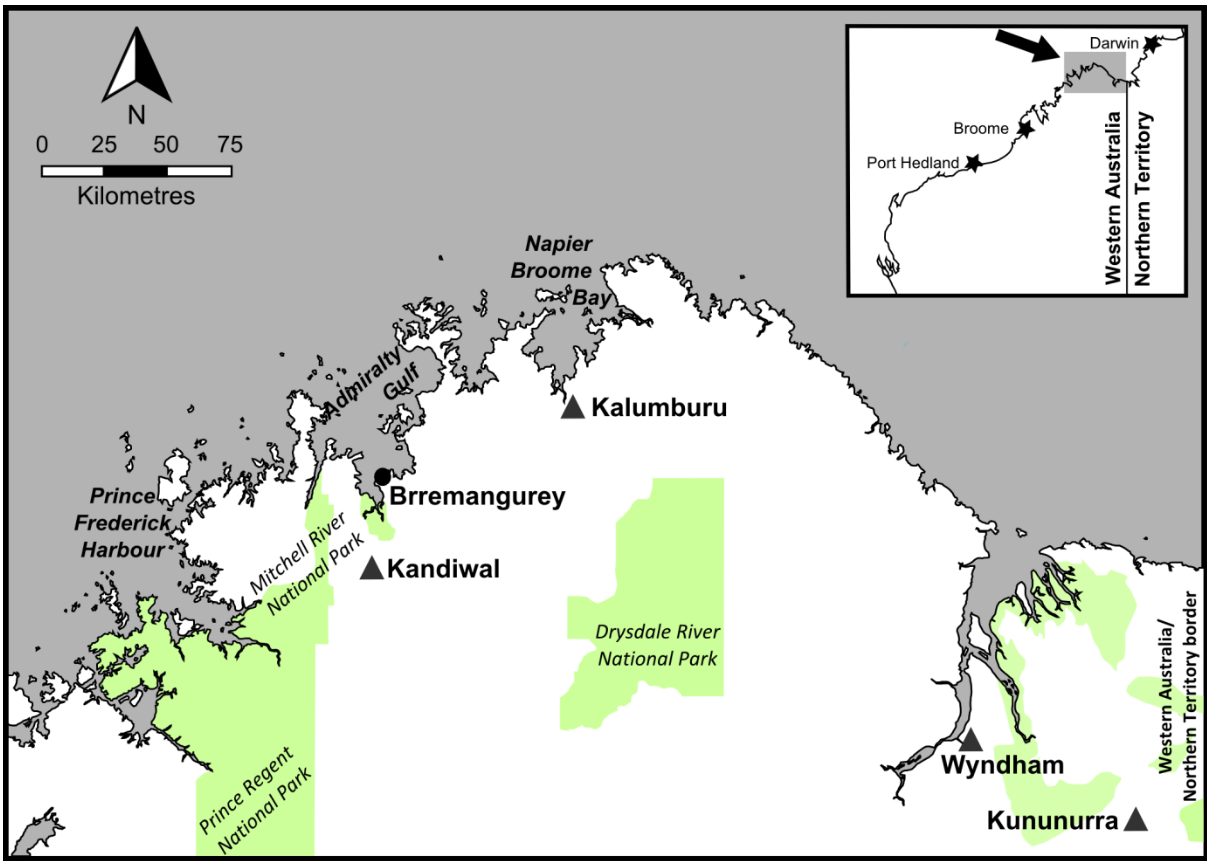


Figure 1.1 – Location of Brremangurey and surrounding region.

The example of Brremangurey is not an unusual case within midden archaeology across the globe. Complex formation histories and the impact of transformation processes are common issues that need to be addressed. Similarly, the case of Brremangurey also represents the typical approach in which shell middens are excavated in some regions of the world. All of these factors potentially muddy interpretations regarding the behaviours of the people that created the site. To appropriately describe and interpret depositional behaviours, these processes need to be untangled. This thesis presents new methodological approaches to analysing and interpreting shell middens within archaeological investigation.

Defining shell middens

Shell middens are often written about, though rarely explicitly defined. It appears as though archaeologists studying shell middens have preconceived notions of what shell middens are, and what they represent (e.g. Stein 1992:8, Hardy 2016:30 and discussed further later in this chapter). The analysis of middens began with Worsaae, who investigated the origins of the large shell mounds of the Danish fjords in the mid-19th century, though it was the material culture within the mounds that he principally focussed on, and not the shell itself (e.g. Steenstrup *et al.* 1851, Morlot 1861:14-23, Troels-Smith 1967:505, Trigger 1989:82, Gräslund 1987:36). This approach to midden analysis, almost entirely treating a midden as a receptacle for artefacts, continued well into the 20th century (e.g. Earl 1863, Laing 1865, Morse 1879, Ihering 1896, Colson 1905, Uhle 1907, Kroeber 1909, Body 1913). The view of shell middens among archaeologists began to change in the mid-20th century, when the California School of midden analysis introduced an economic perspective, and brought the investigation of the shell itself to the forefront of investigating midden deposits (e.g. Cook and Treganza 1950, Ascher 1959, Shawcross 1968). Since then, the analysis of shell middens has diversified as archaeologists began to understand more and more about these particular deposits, and the human behaviours behind their formation.

In the archaeological literature, definitions of shell middens largely centre across two main themes: the form and composition of a deposit, or the agency of deposit formation. As examples for the former, Vila *et al*. (2009:109) defines shell middens as "… a sort of archaeological site characterised by high accumulations of shells", and Szabó (2016:772) describes shell middens as "a refuse deposit in which molluscan shell is one of the major constituent materials", among others. For the latter, Stein (1992:6) defines a midden as "an accumulation of refuse about a dwelling place", while Aldeias and Bicho (2016:1) describe shell middens as "the by-product of human reliance on marine resources". Some authors have presented a definitions centred on both compositional factors and processes of formation, for example Bahn's (1992:453) definition of "an archaeological deposit consisting primarily of mollusc shells resulting from food procurement activities" (see also Erlandson *et al*. 1988:102, Álvarez *et al*. 2011:1).

All of these definitions are rather generalising in their descriptions of shell middens. In a sense, this is necessary, considering the range in which shell middens manifest on the archaeological landscape in both form and composition. For example, large mounded middens of northeast Australia and the Western Cape of South Africa (e.g. Bailey 1977, Parkington 2012), or the thin and diffuse, but spatially broad shell middens of the Lapita cultural complex across the Pacific (e.g. McNiven *et al*. 2011), as well as the ring and horseshoe shaped middens of Sapelo in Georgia, North America (e.g. Thompson 2007). Similarly, composition in middens can vary substantially as well, with deposits being dominated by marine (e.g. Uhle 1907), freshwater (e.g. Balme and Hope 1990, Morey and Crothers 1998) and terrestrial (e.g. Lubell 2004, Lombardo *et al*. 2013) mollusc species. This variety in midden deposits also includes the cultural significance and extra-economic importance behind midden deposits (e.g. Luby and Gruber 1999, Henderson *et al.* 2002, Faulkner 2009, Marquardt 2010, Russo 2014), which includes the growing research into ritualised middening practices (e.g. McNiven and Feldman 2003, Milner 2005, McNiven and Wright 2008, McNiven 2004, 2010, Thompson and Pluckhahn 2012, Thompson and Moore 2015). With this breadth of midden form and function associated with shell middens in mind, I use the term 'shell midden' in a broad sense, most closely aligned with Szabó's (2016:772) definition presented earlier.

Considering the broad range of shell midden form and function across the archaeological landscape, attempts have been made to refine shell middens into more specific categories based on the characteristics of the deposit, representing varying types or intensities of depositional behaviour. A survey of the literature indicates that there have been three different approaches used in this refinement of shell midden types. Firstly, researchers have used the pure metrics of midden morphology where deposit size is used to differentiate between classes of midden deposits. Bailey *et al*. (2013) adopts this approach in differentiating between scatters, low mounds and mounds in Saudi Arabia's Farasan Islands, as does Cochrane in separating shell middens and mounds in Queensland, Australia (Cochrane 2014, discussed in more detail in Chapter 2 of this thesis). A second approach to categorising middens utilises the characteristics of the archaeological material itself. McManamon (1984) uses density indices of cultural material within midden deposits to define four different types of midden deposits: primary refuse and limited activities, primary refuse and wide range of activities, secondary refuse shell midden, and secondary refuse general midden. Widmer (1989 as applied by Claassen 1998) centres his classifications on the interpreted behavioural processes behind midden deposition (Claassen 1998:11) in defining his four midden types: shell midden site, shell midden, shell-bearing site, and shell-bearing habitation site.

A third approach in classifying shell middens comes from incorporating ethnographic analogy in describing categories of middens and patterns of deposition in archaeological deposits (e.g. Kirch and Dye 1979, Waselkov 1987:96-117, Thomas 2002, Jerardino 2012:77). Villagran *et al.* (2011) combine ethnohistorical accounts of shellfish deposition with micromorphological analyses to differentiate between differing functional areas of midden deposits in a site in Tierra del Fuego, Argentina. Connuaghton *et al.* (2010) presents a case arguing that a portion of midden assemblages of Tongan middens, valves of *Anadara antiquata* with detached umbos, are the result of a 3,000 year old game played by people in which shells are struck until fractured – an interpretation based on observations of contemporary locals. Similarly, Hardy *et al*. (2016) uses the formation of contemporary middens in Senegal whose interpretations raise questions regarding the immediate assumption of archaeological middens representing localised subsistence practices, presenting the broad range of processes, including the gathering and processing of shellfish for long-distance trade as well as ceremonial practices that result in shell midden formation. Betty Meehan's influential anthropological study of the indigenous An-Barra people of Australia's Northern Territory (1982) is arguably the prime example of ethnographic analogy contributing to archaeological interpretations and explanations of prehistoric shellfish gathering and midden formation (e.g. Mannino and Thomas 2002, Thomas *et al*. 2002, Marquardt 2010).

The representation of time in shell middens

Ethnographies allow the recording of events in exceptionally high resolution where, with specific regards to shell middens, each individual depositional event can be observed as material enters an archaeological context (e.g. Meehan 1982, Bird and Bliege Bird 1997, Villagran *et al*. 2011). The ability to capture depositional events on such a fine temporal scale that ethnographic analogy provides is an attractive course in interpreting patterns in archaeological deposits; "[i]t is to ethno-archaeology, however, that we turn for a methodology of *control* [sic] for an integrating framework that permits a more analytically rigorous reconstruction and interpretation of the disparate archaeological evidence" (Kirch and Dye 1979:55). However, whether or not our methods in investigating the archaeological record can facilitate the level of resolution of individual depositional events is another question.

There exists a spectrum of what is perceived to be preserved in shell middens, and the assumptions of what is preserved within a shell midden and how it is preserved directly affects the manner in which material is approached and analysed (Claassen 1991:254). On one side of the spectrum are those who perceive shell middens as “a deflated mass of multiple deposits, the stew from millennia of activities” (Claassen 1991: 254 citing Begler and Keatinge 1979: 220), and on the other hand, that shell middens preserve discrete periods of deposition “each conflated with and separated by the shells deposited along with the other debris” (Claassen 1991:254). Put another way, the former sees a shell midden as an irreconcilable and homogenised mass, compared with a midden representing phases of deposition somewhat distinguishable in both time and space. These perceptions directly influence the manner in which excavation strategies are conducted. Those who see a shell midden as a homogenised mass will tend to excavate in units of arbitrary thickness as the temporal distinctions are taken to have been lost through the process of deposition and subsequent post-depositional processes (e.g. Vila *et al*. 2009:109, Villagran *et al*. 2011:588). Conversely, an alternative approach to excavation is sought by those who see middens as a sequence of discrete depositional episodes where units are excavated according to clearly defined and distinct stratigraphic characteristics (Claassen 1991:254).

A unit excavated using natural stratigraphic horizons is defined by the confluence of different processes (Estevez *et al*. 2013). Each stratum is defined by a set of criteria, which can include species representation, sediment texture and colour among others, and is treated as an independent population to be sampled, thereby seeking to avoid the conflation of material from two distinct and separate strata representative of different depositional and chronological episodes (Waselkov 1987:150). Excavation by arbitrary levels, or spits, imposes spatial boundaries on an archaeological deposit regardless of observable features in the material being excavated (e.g. Estevez *et al*. 2013:109, Harris 2014:15) and likely combines units with potentially substantial differences in age into one time-averaged layer. Harris states that “[b]y imposing the arbitrary strategy of excavation on sites with clear stratification, archaeologists destroy the primary data they seek” (Harris 2014:20), the primary data being material in, or as close as possible to, their depositional context. In an ideal scenario, the excavation process should facilitate the establishment of the heterogeneity of material within a deposit (Waselkov 1987:150), and this is compromised when material from distinct layers are combined and homogenised. In saying this, however, excavation via spits is a favoured option is when stratification is not present or visible, and spatial control of excavated material needs to be forced onto a deposit, rather than defined by it (e.g. Ambrose 1967:177, Waselkov 1987:144, Peacock *et al*. 2005). A third option of sub-dividing distinct individual strata into arbitrary layers has also been carried out (e.g. Chadderon 1983).

With each approach – arbitrary versus stratigraphic units of excavation – the implications regarding the temporal range represented within each unit has to be considered. We cannot disentangle shell middens to the resolution of individual mealtimes. Instead, we have to work with a series of palimpsests – the agglomerated accumulation of previously temporally distinct events into one time-averaged unit (the "cumulative palimpsest" of Bailey 2007:207, see further discussion below). Temporally, by excavating via natural stratigraphy, the time represented within a unit is defined by the features of the excavated material (colour, grain size, patterns of fragmentation etc., see Harris 2014:15), and while extracting depositional events of the resolution of the discarded shell from a single mealtime is unattainable (but see Villagran *et al*. 2011), the separation of temporally discrete phases of deposition is possible. Excavating via spits potentially conflates temporal distinctions, exacerbating the palimpsest-nature of shell middens, and arguably the archaeological record in general, by expanding the envelope of time present in an excavated unit.

With this in mind, how do archaeologists engage with the nature of the material record where behaviours and processes are amalgamated in an agglomeration of depositional episodes of variable time spans? Many authors have written on the theoretical concepts of time, temporality, and how these concepts are represented and interpreted in archaeological contexts (e.g. Bintliff 1991, Gosden 1994, Van der Leeuw and McGlade 1997, Thomas 1998, Murray 1999, Bradley 2002, Harding 2005, Lucas 2005). While there is considerable merit and pedigree to these varying approaches, in the specific instance of the Brremangurey midden and the patterns and complexities identified within, Bailey's 'time perspectivism' approach (Bailey 1981, 1983, 1987, 2005, 2007, 2008) to temporally contextualising archaeological material is most applicable.

Defining and working with 'Time Perspectivism'

Time perspectivism, as originally defined by Bailey, is "the belief that differing time-scales bring into focus different features of behaviour, requiring different sorts of explanatory principles" (Bailey 1981:103). In a variation on this original definition, Lucas' (2005:29) interpretation of time perspectivism states that "different processes or phenomena operate at quite different temporal scales". Put another way, processes only become observable when viewed through the appropriate temporal perspective. Defining time perspectivism in more detail reveals the complexity and ambiguity contained behind the term, and Bailey (2007:202-204) outlines four distinct ways in which 'time perspectivism' can be defined and interpreted:

1) Firstly, the definition that most closely resembles the initial description of 'time perspectivism and how the term is most commonly interpreted: "different phenomena operate at different time spans and at different temporal resolutions" (Bailey 2007:202).
2) Secondly, that "different sorts of phenomena are best studied at different time scales" (Bailey 2007:202). Bailey's argument here is that the time-depth of investigation influences the ability to properly describe and interpret processes. For example, small scale phenomena, Bailey uses the example of individual agency, is best studied in the present day or historic past where the temporal resolution is of a fine enough detail to be able to adequately record, describe and contextualise the behaviour. He stresses that this is not to say that "these phenomena did not exist in the deeper past and have a similar impact on past lives… but that these phenomena are much more difficult to investigate in earlier periods because of poorer resolution, quality and detail of the available data" (Bailey 2007:202).Bailey describes this definition as a methodological definition of time

perspectivism, and specifically relates to how archaeologists wield archaeological data in building interpretations about the past.

3) Bailey's third definition centres on the dual nature of 'perspectives' in interpreting time and the past (Bailey 2007:203-204). First, things become more and more distorted and obscured with increasing distance (be that time or spatial distance); and secondly, how an awareness of perspective allows the relationships between processes seem to shift and refocus with varying scales of perception based on available information. "'Perspectivism' in this sense is a double concept, conveying both the negative effect of distortion with increasing distance that needs to be corrected, and the positive effect of putting into their proper relationship different scales of spatial patterning" (Bailey 2007:203).
4) The fourth definition considers the subjective nature of the perception of time, how symbolic and cognitive observation of time is conditioned by various socio-cultural and physiological factors. This definition incorporates how people place themselves in relation to the past, present and future, as well as how we in the present perceive of people and their behaviours in the past. Succinctly summarised by Bailey: "an exploration of the different ways in which people, both past and present (including archaeologists), have thought about the time dimension and their place within it" (Bailey 2007:204).

These four definitions offer a theoretical framework through which researchers can structure their approach to archaeological investigations based on 1) the temporal/spatial scale of their line of questioning and the scale of processes being investigated; and 2) the scale, span and resolution of data afforded to them by the archaeological record. It is recognised by Bailey that these differing definitions and interpretations of time perspectivism can be problematic in their implementation in practical archaeological contexts. The key in successfully applying time perspectivism to the archaeological record, he argues, lies in palimpsests (Bailey 2007:204).

The use of the term palimpsest in archaeological contexts refers to the aggregation, reworking, complete or partial erasure, complete or partial preservation of the material traces of behaviour and human activities in the material record (e.g. Wandsnider 2004, Hull 2005, Lucas 2005, Holdway and Wandsnider 2006, Bailey 2007, Stern 2008, Sullivan 2008). Palimpsests are the accumulated material remains of multiple behaviours, and thus represent a pocket of evidence averaged over the time-breadth of the palimpsest. Despite the negative stance towards palimpsests as a function of the archaeological record (e.g. Wauchope 1966:19), arguments towards palimpsests being an asset to archaeological investigation have also been advocated (e.g. Bailey 1981:110, 2007:205, Binford 1981:197, Foley 1981:14). The "accumulative and transformative properties of palimpsests" (Bailey 2007:205) offer the opportunity to observe processes and behaviours in an empirical sense on a larger scale than what is possible through the lens of ethnographic investigation. With this view in mind, palimpsests are consequently the tools by which time perspectivism can be applied to the archaeological record.

Bailey (2007:205-215) distinguishes palimpsests as they appear in archaeological contexts into five principle categories, once again, a brief summation of each is presented below:

1) *True palimpsests*

True palimpsests in archaeological contexts are the closest representation to the denotative definition of palimpsests: where all material traces or evidence of previous activities or behaviours have been removed except for the most recent. It is recognised by Bailey that it may be impossible to distinguish between a true palimpsest as it appears on the archaeological landscape and the remains of a single depositional episode (Bailey 2007:206-207), however clues may be present in the nearby vicinity that would suggest the presence of a true palimpsest; secondary refuse from repeated episodes of sweeping or cleaning for example (Bailey 2007:207).

2) Cumulative palimpsests

Unlike a true palimpsest which is characterised by a loss of material, a cumulative palimpsest is where the material from successive behaviours is not lost but is mixed and reworked into a single unit. The process of a cumulative palimpsest forming has also been referred to as time-averaging (e.g. Stern *et al*. 1993:215, Stern 1994, Peacock 2000, Lyman 2003), and has been considered to be the most commonly used interpretation of palimpsests in archaeological contexts (Bailey 2007:207). Bailey states that a feature of the cumulative palimpsest is less a loss of material evidence, as in the true palimpsest, but a loss in temporal resolution obfuscating the boundaries between individual events (Bailey 2007:207).

3) Spatial palimpsests

Spatial palimpsests are defined as “a mixture of episodes that are spatially segregated, but whose temporal relationships have become blurred and difficult to disentangle” (Bailey 2007:212). This in a sense is similar to a cumulative palimpsest, where there is a general preservation of material, to a degree, however it is spread over a relatively broad geographical area. A distinction between the spatial palimpsest and the cumulative palimpsest is the interaction and influence of larger geomorphological- or landscape-scale processes such as hillslope erosion or deposition in a sedimentary basin (Bailey 2007:212).

4) Temporal palimpsests

Where a spatial palimpsest describes the spread of segregated pockets of material evidence across a broad spatial scale, a temporal palimpsest refers to a unit or site comprised of a spread of temporally distinct materials as a direct result of the process of deposition. This is a clear distinction from the cumulative palimpsest mentioned above, as the mixing process occurs as one group of material intermingles with the other during deposition. In temporal palimpsests, many different temporally distinct materials are deposited as a single event (Bailey 2007:212-213). Bailey uses the example of Olivier’s (1999) find of the ‘princely’ grave site uncovered at Hochdorf, southern Germany, where artefacts spanning many different temporalities were intentionally brought together during the funerary process. Thus, the grave site represents a temporal palimpsest of material Bailey 2007:213).

5) Palimpsests of meaning

A more subjective form of palimpsest refers to the varied and changing meanings of an object, site, or other feature of the archaeological landscape through time. Lucas (2005:41) hints at the changing meanings of Stonehenge through the Bronze Age, Roman Period, and the modern day: the same feature, but with different meanings attached to it through various points in time. Another example, presented by Bailey (2007:214), is of a flint knife that, through use, becomes repurposed as a scraper through the attrition of the tool's use and its re-modification. The same object, albeit in a slightly different form, but its meaning changes through time.

It is not a long draw of the bow to see the applicability of the concept of palimpsests to shell middens, though some of the categories of palimpsests are more straightforward in their application than others. Cumulative and true palimpsests are the most applicable. Shell middens generally represent the repeated deposition of shell in a location, clearly placing them under the banner of a cumulative palimpsest. Agents of transformation of shell middens, both natural (e.g. Stein 1983, Dwyer *et al* 1985, Specht 1985, Rick 2002, Robins and Robins 2011, Szabó 2012) and cultural (e.g. Meehan 1982:114, Ceci 1984:64, Muckle 1985, Connock *et al*. 1991, Schiffer 1996, Luby and Gruber 1999), have been known to completely or partially remove, or displace midden material post-depositionally, thereby resulting in a true palimpsest as additional episodes of deposition are superimposed on top. Spatial palimpsests by definition encompass broad geographic areas, so this particular type does not necessarily lend itself as neatly in discussing a discrete deposit such as a midden site; however an argument can be made for its applicability in discussing regionally associated complexes of shell midden deposits (e.g. Bailey 1977, Jerardino and Yates 1997:43, Luby and Gruber 1999, Rick *et al.* 2005, Claassen 2012). Temporal palimpsests can manifest in shell middens with the inclusion of significantly older material mixed with relatively younger objects in the same episode of deposition, for example old artefacts being deposited along with recently collected shellfish (e.g. Rick *et al*. 2005:1644). Finally, palimpsests of meaning can be explained in shell midden deposits as the cultural meaning or interpretations attached to a midden deposit potentially changes through time. For example, how the cultural significance of the large shell middens of coastal central Arnhem Land in the Northern Territory has been interpreted to have shifted from strictly as a by-product of an economic/subsistence behaviour, to then become mythologised through time through stories being passed down from generation to generation of Indigenous Australians (e.g. Hiscock and Faulkner 2006:216-217).

In working with palimpsests, particularly with cumulative palimpsests, Bailey describes two differing approaches: the 'macroscopic' and 'microscopic' tendencies. The former sees the archaeologist view the palimpsest as a whole data set, or expands the palimpsest to incorporate a broader range of processes, whereas the latter aims to reduce a palimpsest into units of higher resolution (Bailey 2007:216). While there is merit to both approaches, archaeologists typically tend towards the microscopic tendency as they look to 'deconstruct' archaeological deposits with an aim of interpreting behaviours and processes on a smaller, more refined temporal scale. Reducing a site into smaller parts provides the opportunity to compare patterns of continuity and change through a deposit which would otherwise be obscured with a larger-scale perspective. That is not to say that the macroscopic approach is not valid, as stressed by Bailey (2007:217), but is more appropriate in identifying, observing, and questioning processes on a larger spatial or temporal scale.

In implementing the microscopic tendency, an archaeological deposit is 'deconstructed' into a series of layers or units, either following natural stratigraphic elements such as substrate composition, colour or texture, or in excavation units of regular, arbitrary depths (e.g. Harris 2014:15). Each of these still represents a palimpsest, though a palimpsest representing a finer spatial and temporal resolution compared to the palimpsest of the whole shell midden in its initial form. Spatially, the distinction between layers is defined by a set of predetermined criteria, some of which are mentioned above. Temporally, however, in the sense of how much time is represented within an arbitrary spit or natural stratigraphic stratum, far less control can be exercised by the excavator. This is due to the fact that the temporal range present within an excavated unit only becomes apparent after the material is dated; assuming the lack of other indicators of age, such as typologies of material culture (e.g. Willey 1939:147, Álvarez *et al* 2011:1). The reality of temporal 'knowns' and 'unknowns' is a complicating aspect of the archaeological record. We cannot appropriately scale our level of investigation based on the temporal resolution afforded to us by the material we have excavated if we do not have a firm grasp on the chronology of the material in the first place. Put another way, no amount of precision with regards to excavation and recovery methodologies can circumvent the problem of an unknown temporal span.

This raises a problematic aspect about dating archaeological deposits. A single age determination from a unit will give you a single age (or more appropriately an age range considering the inherent error margins of chronometric dating methodologies). Two age determinations will provide a maximum and minimum age which then represents an envelope of the time represented within the unit. Whether or not this range actually represents the true chronological extent of the material being investigated is another question. The likelihood of selecting the oldest and youngest specimens from within a sample is low, especially in contexts such as shell middens where vast numbers of individual specimens are available for dating.

A study conducted by Stein *et al*. (2003) demonstrated the complexities of dating shell midden deposits resulting from variable rates of accumulation rates during midden formation and the complicating effects of undetected post-depositional movement of midden shell. Borrowing approaches from the geological sciences, Stein *et al*. (2003:298-300) isolate a maximum and minimum age from material dated within a shell midden layer and compared this age range with the amount of physical archaeological material, measured as depth, to quantitatively establish the time layers within a shell midden took to accrete (Stein *et al.* 2003). One of the major points advocated by

Stein *et al.* is that a more rigorous dating program through the increased number of analysed samples will provide a more accurate rate of accumulation (Stein *et al* 2003:314). In principle, this is a fair point, as an increased number of dated specimens of midden shell results in a more representative sample of ages of the site as a whole. The approach exercised by Stein *et al*. (2003) is therefore an attempt at chronological refinement – but how far and to what extent must chronological refinement be extended to start building reliable interpretations of behavioural patterning of ancient people? To what extent can linear accumulation rates expressed as an equation be extended towards explaining and describing the behaviours that ultimately created the shell midden in the first place?

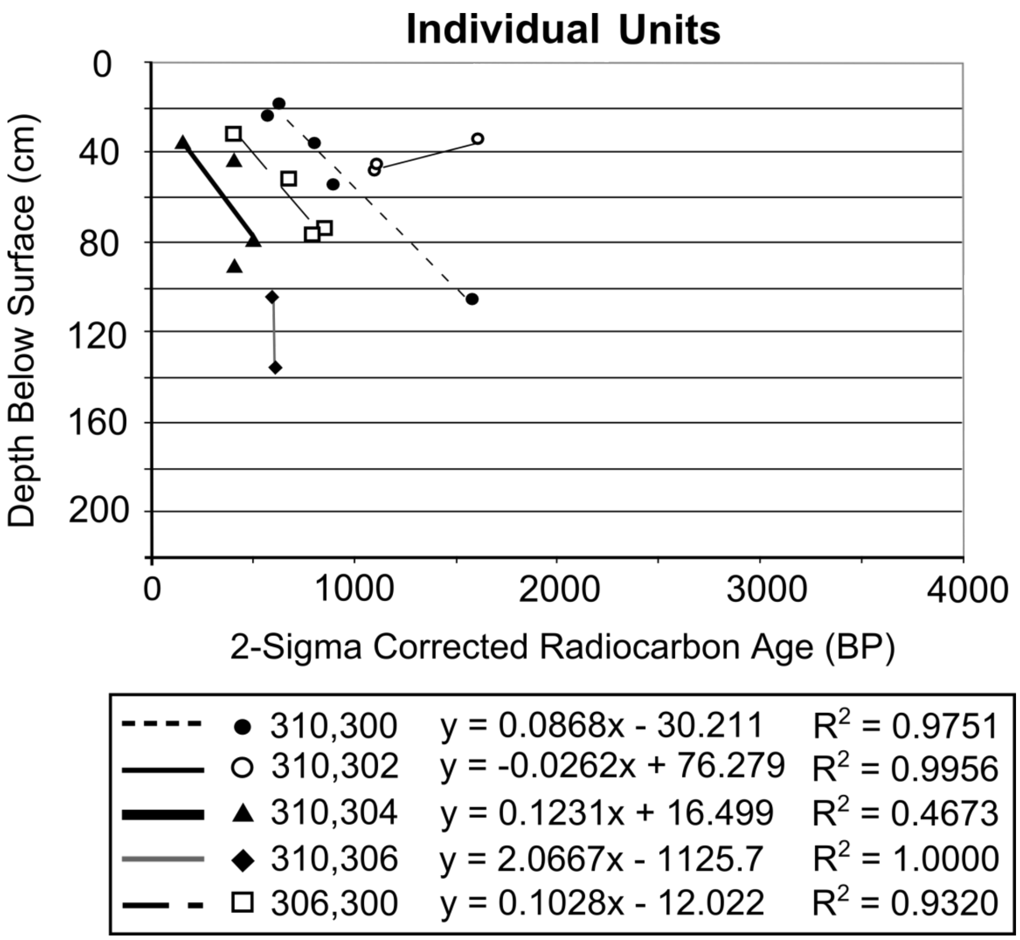


Figure 1.2 - A demonstration of site formation of a shell midden using rates of accumulation as an explanatory device as presented by Stein *et al*. (2003:308). Figure presented is of 45SJ24, English Camp, Operation A site. "Graphs show depth below surface versus 2σ calibrated radiocarbon age for individual units. Slopes of regression equations represent accumulation rates in cm/yr" (Stein *et al*. 2003:308 – Figure 4).

The approach presented by Stein *et al*. (2003) averages the patterns of deposition through a series of lines, clines and plateaus, though offers very little interpretative value to describing the human behaviours behind midden formation. In one example, see Figure 1.2 above, Stein *et al*. (2003:308) calculates the accumulation for a particular unit within a midden to be rapid at a rate of 58.54 cm/100 yr, while another unit from another site results in a slower rate of accumulation of 4.14 cm/100 yr. What do these calculations represent behaviourally? Immediately, the use of cm/yr to describe midden formation gives the impression of a constant accretion of midden material between two points in time and space – an unlikely scenario in reality. On its own, the approach presented by Stein *et al*. (2003) would not be able to differentiate between discrete depositional episodes in a seasonal, annual or decadal scale as they would all be averaged into one calculation. Nor would it be likely be able to detect a time-averaged unit that could potentially exhibit a slow rate of accumulation as two similarly aged specimens of shell spatially separated by some vertical distance.

Temporal Packaging: an introduction

Stein *et al*. (2003), in their study, incorporated a dating program that consisted of 82 radiocarbon age determinations on charcoal, 20 of which were AMS dates, spread over six midden deposits (Stein *et al.* 2003:302-304). While a dating program of this scale is indeed a departure from the typical approach to dating shell middens which generally involves only a handful of age determinations, the results still restrict interpretations of site formation to that of the broadest sense. Despite this expanded and refined chronological framework for each of the study sites, with one of the six sites contributing 22 individual age determinations (Stein *et al*. 2003:302), there is still not enough data to decisively and convincingly 'envelope' or 'package' the temporality of phases of deposition. Again, expanding the number of radiocarbon age determinations for each site even further will facilitate the isolation of these depositional phases, however, considering the nature of sampling shell midden deposits and the reality of representative samples, this approach is only possible “given a sublime disregard for time and money” (Waselkov 1987:152).

In taking the dating of shell midden deposits to the extreme, in the magnitude of potentially several hundred individual age determinations per site, new opportunities present themselves in approaching and analysing shell middens beyond simply refining the chronology of the deposit. The subtle changes in the patterning of deposition of midden shell, which would otherwise have been averaged out with a coarser outlook towards dating a shell midden, instead become apparent through such a high-resolution approach. With these subtleties exposed, more refined packages of similarly aged specimens, representative of an equally refined series of behavioural processes can be established. This resulting dataset will present a clearer, more robust picture of the temporality of the material that comprises a midden assemblage directly attributed to such a large sample size of age determinations. Comparing the ages of the dated material from the deposit, phases of shell deposition become differentiated from each other in ‘Temporal Packages’ – or groupings of similarly aged material. This process of ‘Temporal Packaging’ effectively offers a new approach to deconstructing a midden into its constituent parts. In other words, reducing a midden deposit, or cumulative palimpsest, into palimpsests of finer temporal and spatial resolution than what was previously possible (Bailey 2007:207-208).

This is an overt adoption of the microscopic tendency towards approaching archaeological deposits, as described by Bailey (2007:216). Though what separates Temporal Packaging from a simple refining of a chronology or production of accumulation rate data (e.g. Stein *et al*. 2003) is the interpretive value provided by Temporal Packaging. Each Temporal Package provides a temporally discrete universe of samples from which investigation and lines of questioning can be appropriately scaled to the temporal span represented by each Temporal Package. Following on from this, temporal packages can then be compared and contrasted as patterns of continuity and change are identified throughout a deconstructed deposit. As each Temporal Package represents the material evidence of a restricted and defined span of time, each Temporal Package therefore represents a period of time representing behavioural continuity which can be scrutinised largely independently of other Temporal Packages.

A key feature of Temporal Packaging is how it allows an alternative approach to working with material displaced by post-depositional processes centred on how individual packages of time sit spatially within a deposit. As Temporal Packaging is largely independent of the spatial positioning of samples, instead focussing on the relative temporalities between specimens, Temporal Packaging offers a method in which displaced or time-averaged material, removed from its original context, is re-established within its appropriate Temporal Package regardless of how far the specimen has moved. This opportunity to re-establish displaced samples back into a grouping of temporally comparable samples allows disturbed material to still be incorporated into investigations as 1) temporality relative to other specimens from within the deposit is clearly established, and 2) adds an additional aspect of the history of the deposit, namely the timing and extent of influence of post-depositional processes, to be explored.

In applying Temporal Packaging to shell midden deposits, as mentioned above, a substantial number of ages are required. A dating program of that size therefore renders radiocarbon dating, both AMS and conventional, completely unfeasible purely down to cost of those particular dating methods. The basis of Temporal Packaging is on the relative temporalities between phases and episodes of deposition in archaeological deposits. As such, numerical dating techniques, such as radiocarbon, are not necessarily required in using the Temporal Packaging approach resulting in relative dating methods becoming more applicable, with numerical dating techniques such as radiocarbon dating acting more as a complementary role rather than the focus. With specific regards to shell middens, amino acid racemisation (AAR) is a clear substitute for radiocarbon, especially considering the composition of these deposits being dominated by molluscan shell providing an abundance of dateable material.

Amino acid racemisation (AAR) centres on the rearranging of the molecular forms of specific proteins in biogenic material. After an organism dies, amino acids reorientate themselves from one form to another. This process, called racemisation, occurs at a regular rate over time, and measuring the relative proportions between the two forms of specific amino acids provides a relative indicator of the time since the death of the animal (e.g. Wehmiller 1977, Masters and Bada 1977, see Section 4.4 of this thesis for a more detailed description of the method). A key advantage of AAR is the method's cost-effectiveness, allowing a large number of samples to be analysed to create a relative age sequence that makes Temporal Packaging possible. Recent methodological developments in the AAR technique have improved the reliability, accuracy, and precision of results (Sykes *et al.* 1995, Penkman *et al.* 2008).

While AAR is not a numerical dating method like radiocarbon, for the purposes of Temporal Packaging and shell midden deposits, it does not have to be. It needs to be stressed that Temporal Packaging is not an exercise in refining chronologies in a deposit. Rather the approach intends to better understand the ebbs and flows of depositional behaviours through time in midden deposits using Temporal Packaging.

Thesis aims

The study discussed above by Stein *et al*. (2003) attempted to refine the chronology of a shell midden deposit, but in doing so, reduced the human behaviours behind midden formation into an equation and a series of clines and plateaus. Exactly which behavioural questions such a study could address, and how, is unclear. This thesis takes a different approach, attempting to use a high-resolution relative dating program focussed on AAR, anchored by strategic radiocarbon determinations, to present a more detailed and more representative depiction of the behaviours of shell deposition that results in shell midden formation.

This aim will be presented within the context of Holocene coastal archaeology of Australia's tropical north. There, shell middens are ubiquitous, though debate still rages regarding the timing and nature of midden formation, and the interplay between ancient Aboriginal Australians and the dynamic nature of the environments. A critical survey of these themes, including previous research conducted on shell middens in Australia's north will be presented. The Brremangurey midden will then be introduced, and framed within the regional setting of the northern Kimberley region of Western Australia. The results of the excavation of the Brremangurey midden will be presented relative to addressing a series of specific questions. These questions include:

1) Can a shell midden be deconstructed using Temporal Packaging to isolate the formation processes and behavioural patterning of a site?
2) Can a time-averaged unit be untangled into its constituent parts to facilitate a finer temporal scale of investigation?
3) Can vertically displaced midden shell from within a midden deposit be identified as such, and if so, can temporally comparable material be identified within the rest of the midden assemblage?

Following this, a similar methodology will be applied to a regionally associated midden. This midden, called Idayu (Veitch 1999a, 1999b), exhibits a number of similarities compared to Brremangurey with regards to morphology and broad species composition, yet distinct differences in the formation histories of each site suggest that a direct comparison between deposits may not be so simple. The results from the analysis of both Brremangurey and Idayu will then be synthesised, and those interpretations will be contextualised back into larger scale themes and discussions centred on middens in Australia's north. To conclude, a final discussion about the strengths, possibilities and capabilities of AAR and Temporal Packaging will then be presented within the scope of suggesting a new and powerful perspective in the way shell middens are approached and perceived.

Chapter 2 – The investigation of shell middens in north Australian archaeology

Introduction

Few archaeological features of the Australian landscape match the visibility and ubiquity of anthropogenic shell mounds. The scale of examples of these cultural features rival the massive shell mounds of the Americas (e.g. Sandweiss 1996, Luby and Gruber 1999) and South Africa (e.g. Buchanan 1988). The analysis of prehistoric cultural accumulations of shell has long received attention in Australian archaeology as their potential to inform on a range of significant themes of study related to the interaction of humans with the coastal environment they inhabited. While early studies of shell middens focussed on the artefacts contained within (e.g. McCarthy and Setzler 1960, Wright 1963), it was with Bailey's research into the Weipa shell mounds (Bailey 1975, 1977) that the potential of analysing the midden itself became apparent; where shell middens themselves became a focus of investigation as opposed to the material culture they contained (Bourke 2012).

Over the years, the analysis of shell middens has become a staple of archaeological investigation in Australia, and the results of midden investigation have been applied to significant discussions in Australian archaeology. The impressively large shell middens of Australia's tropical north have remained in constant focus, while other scattered research has hinted at the variability shell middens can display: morphologically, compositionally, spatially and temporally. Linking this variability to environmental or behavioural processes remains problematic, as the difficulty in isolating a deposit's formation history muddies this connection. This chapter will discuss this complication and its effects, and will propose a new approach to investigating shell middens that has the potential to circumvent these issues.

Defining shell middens in Australia

As was the case with the international literature described in Chapter 1, a definition for shell middens originating from Australian contexts has only been presented in the broadest sense. Edmund D. Gill (1954) was the first to explicitly outline the parameters of what defines a shell midden in Australian contexts. Authors in the early 20th century (e.g. Pritchard 1909, Kenyon 1927) wrote about the difficulties in distinguishing between the common shell-dominated beach ridges and cheniers, and culturally deposited shell middens, in particular across the tropical northern coastlines of Australia, due to strikingly similar morphological and compositional features. In response to this, Gill (1954) proposed a series of criteria that could be used to assist in differentiating between natural and cultural deposits dominated by molluscan shell. Criteria such as the presence of items of material culture, discrete lenses of charcoal and a bias towards certain 'economic' classes of shell size were proposed (Gill 1954:249). In contrast, shelly deposits were said to exhibit features such as a more varied species representation and a wider range of shell size classes, as well as structural features such as fine-grained sedimentological stratigraphic features (Gill 1954:252-253).

The discussion of natural versus cultural origins of shell-dominated deposits continued in the coming decades, especially in Australian contexts. Methods and approaches to distinguish between naturally occurring shell-dominated deposits and those formed through human agency appear regularly in the archaeological literature (e.g. Attenbrow 1991, Sullivan and O'Connor 1993, O'Connor and Sullivan 1994, Carter 1997, Rosendahl *et al.* 2007). A particularly prominent debate on the issue centred on the origins of the Weipa shell middens. The position of Stone's (e.g. Stone 1989, 1991a, 1991b, 1995) that the often large shell mounds were the result of scrub-fowl (*Megapodius reinwardt*) nesting habits was disproven by Bailey (e.g. Bailey 1977, Bailey 1991, Bailey *et al*. 1994) using multiple directions of evidence, such as deposit formation processes, taphonomy and composition, to demonstrate an origin through human agency (Szabó 2016: 774).

With regards to explicitly defining a shell midden, a survey of the more recent archaeological literature suggests that authors in Australia tend to typically favour a looser, less restrictive definition. Bowdler states a shell midden is a deposit that "contains 50% or more by weight of shellfish remains" (2006:316, see also Bowdler 1983:135). This definition seems to be the most widely used definition in Australian archaeology, and has been sometimes adapted to include further specific stipulations, including the requirement of specific size classes and edible species (e.g. Bowdler 1983:137) and the explicit inclusion of human agency as a mechanism of shell deposition (Faulkner 2013:43, Bourke 2012:28).

Variability and the implications of variability in shell middens

It appears that, over the last few decades, an increasing focus has been directed towards the variability in shell middens across northern Australia. While the stereotype of massive mounded deposits of soft-shore bivalves deposited during the late Holocene seems to characterise shell middens in tropical northern Australia and still dominates the archaeological literature (e.g. Bailey 1977, Veitch 1999a, Bourke 2004, Faulkner and Clarke 2004), more and more cases of the true variability of shell midden deposits across this region is becoming apparent. Despite this variation, no attempt has been made to systematically organise and categorise shell middens of north Australian contexts.

This variability in shell middens can take a number of forms. Temporally, marine/coastal shell midden deposits have been dated to the terminal Pleistocene on islands off the coast of northern Western Australia (e.g. O'Connor 1999a, Manne and Veth 2015, Veth *et al*. 2016), and in all likelihood countless other sites have since been destroyed by rising sea levels associated with interglacial time periods (e.g. Bailey and Flemming 2008, Ulm 2011, Manne and Veth 2015, see also Bowler and Price [1998] for an example of a Pleistocene dated freshwater shell midden). Compositionally, middens comprised of the soft-shore bivalves *Tegillarca* (=*Anadara*) *granosa* and

Marcia hiantina are the most commonly reported taxa. Mangrove, estuarine as well as rocky shore species of shellfish have been identified to dominate midden assemblages in specific locales (e.g. Schrire 1982, Kendrick and Morse, 1982, Woodroffe *et al*. 1985, Bowdler 1990a and 1990b, Lorblanchet 1992, O'Connor 1999, Clune and Harrison 2009:71). Finally, morphologically, middens exist in a large spectrum of sizes and forms (e.g. Bailey 1977, Alexander 2009, Hiscock and Faulkner 2006); from small scatters (e.g. Rowland 1985, Morse 1988, Sim and Wallis 2008) to large mounded deposits (e.g. Bailey 1977, Morrison 2003, Bourke 2012, Faulkner 2013).

Elsewhere around the world, classifications have been posited that attempted to establish types of shell middens. For example, Bailey *et al*. (2013:245-248) separate types of middens of the Farasan Islands into scatters, low mounds and mounds based on overall deposit size and spatial segregations of dominant species. Marquardt (2010) describes a range of differing midden types commonly referred to across the American southwest: for example shell mounds, shell works and temple mounds. Dupont (2006) defines three classes of middens – *Amas coquillier*, *Dépôt coquillier*, and *Lit coquillier* – based on volume alone. The schemas proposed by McManamon (1984) and Widmer (1989 in Claassen 1998) attempted to link compositional and morphological features of shell middens to varying behavioural processes driving midden formation. It must be stated that the intent of McManamon (1984) and Claassen's (1998) application of Widmer (1989) was to apply these classifications of midden types to other contexts beyond the site-scale focus from which the initial types were described.

There has been little attempt by Australian archaeologists to develop a systematic schema of shell midden deposits that speak to behavioural variations in midden formation across a broad spatial and temporal scale. From geomorphological quarters, a schema devised by Woodroffe *et al.* (1988: 96) which includes midden deposits as a category, has sometimes been adopted. Woodroffe *et al*. (1988:96) propose four classes of shell middens near the Alligator Rivers, Northern Territory: coastal middens, surface mounds, palaeochannel middens and surface scatters. The classification of each midden type was based on the size and shape of the deposit, as well as its geomorphological/environmental setting with regards to the deposit's position on dunes, river banks or palaeochannels.

These four midden types were used by Mowat (1995) in investigating the shell middens of western Arnhem Land, though no attempt was made in linking observed midden variation to human behavioural processes. The classifications of Woodroffe *et al*. (1988) were adapted by Roberts (1991), who also incorporated the terminologies and descriptions used by other midden researchers (e.g. Cribb 1986, Meehan 1982, Beaton 1985). In his research of the Millingimbi shell middens, also of the Northern Territory, he proposed five different forms of shell middens in the area (Roberts 1991:101-102): mudflat mounds, midden (dune) mounds, conical shell heaps, base site mounds and midden scatters. Roberts' extension of Woodroffe's schema incorporated ethnographic accounts, specifically those recorded by Meehan (1982, 1988). Interestingly, Roberts' (1991:146) terminology makes it clear that he recognises the potential of a behavioural explanation of midden variation in his research area, however does not develop this further.

Types and typologies

Typologies and their use in archaeological research have been, and still are, a critical part of archaeological investigation (e.g. Klejn 1982, Dunnell 1986, Read 2007). Human material manifestations are grouped into classes or types based on pre-selected attributes of those artefacts; be those attributes constitute physical, cultural or temporal features and characteristics (Bahn 1992:519). Such attributes are inscribed with meaning. For example, Kroeber's (1916) analysis of pottery types in archaeological assemblages from New Mexico was used to infer relative chronologies of prehistoric occupations. Another prominent example is the typology established by Bordes (1950) which describes the stone artefacts of the European Palaeolithic, which was intended to carry with them specific reference to the stage of technological capability of the hominin creating the artefact (Bisson 2000:2). Typologies, therefore, represent distillations of archaeological interpretations that can be applied to artefacts and features found on the archaeological landscape (Trigger 1989:21-22, Read 2007:204).

Typologies and types within a typology should act as a heuristic device. In an ideal setting, drawing upon a type in describing an artefact or archaeological feature should implicitly attach a suite of additional meaning relevant to the cultural processes behind the physical/morphological, cultural or temporal features of that artefact which defines the typology used (Gifford 1960:341). In short, typologies allow the use of one word or term to impart a large amount of information and most importantly a critical interpretation and inferred meaning. To quote Gorodzov (1933:102), "…the *purpose* of the typological method is the accurate determination of each type in space and time, so that in the final analysis it will be possible to give each type of archaeological objects the meaning of a hieroglyph, with the help of which one will be able to read the history of the material and social culture of all extinct generations of humanity".

Taking the position that shell middens are artefacts of ancient human behaviour, and potentially its temporal or and environmental context, and that they display variation, midden form and composition is therefore representative of a range of processes. As described above, shell middens of Australia's tropical north exhibit a range of temporal, compositional and morphological variation. It stands to reason that therefore a range of processes have been at play in the formation of Holocene shell middens in northern Australia. In itself this is not necessarily the issue, the manner in which the variations of midden form and composition have been mobilised in describing ancient human behaviours Australian archaeology is.

Across the archaeological literature on Australian shell middens, the terms shell scatter, midden and mound are frequently used as descriptors. Although these three terms are used in a manner similar to a typology, without an explicit and clear description of what information is being carried by the use of a typology, the use of these terms is in fact not. For example, the distinction between shell middens and shell mounds is often based on an arbitrary measurement of height that varies between investigators (e.g. Cochrane 2014:48, Bowdler 1983:135, Sullivan 1989:49, Bourke 2000:60). Fundamentally, however, no behavioural explanation is attached between the potentially varying cultural processes between shell middens and shell mounds. Basically, the use of these terms in Australian archaeological explanations fails to do the primary point of what a typology should do: explicitly link and describe artefact form and composition with the processes behind the artefact's creation/formation.

This lack of clarity between what a "shell mound" is, and particularly what distinguishes it from a "shell midden" problematizes the interpretations of midden investigation. Without a clear and explicit interpretation or classification of what a shell mound is, and what distinguishes a shell mound from a shell midden, how useful are these terms beyond describing that one type is larger than the other? Neither term gives any information regarding the composition, temporality, position on the landscape, or infers behaviours

Without a schema that provides clear definitions accompanied by inferences about reasons for variation, how can we approach describing the variations we observe in shell middens as evidence of human behaviour? At present, our models of midden formation processes are arguably not sufficient to account for 1) the variation in midden deposits we can observe, and 2) the potential variation that we cannot confidently constrain using modern methods and approaches to shell midden archaeology, for example the debate between steady accumulation versus punctuated accretion of a large midden deposit (see discussion in Morrison [2003] of competing models of this concept). Each of these factors has significant ramifications in the behavioural explanations of how people and populations created these deposits. Once again, if we take the position that variation in midden deposits are the result of a suite of behaviours and/or processes, a strong understanding of the formation processes behind midden accumulation is necessary. Teasing apart these formation processes is therefore critical to bridge the gap between ancient human behaviour and the material evidences that are left behind.

Linking midden patterning to behaviour

The describing of shell midden formation processes in north Australian contexts typically falls on two opposing ends of a scalar spectrum. On the one hand, large scale environmental processes are posited to drive patterns of resource availability, subsistence gathering, and the subsequent variation in midden form and composition. In a contrasting perspective, short-term ethnographic accounts of shellfish collection and deposition are used to model the patterns observed on the archaeological landscape. While in the end, both perspectives aim to address the same issue, that being the describing of midden formation as well as offering explanations for variability in midden deposits, neither is able to tell the complete story.

Environmental processes are commonly drawn on to explain patterns and variations in shell midden deposits, particularly in sites along the coasts of Australia's tropical north. For example, the surge in mangrove forests in estuarine locations in the early- to mid-Holocene immediately post-sea-level stabilisation (e.g. Woodroffe et al. 1985, Lambeck and Nakada 1990) has been interpreted to have initiated the gathering of molluscan fauna associated with this biome, resulting in mangrove-species-dominated midden features (e.g. Lorblanchet 1977, Kendrick and Morse 1982, Schrire 1982, Woodroffe et al 1988, Bowdler 1990a, Morse 1993, O'Connor 1999a). Similarly, the decline of mangrove forest extent towards the late-Holocene is argued to have made the previously inaccessible seaward margin of mangrove-associated mudflats reachable and targeted gathering of shell beds could occur (O'Connor 1999b:47). This then drove a species turnover in available molluscan fauna from mangrove dominated taxa, to soft-shore bivalves – in particular *T. granosa* and *M. hiantina* (O'Connor 1999b).

O'Connor (1999b) has also proposed that a cline exists of ages in midden deposits dominated by soft-shore bivalves along the northern coast of Western Australia. Midden formation is posited to have occurred along a cline from the south to the north through time. Middens typically comprising of *T. granosa* have been dated to approximately 4,270 BP (Veitch and Warren 1992) in the Pilbara. Yet further north, the earliest midden sites in the northern Kimberley containing similar species of bivalves date closer to 3,000 years BP (Veitch 1994). O'Connor (1999b), citing a suite of environmental literature (e.g. Jennings 1975, Semenuik 1982, 1993, Wyrwoll *et al*. 1986, Lees 1992) attributes this northward trend to a weakening of the monsoonal regime of the region caused by increasing climatic variability of the mid- to late-Holocene in northern Australia. Increased climatic variability is also argued to have placed increasing pressure on the subsistence base of Aboriginal populations therefore forcing a reorganisation of gathering strategies with an increasing focus on foods of a lower trophic level that would be more reliable resource base (e.g. Bailey 1993, Veitch 1999b). A comparable refocussing of subsistence resources is also noted to have occurred in the arid regions of the Australian interior through the increasing prevalence of seed grinding technology (e.g. Smith 1986, 1988, 1989, Veth 1989).

On a similar broad temporal and spatial scale, increasing population has also been attributed as a major influence instigating the phenomena of 'intensification' across the Australian continent (Lourandos 1983, 1985, see also Bourke 2012: 6). Considering the drive for population growth to be an inherent characteristic of all living things, Beaton argues that while remaining relatively stable up until the late Holocene, a significant population increase forced terrestrial communities to begin exploiting previously neglected environments (Beaton 1985). In a now famous quote, Beaton (1985: 18) states "the late Holocene sites on our coast are not just some tail end of our coastal history they are it". Beaton argues that increasing populations, due to spatial pressures forced groups to relocate to marginal and less favourable environments; in this case coastal regions. Social dynamics between cultural groups became increasingly competitive and forced a reliance on different sources of subsistence; in this instance the bivalve colonies of estuaries and mudflats.

These examples clearly relate to processes acting at a large scale, both temporally and spatially. In contrast to these, the use of ethnographic analogy as mobilised through ethnoarchaeological study has also been called upon in explaining shell midden formation and variation. For example, Bird and Bird (2000) describe the contemporary shellfishing strategies of children of the Merian, eastern Torres Strait. The authors note that children typically gather a wider range of shellfish taxa, with a notable lack of higher ranked species typically targeted by mature adults, a fact attributed to the physiological inability of collecting species such as giant clams (*Tridacna* spp.) (Bird and Bird 2000:468). The resulting midden post-processing, they argue, could potentially be interpreted as the result of an 'intensification' of resources (*sensu* Lourandos 1983:82), rather than an incidental by-product of a child's physiology. In a similar study, the gathering habits of adults of the Meriam demonstrated that that the processing of different species of shellfish occurred at different locations (Bird and Bird 1997). In particular the *in situ* processing of large *Tridacna* spp. specimens on the reef flats resulted in an underrepresentation of the taxa in mainland midden deposits. Applying this observation to archaeological deposits, Bird and Bird (1997:52) suggest that the potential exists that the calorific importance of these large and remotely processed taxa may not be appropriately incorporated into dietary reconstructions of past communities based on the lack of evidence in 'dinner-time camps' on land (Bird and Bird 1997:54).

Early anthropological observations of northern Australian Aboriginal populations have also been used in an attempt to glean patterns and explanations for ancient human behaviours related to middening behaviour. Faulkner (2013) cites a number of these early ethnographic accounts (e.g. Thomson 1949 and 1983, McArthur 1960, McCarthy and McArthur 1960, Warner 1969), which describe the gender- and age-based structural nature of local Aboriginal groups of Arnhem Land and how the wet-dry cycles influence social dynamics, with particular focus on the changing resource base associated with these seasonal cycles. Patterns of movement and mobility as well as locations of gathering are similarly recorded. Likewise, Morrison (2003) uses Roth's (1901) accounts of Aboriginal Australian ceremonial activities as a means by which shell midden formation occurs. Roth

(1901) describes intermittent gatherings of indigenous people coinciding with in ecologically driven booms *in T. granosa* populations. Morrison (2003:4) argues that this explains why one specific taxon dominates shell middens due to the intermittent abundance and subsequent focussed collection of this *T. granosa*. This hypothesis also offers a model by which midden formation can be inferred – punctuated events of intensive deposition of shell as opposed to a slower and more steady accretion of midden material.

Possibly the most prominent ethnographic study that has then been incorporated into archaeological investigation is Meehan's (1982) seminal research into the subsistence behaviours of the An-Barra people of Blyth River, central Northern Territory. In *Shell Bed to Shell Midden*, Meehan, in great detail, records the entire gathering process of shellfish; including the taxa being collected, the weights of shellfish collected and their calorific contribution to the overall diet of the An-Barra. Of particular note, and of particular relevance to the archaeological record, Meehan also records the manner in which shellfish are processed, including cooking methods, and how shellfish are discarded. Meehan's description and observations of 'dinnertime camps' (Meehan 1982:26) has featured prominently, although sometimes implicitly visible through choices of terminology, in interpreting archaeological deposits both in Australia (e.g. McDonald 1992, Nicholson and Cane 1994, Brockwell 2006) and in international contexts (e.g. Reitz 1988, Thomas 2002, Mannino and Thomas 2002, Erlandson *et al*. 2009, Marquardt 2010).

The problem of scale and interpretation

It is critical that the interpretations generated from the analysis of archaeological material have are grounded in the appropriate scales of investigation and the use of suitable methodologies to answer the questions being asked. As discussed in the previous chapter, different processes occur at different time scales and time spans, and therefore these processes should be investigated only once framed within the appropriate time scale (Bailey 2007:201). Coarser resolutions of evidence naturally tend to strengthen or favour larger scales of interpretations and processes. Conversely, events reflecting smaller temporal spans are best investigated within a higher resolution of time scales (*sensu* Bailey 2007:201). These concepts are termed the macro- and microscopic tendencies respectively (Bailey 2007:210). Recognition of the macro- and microscopic tendencies therefore becomes a key step in approaching and engaging with archaeological deposits.

In attempting to build interpretations of large-scale processes, the methods we employ need to be appropriately resolved. Similarly, if the focus of investigation is on events or processes of a finer resolution, the methods need to be altered accordingly. Using middens to describe large scale environmental processes over long timescales, such as climate change, a broad and generalised chronological control of the deposit can be considered acceptable. Modern day approaches to excavating and in particular dating shell middens (discussed in Chapter 1) typically fail to establish anything more than a very broad and generalising chronological framework of a deposit (e.g. Stein *et al.* 2003). This broad scale macroscopic approach, whether intentional or as a result of inadequate approaches to dating, comes at the expense of identifying or engaging with processes on a finer temporal scale, which are often behavioural, and therefore results in a bias towards environmental explanations.

Turning this example on its head, the realities of what the archaeological record actually preserves with regards to human behaviour becomes an issue. Whether or not the archaeological record can preserve individual episodes of deposition, and whether or not we as archaeologists can disentangle these episodes to the highest resolution has long been a focus of discussion (e.g. Ascher 1961, Wauchope 1966, Binford 1981, Schiffer 1985). While examples of 'the Pompeii Premise' (Ascher 1961:324) have been identified in exceptionally rare occurrences, the vast majority of archaeological deposits, in particular shell middens, cannot preserve depositional events on the scale of individual events due to the complex formation and transformation processes of shell middens deposits. Adopting a microscopic tendency, a shell midden can be gradually reduced into phases of midden deposition on increasingly smaller temporal resolutions. However there exists a point where the further honing of temporal resolution becomes impossible, and this point can vary between contexts due to the varying nature of formation, transformation and preservation in individual deposits. In an ideal setting, this point of diminished returns is identified and what is achieved is the entire temporal spectrum preserved within a shell midden deposit with which questions and investigations can be appropriately scaled. This point of diminished return, however, is something that needs to be actively sought.

Herein lies the paradox in building archaeological interpretations using shell midden assemblages. We as archaeologists aim to investigate processes that function across a broad range of time scales, yet the methods we employ in engaging with shell middens do not allow the isolation of the true spectrum of time within a deposit. A broad, macroscopic perspective of a deposit is relatively simple to achieve, as only the coarsest temporal framework is necessary to engage with processes of an equally large scale. In this respect, "standard" approaches to midden analysis, including basic identification and quantification (e.g. O'Connor 1999a) will suffice. A microscopic tendency (*sensu* Bailey 2007:210), requires a higher resolution of temporal understanding of the deposit. However, the techniques we employ, such as micromorphology, in approaching and analysing shell middens, as well as the nature of the archaeological deposit itself and the resolution of processes it can preserve, complicate the building of interpretations of processes across a temporal spectrum.

It is possible to restrict our level of investigation to the broadest scale of inference that is facilitated by establishing an equally broad chronological framework of a midden deposit. This perspective however, outside of extreme cases, renders any discussion of human behaviour largely obsolete and is generalised and averaged to the point of being lost amidst large-scale processes (see Hodder 2000). Speaking on the loss of detail of human behaviour in the archaeological record, Hodder (2000:31) states "[t]he data are often to scanty to allow anything else, and the ability of archaeologists to paint grand syntheses with a broad brush is impressive". In the case of north

Australian shell middens, interpretations and models spanning thousands of kilometres of coastline are deduced from a relatively small number of samples and dates (e.g. O'Connor 1999b).

To properly engage with questions at either end of the temporal spectrum, we need to first determine the scale of time that is represented within the deposit being investigated. As discussed in Chapter 1, if we want to progress beyond the gross over exaggeration of an environmentally deterministic perspective towards processes behind midden formation, we need to readdress the manner in which we approach and date shell middens. Similarly, more detailed interpretations of a much finer temporal resolution need to be grounded in demonstrable evidence. Temporal Packaging, once applied to midden deposits, will reveal the temporality of shell midden material that would previously have remained undetected, allowing an opportunity to appropriately scale an investigator's level of questioning (*sensu* Bailey 2007:210).

It is not the purpose of this thesis to develop a typology for the shell middens of northern Australia. What this thesis aims to achieve in its applicability to shell midden archaeology on northern Australia is to offer a method in which a shell midden can be approached to gain a deeper understanding of the temporal spectrum represented from within a shell midden deposit. This allows the appropriate scale/level of questioning of the midden to be set up to best accord with the temporal resolution that is preserved in the midden itself. Using this new information, a more detailed picture of midden formation can be drawn, and a wider range of processes across a broader temporal range can be engaged with while being grounded in demonstrable evidence.

This thesis presents a new method by which the spectrum of temporal resolution preserved in a midden deposit can be elucidated to establish the most appropriate scale of questioning. As described in Chapter 1, the concept of Temporal Packaging mobilised through the novel application of amino acid racemisation (AAR) has the potential to change the manner in which shell middens are approached by offering a mechanism by which the phases of deposition, previously hidden, can be isolated.

In this thesis, Temporal Packaging is applied to a shell midden that was excavated in the northern Kimberley region of Western Australia at a rockshelter called Brremangurey. During excavation and analysis, it became clear that the Brremangurey midden had a complex formation history and exhibited evidence of post-depositional transformation. To best engage with this deposit and the environmental and behavioural processes behind midden formation and the variability within, these complexities occurring at a range of time scales need to be disentangled. However, in a rather typical example of the manner in which shell middens are approached, the excavation strategies, as well as the nature of the midden itself prevented the straightforward establishing of the spectrum of temporal resolution preserved within the deposit. The following chapters will demonstrate how Temporal Packaging, mobilised through AAR, can resolve these issues.

Chapter 3 – Brremangurey: Regional setting and site report

This chapter is split into two parts. The first will describe the regional setting of the area in which research was conducted, as well as contextualising the main study site of Brremangurey within its local environments. The second part of the chapter will then focus on the Brremangurey rockshelter itself, where the excavation of a dense shell midden in 2011 was conducted. Firstly, the rockshelter will be described, followed by an account of the excavations including justifications of excavation squares and sampling strategies. Following this, the results of the analysis of the excavated midden material will be presented, including the results of the faunal analysis as well as the results from the dating programs implemented using material sourced from the Brremangurey midden. Patterns and issues pertaining to these analyses will then be isolated with specific questions regarding the chronological and behavioural patterning of Brremangurey outlined. Finally, a research agenda to address these questions will then be proposed.

Chapter 3 – Part 1: The regional setting of Brremangurey

Wunambal Gaambera country

Wunambal Gaambera country covers an area of approximately 2.5 million hectares of land, islands and ocean in the northern most portion of the Kimberley region of Western Australia. In modern times, the Wunambal and Gaambera groups of the area collectively refer to themselves as Wunambal Gaambera people. Wunambal Gaambera country extends from Prince Fredrick Harbour in the southwest, to Napier Broome Bay in the northeast.

Wunambal Gaambera country is bounded by Dambimangari country in the southwest, and Willinggin country to the south. These three areas collectively form the Wanjina Wungurr cultural bloc who share creator ancestors (Wunmabal Gaambera Aboriginal Corporation [WGAC] 2011: 8). To the southeast, Wunambal Gaambera country is bordered by the closely related Belaa language families of the Balanggarra people. Today, people of Wunambal Gaambera country mainly live in the communities of Kandiwal, Kalumburu and Mowanjum – the former being situated within Wunambal Gaambera land, while the latter two fall outside of the extent of Wunambal Gaambera country.

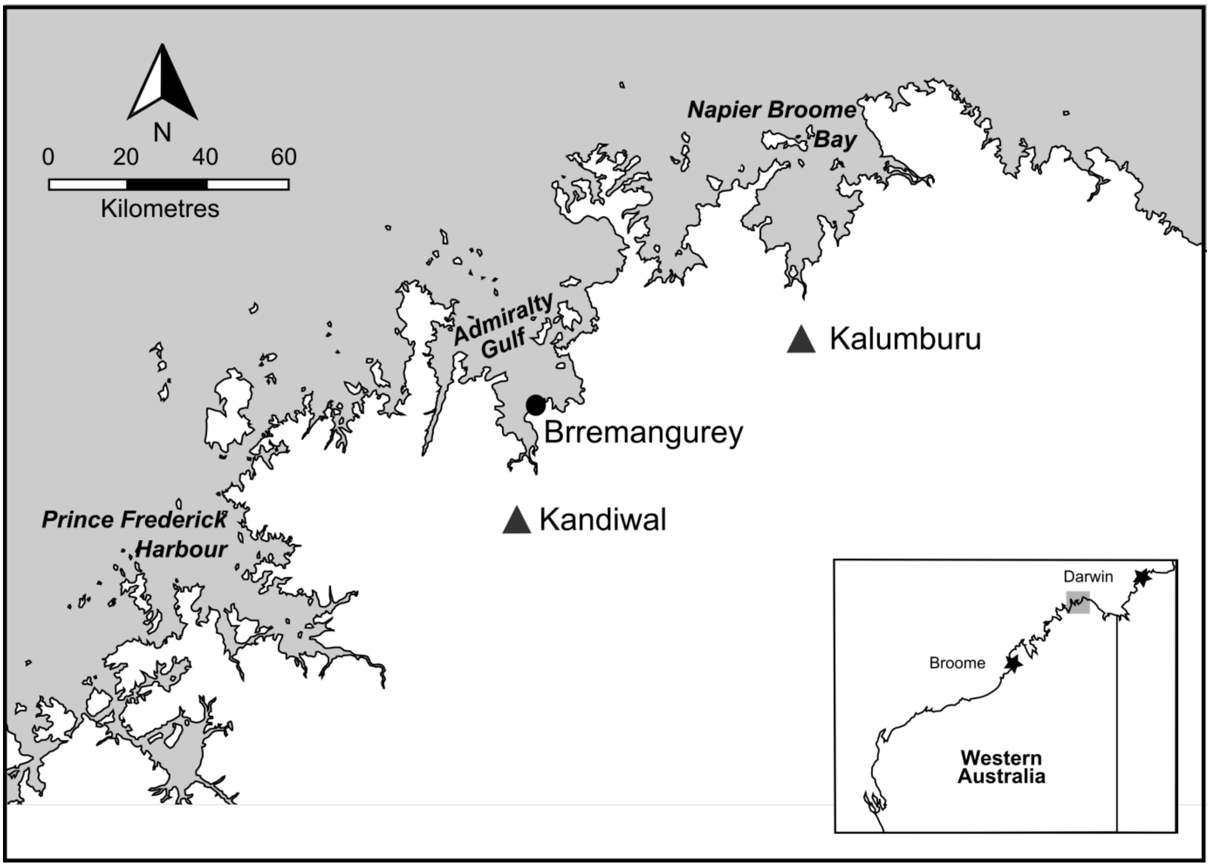


Figure 3.1 – Map of the northern Kimberley region of Western Australia depicting areas and land features mentioned in text

Climate

The climate of Wunambal Gaambera Country has been described as wet-dry monsoonal (WGAC 2011), dry tropical (Beard 1976) and tropical savannah (Slatyer 1960: 12). While maintaining uniformly high temperatures year round, the region's climate is characterised by markedly seasonal rainfall. The majority of the area's annual rainfall occurs in the months between November and April, but particularly in January and February (Figure 3.2c). Strong, potentially destructive storms are experienced at the beginning of the wet season and tropical cyclones typically occur at a frequency of one per annum (Wilson 1981: 5-6).

Climatic data gathered by the Bureau of Meteorology for Kalumburu (Figures 3.2a-c) show a pattern typical of the Kimberley region with regards to temperature and precipitation. Average annual maximum temperatures between 1999 and 2012 reached 32.8 degrees Celsius. Monthly maximum temperature reached 36.6 in the early summer months of October and November, and 28.5 in the winter months of June and July. Patterns of rainfall at Kalumburu exhibit a clearly monsoonal regime with 85% total annual precipitation falling between the months of December and March. The north-western Kimberley has been noted to enjoy higher total rainfall than more southern regions, and the coast more so than inland areas (Beard 1976).

Local indigenous groups of Wunambal Gaambera recognise four major seasons, and are described below (WGAC 2011: 14-15):

1) *Wunju* (January to mid-March)

   The wet season, characterised by monsoonal rains and consistently hot temperatures.

2) *Bandemanya* (mid-March to May)

   The early dry season. Monsoonal rains cease, though episodes of heavy, driving rain are experienced. Temperatures remain hot.

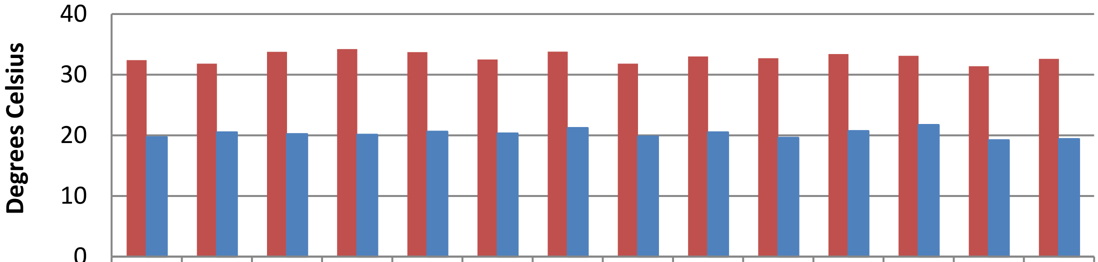
3) *Yurrma* (May to September)

   Dry season. Temperatures fall and rains effectively cease. Southeast winds are prevalent.

4) *Yuwala* (September to January)

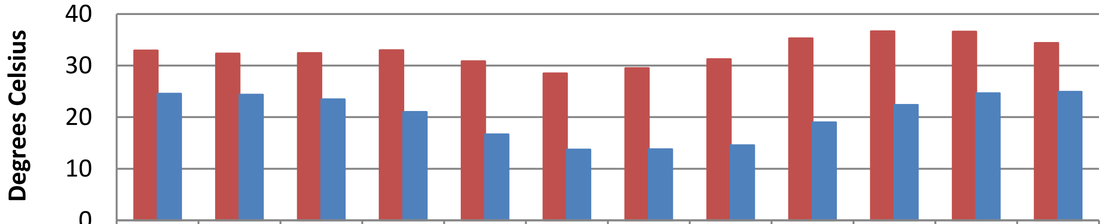
   Referred to as the storm season as thunderstorms, originating from inland, signal the first indicators of the coming monsoonal rains. Temperatures begin to rise as winds fall.

a) Annual mean temperature (1999-2012)



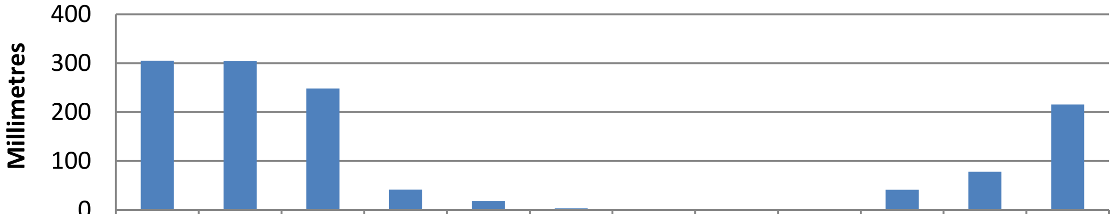
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Maximum	32.4	31.8	33.76	34.2	33.7	32.5	33.8	31.8	33	32.7	33.4	33.1	31.4	32.6
Minimum	19.7	20.5	20.2	20.1	20.6	20.3	21.2	19.8	20.5	19.6	20.7	21.7	19.2	19.4

b) Monthly mean temperature (1999-2012)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	32.9	32.3	32.4	33.0	30.9	28.5	29.5	31.2	35.3	36.7	36.6	34.4
Minimum	24.6	24.4	23.5	21.0	16.7	13.7	13.8	14.6	19.0	22.4	24.6	24.9

c) Mean Monthly Rainfall (1999-2012)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	305	305	248	42	18	4	0	0	2	41	78	216

Figure 3.2a-c - Climate data generated by the Bureau of Meteorology, Australia. Readings were taken at a station in Kalumburu.

Physical setting

The geology of the Kimberley region in northern Western Australia is limited by the King Leopold Orogen in the southwest, and the Halls Creek Orogeny in the southeast. The geology of the north of the Kimberley includes of Palaeoproterozoic Era siliciclastic sedimentary rocks and mafic volcanics comprising the Kimberley Basin block (Tyler et al. 2012). In Wunambal Gaambera country, three distinct geological units dominate the landscape, the King Leopold Sandstone at sea-level, overlain by Carson Volcanics, and Tertiary laterite in the topographically highest parts of the area (Dow and Gamuts 1969, Wilson 1981, Tyler *et al*. 2012).

The King Leopold Sandstone is predominantly comprised of fine to coarse grained quartz sandstone derived from marine delta deposits, with minor instances of fine conglomerates and rare examples of thin siltstone layers (Beard 1976, Dowens *et al.* 2007). Restricted outcrops of dolomite have also been observed within the King Leopold Sandstone (Tille 2006: 110). Harder portions of the exposed exposed King Leopold Sandstone outcrops across Wunambal Gaambera country are quartzarenite – a technical distinction from the more commonly known quartzite rock type (Huntley 2014: 44). While both rock types are considered highly silicified quartz dominant rocks, the process of their silicification drives this distinction (Schmidt and Williams 2008). Quartzite is a metamorphic rock formed through the chemical alteration of deeply buried quartz dominant sandstones. This metamorphism is driven by the extreme pressure and temperatures associated with deep subterranean burial silicifying matrix and clasts. On the other hand, quartzarenite, despite being visually and chemically comparable to quartzite, silicifies through the dissolution and precipitation of dissolved silica mobilised by groundwater (Jennings 1983). The King Leopold Sandstone exhibits essentially no tectonic deformation, aside from minor folding and faulting at contacts between adjacent orogens, indicative of deep burial reinforcing the identification of quartzarenite over quartzite (Huntley 2014: 44). A recurring feature of the King Leopold Sandstone is its strong bedding, cross-bedding and jointing, leading to the tendency to fracture in large angular blocks resulting in

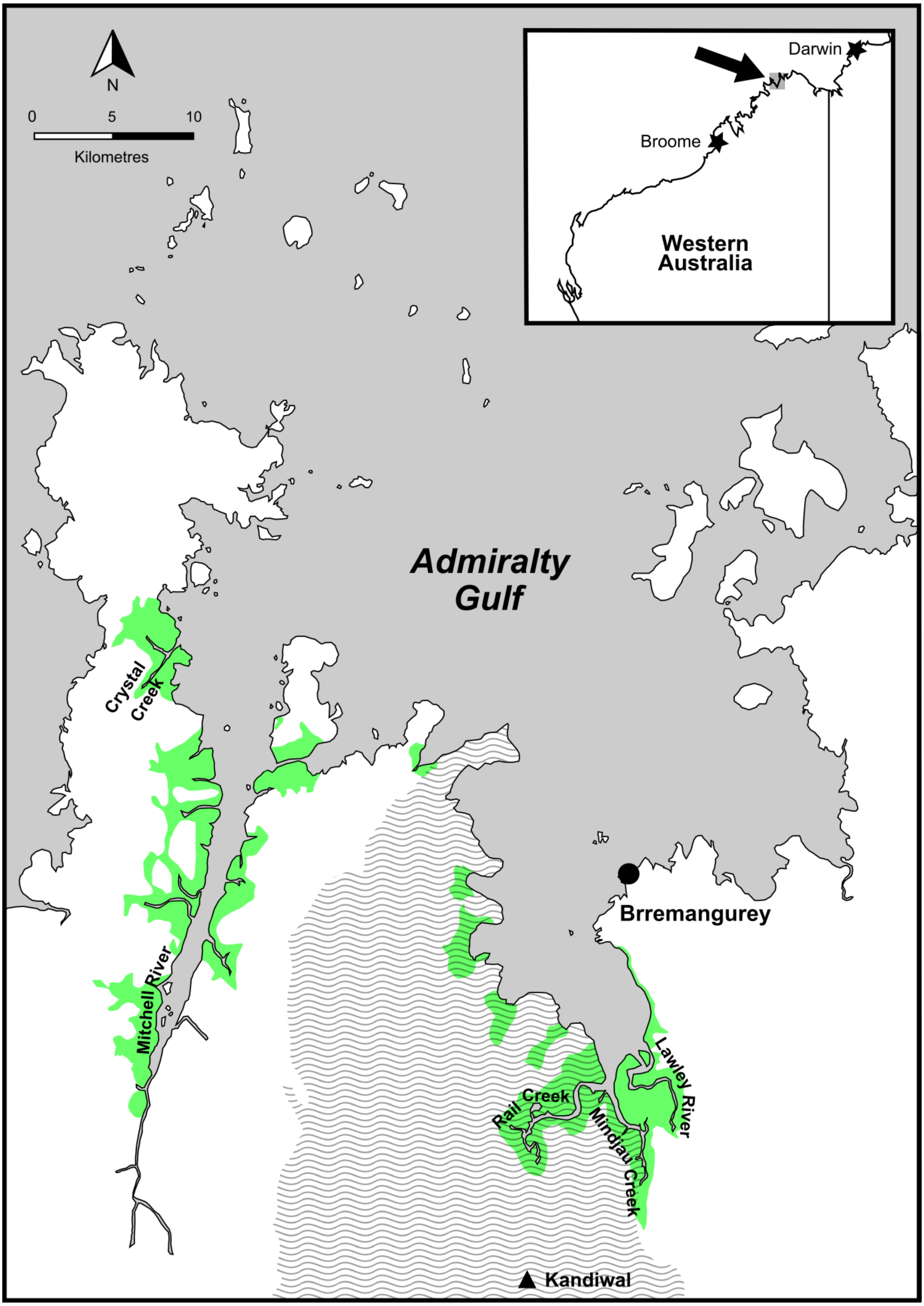


Figure 3.3 - Map of the Admiralty Gulf depicting locations and land features mentioned in text. Areas in green represent modern mangrove forests. Hashed area represents the extent of the Carson Volcanics and the Mitchell Plateau.

the landscape so characteristic of the Kimberley region (Figure 3.4). Overlying the King Leopold Sandstone are the rocks of the Carson Volcanics. This unit is characterised by fine-grained and massive amygdaloidal basalts interbedded with micaceous siltstones with minor pyroclastic rocks and feldspathic sandstones (Wilson 1981, Williams 2005, Dowens *et al*. 2007). This rock unit extends up to approximately 300 metres above sea level and forms the flanks of the Mitchell Plateau (Griffin and Grey 1990). Finally, overlying the Carson Volcanics is a layer of laterite deposited in the Tertiary period. This 3-15 metre thick unit forms an undulating cap on the topographically highest portions of the Mitchell Plateau between the 300 and 350 contour lines (Allen 1971: 10-11, Stewart *et al.* 1960: 28, Wilson 1981: 4).

Figure 3.4 - Typical landscape of the northern Kimberley. Photo taken by Koppel during surveys in 2012 of the Mitchell Plateau.

Two major rivers flank the eastern and western sides of the Mitchell Plateau: the Mitchell River to the west, and the Lawley River to the east. The Mitchell River flows directly into the Indian Ocean. The Lawley River, partially fed by Mindjau and Rail creeks, flows into the Admiralty Gulf to the northeast of the Mitchell Plateau. Both the Mitchell and Lawley Rivers flow into landscapes dominated by King Leopold Sandstone on either side of the Mitchell Plateau. Mangrove stands occur regularly along the extents of both Mitchell and Lawley rivers, and an especially expansive system is found at the mouth of the Lawley River where it contacts the Admiralty Gulf (Wells 1981).

Shoreline types vary across the coastline of Wunambal Gaambera country; ranging from steep, rocky headlands, mangroves and wide soft shore beaches tending towards finer muds and silts as a result of the very sheltered nature of the Admiralty Gulf and the shallow water depth (Wilson 1981). A substantial amount of coarse shell grit is found from slightly below the low tide mark to well beyond the high tide line. The origin of this shell grit found across the region has been attributed to parrotfish (Family: Scaridae) crushing and eating shell and coral (Robert Vaughn personal communication 2012). The parrotfish's beak-like teeth crushes and grinds coral which is then eaten and associated algae is digested (Morton 2004: 448). Pristine coral sand and grit is then excreted by the fish post digestion (Ryan 1994: 148). The grit is then carried by water currents to be deposited on the shores. Highly sheltered beaches, such as those in small enclosed bays have little to no shell grit apparent, whereas in relatively open beaches exhibit huge amounts of shell grit, especially towards the high tide marks of the intertidal fining to silts and muds towards the subtidal region of the shoreline.

One of the defining characteristics of the Kimberley coast is the extreme tidal range of the ocean; the largest in the southern hemisphere (Garrow 2002: 1). Vertical difference in water levels between high and low tide upwards of 10 metres have been observed in the shorelines of the Kimberley region (Cresswell and Badcock 2000), and similar tidal amplitudes in the Admiralty Gulf have been recorded in the Admiralty Gulf (Wells 1981). Translating this vertical difference to horizontal distance results in over 100 metres separating the high and low tide marks. This is further increased in shorelines with exceptionally shallow gradients, such as the mangrove system at the mouth of the Lawley River with well over 150 metres separating high and low tide positions (Koppel pers. obs. 2011). Tidal amplitudes of the Lawley River have reached 7 metres, with a maximum range of tidal influence upriver reaching a distance of 10-20 kilometres (Wells 1981: 97).

Brremangurey

On the eastern banks of the Lawley River and extending along the eastern coastline of the Admiralty Gulf lies an area called Brremangurey (Figures 3.3 and 3.5). Brremangurey is a subdivision, or *graa*, of Wunambal country taken care of by a family group (WGAC 2010). Within the Brremangurey area lies a rockshelter approximately 70 metres from the present day coastline and formed through the undercutting and internal collapse of softer layers of an outcrop composed of King Leopold Sandstone. This rockshelter was the focus of archaeological excavations in 2011 and local ecological surveys in 2012, both feed into the core themes of this thesis.

As this was the first major archaeological investigation to be conducted in the area, the rockshelter was named Brremangurey (Moore in Ross *et al.* 2011: 63). From this point on of this thesis, Brremangurey refers to the name of the rockshelter rather than the *graa* name for the area the rockshelter is located unless stated otherwise. A report of the excavation of the Brremangurey rockshelter, as well as the chronological and faunal analyses of the shell midden that was excavated is presented in Part 2 of this chapter.

The importance of marine resources and coastal environments to the ancient inhabitants of Brremangurey was clearly demonstrated by the size and density of the midden deposit found within the rockshelter. During the field seasons of 2011 and 2012, rapid environmental surveys were carried out. The main aim of these surveys was to identify the nature of the different shoreline environments (relative water energy levels, substrate type etc.) near the Brremangurey rockshelter that could have feasibly been targeted by the ancient occupants of Brremangurey for shellfish gathering. Specific focus was placed in identifying contemporary communities of live molluscs with the intention of comparing modern populations with the findings of the analysis of the midden material excavated at Brremangurey. A brief discussion of these surveys is presented here.

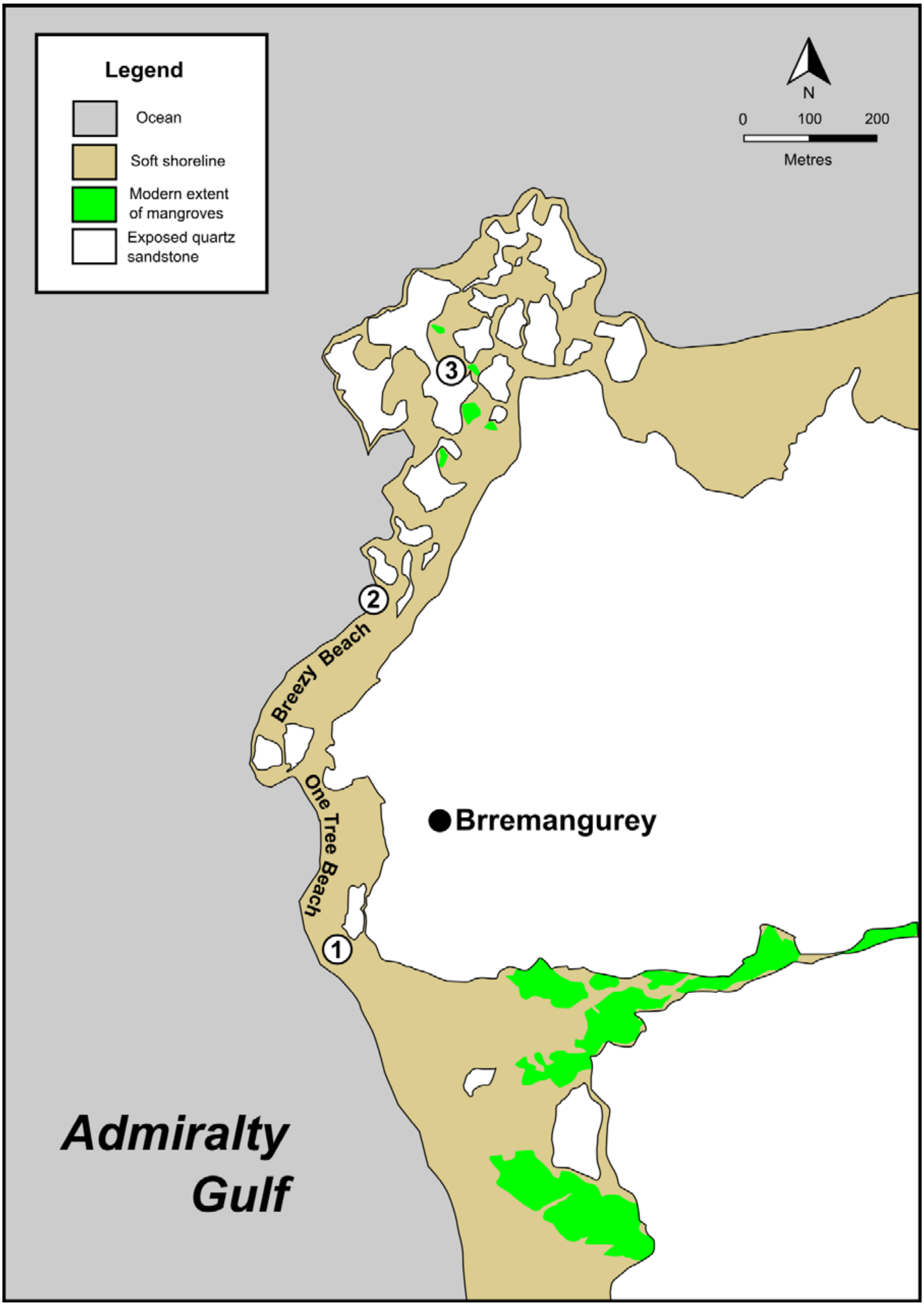


Figure 3.5 - Schematic of the varying coastal ecologies surrounding Brremangurey: 1) the rocks at the southern end of One Tree Beach; 2) soft intertidal sands at northern extent of Breezy Beach; 3) the mudflats and mangroves further north of Breezy Beach.

Coastal environments near Brremangurey

Wunambal Gaambera Country has been "recognised as one of Australia's intact biodiversity hot-spots" (WGAC 2011: 13) with a broad range of landscape and vegetation types being found within the region. Coastal ecologies of the Admiralty Gulf exhibit similar diversity. A broad range of shoreline types results in a wide range of fauna that can potentially be gathered as part of a subsistence regime of people inhabiting the area. Within walking distance from the Brremangurey rockshelter, a number of different shoreline environments were identified. As expected, a range of different species of molluscan fauna were observed in varying abundances and with associations between specific taxa. The results and observations of the surveys across the different shorelines visited are presented here.

It should be noted that during the time of surveying, with the exception of the mangroves at the Lawley River mouth which will be discussed separately, a period of neap tides were in effect. While each of the beach environments was assayed during a low tide, the typical low-tide mark was still submerged. Despite this, a useable dataset was gathered of the representative faunal assemblage of the various shoreline environments for comparison with the archaeological assemblage excavated from the Brremangurey midden.

1) One Tree Beach

North of the Lawley River mouth lies One Tree Beach. One Tree Beach is characterised by a stretch of beach of predominantly coarse shell grit and sand progressing to fine sands and muds past the low-tide mark. Like all coastal regions of the Admiralty Gulf, One Tree beach experiences an exceptionally large tidal range; upwards of 10 vertical metres separating the high and low tide (Wells 1981).

Enclosing the stretch of soft-shore is a rocky headland to the north, and a rock platform to the south composed of coarse quartz sandstones of the King Leopold Sandstone (Beard 1976). Surrounding the southern rock platform are boulders of the same rock unit partially buried by beach sand. Numerous fissures, crags and depressions cover the rock surface creating rockpools, as well as providing some degree of cover from direct sunlight. Only one crag is sufficiently deep enough to provide complete protection from sunlight over the entirety of a day.

Surveying of this location was broken up into two parts: 1) the soft, sandy beach, and 2) the rock platform to the south. A transect across the extent of the intertidal zone of the soft-shore of One Tree Beach was established, and at four metre intervals, a one by one square quadrat was placed. The area enclosed by the quadrat was then excavated to a depth of approximately thirty centimetres. Sands were sieved to isolate any molluscs from the sandy substrate. Survey of the rock platform involved visual inspection over the entire extent of the structure with species distributions recorded.

The transect survey of the sandy shore of One Tree Beach yielded no evidence of live molluscan fauna within the sands. Considering the survey was undertaken during a neap tide where the low tide mark of the day was considerably higher than usual, it is possible that populations of live

Figure 3.6 - One Tree Beach from its southern extent. The rock platform surveyed is slightly further south.

molluscs inhabit sands below the neap low tide mark, closer to typical low-tide levels. Due to the threat of saltwater crocodiles (*Crocodylus porosus*) in the area, surveying the submerged sands could not be attempted. Digging the quadrat to a greater depth was attempted but rapid and relentless infilling of the soft and waterlogged sands prevented progress.

The survey of the rocky portion at the southern end of One Tree Beach proved more productive with a range of different taxa identified and distinct habitat niches and species associations identified. Like the survey of the soft beach sands, the survey of the rock platform was undertaken during a neap tide. The entirety of the platform was exposed which allowed observation of the entire structure. At high tide, only the highest and landward-most extent of the rock platform remains exposed while the rest is submerged.

With regards to abundance, the most numerous species present on the rock platform was *Planaxus sulcatus*. Large clusters of this gastropod were found adhering to the rock, confining themselves to crags and crevices which would offer partial relief from the sun at particular times in the day. Similar behaviours were observed in the chitons *Acanthopleura spinosa* and *Acanthopleura gemmata* which adhere themselves into similar crevices out of direct sunlight for a portion of the day. Interestingly, both chiton species were only found on algae covered portions of the rock platform, which is to be expected due to their grazing feeding habits. The chitons were also confined to the seaward extent of the platform to a range of approximately 7 metres from the neap-low tide mark. Small communities of the gastropods *Peristernia fastigium* and *Nerita balteata* were scattered across the rock platform often in association with the *P. sulcatus* and both chitons (see Figure 3.7). Individuals of *Thais echinata* were identified in small individual cases across the platform, as was the limpet *Patelloida saccharina*.

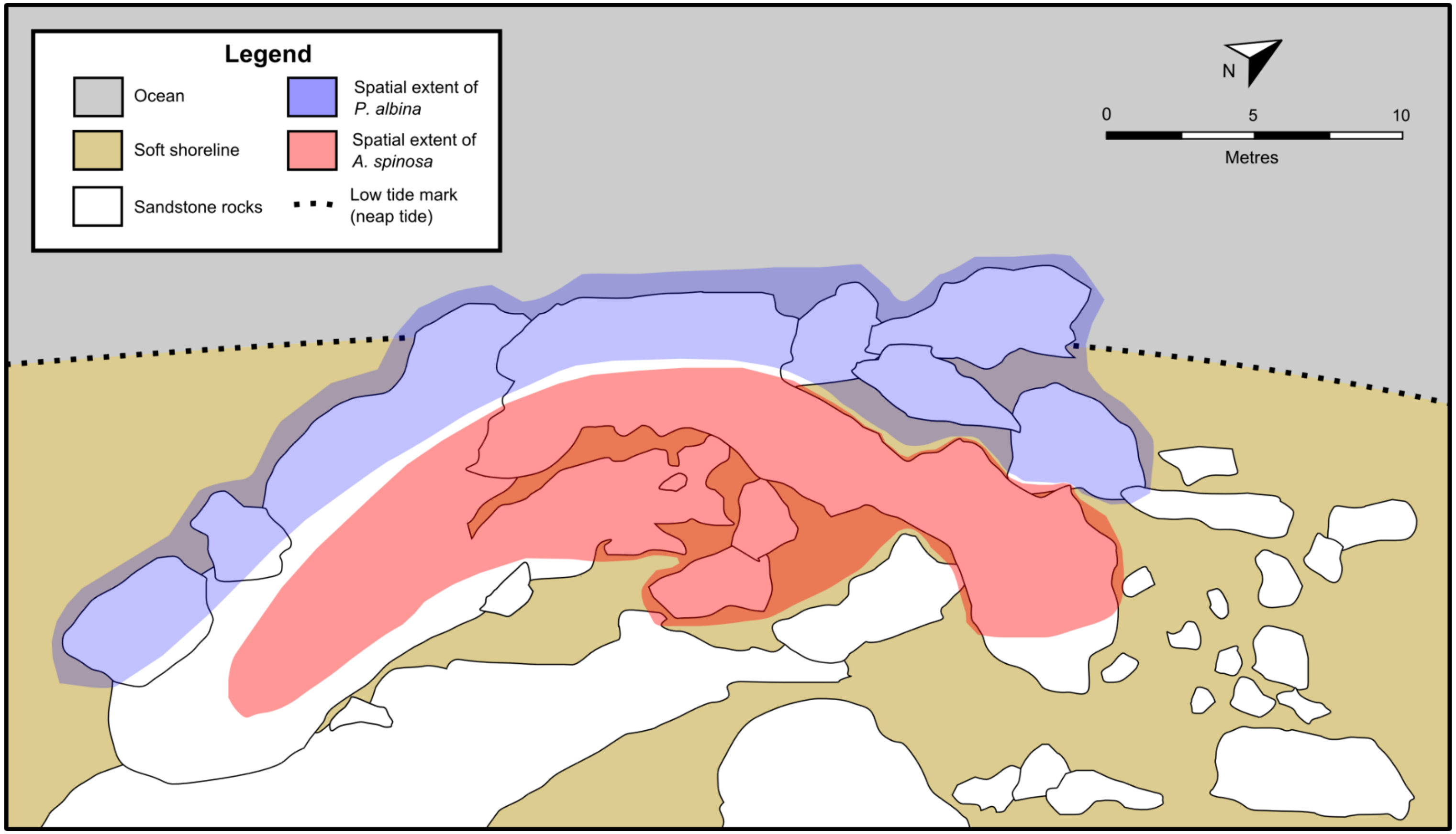


Figure 3.7 – Schematic of the rock platform to the south of One Tree Beach with spatial extents of *Pinctada albina* and *Acanthopleura spinosa* depicted.

The pearl oysters *Pinctada* c.f. *albina* and *Isognomon ephippium* were also identified, and both had contrasting niches of habitation. *Pinctada* c.f. *albina* were only noted in small rockpools that were filled with seawater throughout the low tide cycle, and were constantly exposed to sunlight throughout the day. This species was regularly found as single individuals not displaying any clustering behaviours, though up to three individuals were recorded to inhabit the same small rockpool. In contrast, *I. ephippium* was noted to form dense clusters bysally attaching to one another. Clusters of this species were found attached to the rock platform in the deep crag completely out of both direct sunlight and not protected by any water body during low tide.

2) Breezy Beach

Following the coastline just north of One Tree Beach is Breezy Beach, a stretch of sandy shoreline bordered by rocky outcrops. As with One Tree Beach, very low wave energy acts on the shoreline at Breezy Beach. The sediments are principally coarse shell grit at the upper reaches of the beach profile which gradually become finer to muddy silts at the low tide mark. Like the survey of One Tree Beach, the survey at Breezy Beach was conducted during a neap low tide which prevented access to the typical low tide sediments. The sandy portion of this part of the coastline was targeted, and using spades, buried communities of mollusc could be collected for identification.

The sands at Breezy Beach proved shallow, with bedrock being reached at a depth at approximately 20 centimetres. Despite this, abundant populations of the venerid clams *Marcia hiantina* and *Gafrarium tumidum* were collected in a very short period of time. There is little doubt that further populations of these species would have been identified below the neap-low tide mark. Interestingly, only these two species were identified in the sands at this extent of shoreline. Whether or not deeper sediments or sediments beyond the low-tide mark would yield further taxa, we could not determine at the time of the surveys.

Figure 3.8 - Soft sands at the northern extent of Breezy Beach. Live populations of *M. hiantina* and *G. tumidum* were found in abundance buried at this site.

Figure 3.9 - Upper mudflat north of Breezy Beach, overlooking the lower mudflat in the background.

3) Mangrove stand north of Breezy Beach

Slightly further north of the rocks at the northern extent of Breezy Beach are two relatively small mudflats enclosed by rocky outcrops and *Rhizophora* sp. mangrove trees. The sediments that infilled the enclosed area were notably finer than the beaches surrounding the mudflats, presumably due to the rocks surrounding the mudflats reducing the energy levels of water flow. Clusters of *Rhizophora* sp. trees, including saplings, scatter the upper landward mudflat, while smaller clusters are present at the lower seaward mudflat.

The neap tide that was in effect at the time of survey had relatively little influence with regards to the investigation of the mudflats compared to the other previously mentioned survey sites. The rocky outcrops that form the natural boundary of the lower-most mudflat's seaward extent lie above the neap low tide mark. The implications of this are that the same conditions are present at these mudflats with regards to low-tide exposure during neap tide as well as typical tidal situations, unlike the other sites surveyed.

The rock oyster *Saccostrea cucullata* is abundant throughout this location with specimens being found adhering to hard substratum such as rocks and the stems, trunks and roots of *Rhizophora* sp. trees. Clusters of the gastropod *Clypeomorus bifasciata* were also found on the rocks surrounding the mudflat. Articulated and disarticulated valves of the clam *G. tumidum* were found clustered at the base of *Rhizophora* sp. trees throughout the upper landward mudflat. Live specimens of *G. tumidum* were found exposed at the base of the *Rhizophora* sp. trees as well as some being found buried in the surrounding muds. Alongside the dead *G. tumidum* at the base of *Rhizophora* sp. trunks were shells of the gastropod *Volegalea cochlidium*, however on closer inspection these were occupied by hermit crabs. As with *G. tumidum*, no live examples of *V. cochlidium* were found. Despite the presence of the *Rhizophora* sp. mangroves, the typically mangrove-associated oyster *I. ephippium* was absent in this area (Carpenter and Niem 1998: 191).

Populations of the whelks *Telescopium telescopium* and *Terebralia palustris* were also abundant in this area. Interestingly, the populations of *T. telescopium* that were identified were mostly confined to pools of standing water that remained after the tide dropped. In contrast, *T. palustris* seemed to largely avoid pools of water and were found exposed on the surface of the mudflat. While specimens of both *T. Telescopium* and *T. palustris* were noted to occupy spaces in full, direct sunlight, dense clusters of *T. palustris* were found in the shade created from the *Rhizophora* sp. trees scattering the area.

4) Lawley River mouth

Approximately 10 km south from Brremangurey is the mouth of the Lawley River and its juncture into the Admiralty Gulf. This location is characterised by an extensive mangrove forest directly adjacent to an expansive mudflat from the forest's seaward boundary. The tidal range at this particular site is substantial, even by the typical standards of the Kimberley region. With an exceptionally shallow shoreline gradient, coupled with the massive tides of the area, the distance between high and low tide can extend beyond 200 metres. Unfortunately, due to the very real threat of saltwater crocodiles which were observed to frequent the area, this location was deemed unsafe and could not be surveyed.

Chapter 3 – Part 2: The excavations at Brremangurey

The Brremangurey Rockshelter

The Brremangurey rockshelter lies within a flat-lying quartzite outcrop which forms a ridge-like feature rising approximately 8 metres from the ground at the southern main entrance. The shelter itself formed through the internal collapse of the bedrock forming internal cavity with a varying roof height ranging from approximately 1.2 to 4.5 metres in height, though these measures are as much influenced by the undulating and uneven floor surface as the roof of the shelter itself (Moore 2011: 64). The primary entrance to the shelter is its southern extent, while a smaller, less accessible entrance is found in the shelter's rear. Both the eastern and western extents of the shelter are closed off due to the roof and floor contacting. The southern entrance is ca. 23 metres in width and the rockshelter extends approximately 31 metres towards the northern entrance in the rear of the shelter. A shelf or bench of bedrock extends across the southern entrance of the shelter in a westerly direction and acts as a platform up to 3 metres in width protected by an overhang of quartzite bedrock. A talus slope of midden material approximately 2 metres in height is present outside the southern entrance to the shelter, extending past the dripline. The talus slope contacts a sandsheet outside the southern entrance of the shelter that, in contrast with the interior of the rockshelter, appears largely devoid of shell material or significant boulders.

Rock art is abundant at this location, with motifs covering the internal wall and roof panels, as well as extending across the quartzite wall along the quartzite shelf to the shelter's west. The art present at Brremangurey will not be discussed in this thesis, though is presented elsewhere (Ross *et al.* 2011, Ross and Travers 2013, Huntley 2014, Travers 2015, Ross *et al.* 2016, Travers and Ross 2016).

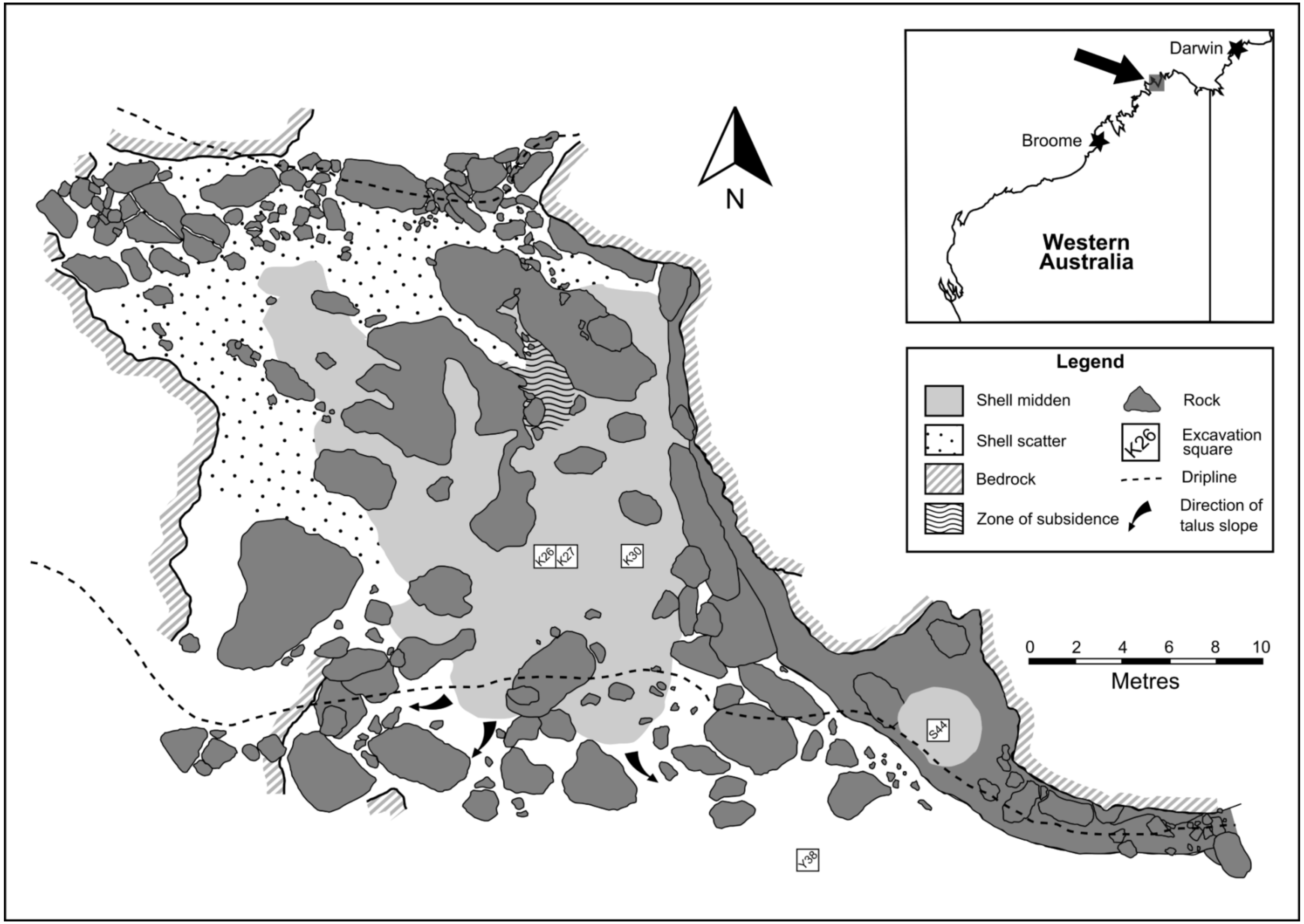


Figure 3.10 - Schematic of the Brremangurey rockshelter. Note small midden and square S44 to the east of the principal entrance to the rockshelter.

Overall the entire surface area of the shelter is approximately 1200m^2 (Moore 2011, Ross *et al.* 2011). Except for a few quartzite boulders, the floor surface inside the rockshelter is loose shell midden with an ash/silt matrix, as seen in Figures 3.10 and 3.11. The surface midden deposits appear dominated by equal proportions of *M. hiantina* and *T. granosa*, with smaller proportions of the mangrove pearl oyster *I. ephippium*. The shelter floor is largely flat, however some undulations are apparent. A zone of subsidence is apparent towards the centre of the shelter that is potentially the result of water flowing into the rear of the shelter during periods of abundant rainfall, such as during the summer monsoons (Robert Vaughn personal communication 2011). Towards the western portions of the shelter where the roof is considerably lower than the central and eastern parts, isolated patches of burnt shell is common across the surface – likely the remains of fireplaces.

Figure 3.11 - Surface of the midden deposit inside the Brremangurey rockshelter. Photo taken from the shelter's southeast corner facing north. The northern entrance can be seen in the background.

Along the bedrock shelf, approximately 11 metres to the east of the rockshelter's southern entrance, another smaller midden was identified. This midden forms a shallow mounded deposit 3.5 metre in diameter and approximately 35 centimetres in depth (Moore 2011: 67).

An alphanumeric grid was applied to the site, inclusive of the bench to the east as well as the sandsheet to the south. The datum point by which the alphanumeric grid was structured was carved into a portion of bedrock near the shelter's eastern wall (Moore 2011: 67-68). This datum point also acted as a control of Z-coordinates by which the depths recorded during excavation (discussed below) were measured against.

The excavations

Justification of square placement

A total of five 1x1 metre squares were excavated at Brremangurey; three squares (K26, K27 and K30) within the rockshelter's principal occupation zone; one square (S44) centred on the small, mounded midden located on the bedrock shelf east of the shelter's main entrance; and one (S44) on the sandsheet outside of the rockshelter beyond the talus slope. The justification for the positioning of these squares, as initially presented by Moore (2011: 68-69) is discussed below:

- Squares K26, K27 and K30 were placed at what was initially thought to be the area where cultural deposits were deepest. As well as this, K30 was positioned directly underneath a principal motif of rock art where ochre crayons and other pieces of material culture associated with the production of art could be found. K27 was similarly deliberately positioned underneath other motifs, though motifs where the underlying rock had spalled and detached with the art itself were specifically targeted. K26 was only excavated after K27 reached bedrock at a much shallower depth than initially posited and the remaining time and manpower left after the shorter-than-expected excavation of K26 facilitated the possibility of excavating another square.

- The placement of S44 was justified using a similar argument as the placement of K27. The roof/wall of the overhang directly above the small midden exhibited substantial spalling and exfoliation. The excavation of S44 hoped to extract pieces of art-covered roof fall in a dateable context.
- Y38, in contrast to the other four squares, did not target a shell midden, nor was it placed underneath the protection of the shelter's roof or overhang. Rather, Y38 was placed on the sandsheet outside of the shelter, beyond the talus slope. Previous excavations elsewhere in the northern Kimberley that were conducted as part of this project (though are not relevant to this thesis) used a similar justification of excavation square placement and yielded the positive results of assemblages of material culture. With a similar depositional context being apparent at Brremangurey, the same was expected here as with those other excavations.

Excavation methods

Prior to excavation, measures were undertaken in an effort to protect the rock art of the shelter from the dust generated during the process of excavation. Directly over and behind squares K26, K27 and K30, a sheet of doubled-over shadecloth was erected to act as a physical barrier between the dust and art. At the sieving station, a tarpaulin was hung to direct the flow of air, as well as suspended dust in the moving air, away from the rockshelter, specifically away from S44 and adjacent motifs.

The excavation across all squares at Brremangurey was conducted in 5 centimetre arbitrary levels, or spits. The reasoning behind this decision was that due to the apparent visual homogeneity of the midden deposits as well as the sandsheet outside the shelter, natural stratigraphic layers may not have been preserved in a fashion visible to the digger during the excavation process (Moore 2011: 71). Despite this, excavators were instructed to cease further excavation of a spit when changes in deposit composition or form were observed. Distinct features, such as hearths, were excavated and

Figure 3.12 - Excavation in progress at Brremangurey. Square to the left is K26, and to the right is K27. K30 is situated behind man overlooking the excavation. Note the shadecloth protecting the rockart from airborne dust. Photo by Yinika L. Perston.

analysed as discrete features where possible. At the conclusion of each spit, 5 measures of depth were recorded measured against a fixed datum; 4 in each of the square's corners, as well as 1 in the centre of the square. Spit thickness was reduced to 2.5 centimetres only in K26 after the coarse midden deposit transitioned into a finer sand-dominated layer and a higher resolution of excavation through smaller spits could successfully commence (Moore 2011: 71). Excavation was undertaken using trowel and dustpan, with particularly small or delicate finds, such as articulated animal bones, being excavated using shaped bamboo chopsticks. Excavation proceeded in each of the 5 squares until impenetrable bedrock was reached (Moore 2011: 74).

For each spit or feature across all squares excavated at Brremangurey, a small bulk sample was collected. These samples weighed approximately 160 grams each and were not sieved. Munsell colour readings were recorded for each spit, as well as pH readings. Carbon samples in the form of charcoal were also collected during the excavation of each spit using tea-strainers to avoid bodily contact that may adversely impact further analyses using the charcoal (Moore 2011: 73).

At the conclusion of each spit, all of the material excavated from that level was weighed using a spring scale to the nearest half kilogram. Large rocks were removed and the material was dry-sieved through both 5mm and 3mm nested sieves. The 5mm sieved fraction underwent a preliminary sort on-site to remove any obvious stone (both modified and unmodified), bone and other organics from the remaining shell. Each component was then separately weighed. The remaining ash/sediment was kept in a spoil heap until it was ready to be used as backfill for each of the squares once excavation had concluded.

The results of excavation

Squares K26, K27 and K30, as a result of being situated adjacent to or close to one another, shared common characteristics of stratigraphy and faunal composition. Similar patterns were observed in S44 located nearby. The square Y38, located in the sandsheet outside of the rockshelter, stood out from the others as it was the only square not placed into a shell midden. For this reason, the results of the excavation of Y38 will be discussed briefly first, and then a detailed description of the other four squares will follow.

Y38

The excavation of Y38 reached a total depth of 145 cm when bedrock was reached. The sediments uncovered were principally composed of homogenous medium sand initially grey/brown in colour, but fading to a pale yellow as the excavation progressed. Material culture, in the form of stone tools and ochre crayons, was found throughout the deposit, though appeared to concentrate at specific points in the sequence. The uppermost extent of the sandsheet contained large quantities of marine shell, however no shell was found below the first three spits. Unmodified rock fragments were found throughout the sequence, but increased in abundance rapidly towards the lowest 20-30 cm of the deposit. The sediments were initially alkaline in nature with a pH of 8. At lower levels, the pH of the sediments became more acidic, with a pH reading of 6 being recorded at Spit 8. Below this, until bedrock, pH levels fluctuated between 5.5 and 6, and are likely the reason why no shell was recovered from the lower levels of the deposit (Moore 2011: 88-90).

The presence of the shell uncovered at Y38 is likely the result of a natural, rather than cultural, process. The shell found was highly fragmented in nature, and closely resembles the shell grit that is common across beaches of the area. Considering the close proximity of One Tree Beach to the Brremangurey rockshelter, a distance of approximately 70 m, it is likely that the shell found at Y38 was blown to the site during strong winds (Moore 2011: 88).

No midden shell was present at Y38, and as such, this square will not be discussed further in this thesis.

K26, K27 and K30

All three of these squares were excavated either adjacent to one another, in the case of K26 and K27, or in close enough proximity for patterns of stratigraphy to be shared across squares, as with K30. Because of this, for the purposes of describing the preliminary results and observations of stratigraphic patterning, all three of these squares will be discussed together.

Squares K27 and K30 terminated at the relatively shallow depth of 91 cm below surface (BS) for the former, and 66 cm BS for the latter. In excavating K27, it became clear that both of these squares were situated on top of either a large slab of roof-fall, or an uplifted portion of the underlying bedrock. This platform, however, was noticed to drop off suddenly along the western edge of K27 indicating the presence of deeper sediments to the side of the rock platform. With this in mind, the K27 excavation was expanded along that western edge forming the K26 square to specifically target these deeper deposits. At the termination of the K26 excavation where bedrock was reached, a depth of 181 cm BS was recorded.

Across all three squares, two distinct horizons were identified. Horizon 1 is characterised by a dense shell midden deposit supported by a fine-grained ash/silt matrix. Lenses of ash, charcoal and burnt shell were common throughout the midden of Horizon 1, however discrete hearth features proved rare during excavation. It is likely that hearths were completely or partially dispersed during the occupation of the Brremangurey rockshelter prior to the features being buried by subsequent deposition of material (Moore 2011: 77). While demarcating ash- and charcoal-heavy lenses was problematic during excavation, these features were more noticeable in section view in the square walls once excavation had concluded. The pH of Horizon 1 remained high throughout its extent, with values of 8-9 being recorded. The alkalinity facilitated excellent preservation of organic remains, which included bone, plant material and the abundant molluscan shell.

Horizon 2 underlies the midden-rich deposit of Horizon 1, and was only observed in K26. The basement rock that terminates both K27 and K30 rests above the juncture between Horizons 1 and 2, and is therefore only found in the deeper sediments of K26. Horizon 2 is characterised by a weak-structured medium quartz sands with a subangular shape (Moore 2011: 85). Unlike Horizon 1, Horizon 2 contained abundant examples of material culture, particularly bipolar artefacts created through shaping crystal quartz and metavolcanics, as well as ochre crayons (Moore 2011: 84). Shell is largely absent through Horizon 2, except for a zone of transition at the contact between both horizons. Fragments of *M. hiantina* were identified throughout Horizon 2, and will be discussed in more detail in the following section where the faunal analysis of the excavated Brremangurey material is presented.

A number of layers within both horizons were identified, and are described below. The descriptions of each layer are adapted from the preliminary report by Moore (2011: 84-88).

Layer 1A – This thin layer forms the uppermost extent of the Brremangurey rockshelter deposit and includes the shelter's surface. Crushed shell is abundant, and is the likely result of both human and animal trampling and foot-traffic within the shelter. Shell is supported by loose ash and silt

Layer 1B – Underlying Layer 1A is an approximately 25 cm thick layer of interbedded layers of clast-supported midden shell. Plant remains are abundant, and the pH of this layer is particular high, with readings of 9 being recorded. The colours of the sediments of this layer vary slightly, ranging from greys (2.5Y 6-1), to dark greys (2.5Y 4/1) to greyish brown (2.5Y 5/2) in colour. Layer 1B was continuous across squares K26 and K27, but was discontinuous in the nearby K30 where the layer tails off.

Layer 1C – Similar in composition to Layer 1B, the underlying Layer 1C is characterised by an increase in the number of hearth features compared with the overlying layer. The colours of Layer 1C are comparable to Layer 1B, however the range of pH values drop slightly to 8-8.5. The thickness of Layer 1C is approximately 10 cm in squares K26 and K27, and expands out to approximately 20 cm in K30.

Layer 1D – This layer consists of two principal lenses of clast-supported midden shell separated by a dense shell layer almost entirely composed of the pearl oyster *P.* c.f. *albina*. Within this layer, a small pearl was discovered. This pearl was analysed and published independently of this thesis (Appendix 3). Layer 1D range in thickness from 20 to 26 cm between K26 and K27. The colour of the sediments are similar to the overlying two layers, and like Layer 1C, pH values range from 8 to 8.5 throughout Layer 1D. Layer 1D represents the lowermost layer of Horizon 1.

Layer 2A – This layer marks the upper most extent of Horizon 2, and as such acts as a transitionary layer between the shell dominated layers above, and the sand dominated layers below. Shell is initially abundant in the upper extent of this layer, though this abundance drops towards the bottom of this layer. Interestingly, the midden shell is less preserved in this layer compared with the upper layers despite the pH remaining alkaline with pH values of 8 being recorded. Layer 2A also represents the lowest-most layer of deposit in squares K27 and K30 where contact is reached with the underlying bedrock. A pit-feature was observed in the western wall of K26, where material from Layer 2A cuts into the underlying Layer 2B, as seen in Figure 3.13. The surface of the rock of squares K27 and K30 appears exfoliated, likely heat generated due to the placement of fires directly onto the bedrock surface. The adjacent sands are also organic rich, potentially as a result of decomposed charcoal further adding weight to the interpretation of extensive fire-building behaviours at this location. The transition from Horizon 1 to Horizon 2 occurred during the excavation of Spit 18. Because of this noticeable shift in the nature of the material being excavated, Spit 18 was split into two separate excavation units; Spit 18A and 18B with the juncture between the two representing when the sediments coarsened from ashy-silts to medium sands.

Layer 2B – This layer is only apparent in K26. The contact between layers 2A and 2B is distinct, and potentially represents a "significant behavioural and depositional disconformity at Brremangurey" (Moore 2011: 86). Shell is near absent, with only isolated examples of fragmented *M. hiantina* being uncovered. Colours range between brown (7.5YR 4/3) and very dark grey (5YR 3/1), while pH values of the deposit range from 8.5 to 9.

Layer 2C – The lowest most layer of K26 and is characterised by dark, organic rich sands and discontinuous lenses of lighter coloured sediments. Like Layer 2A in squares K27 and K30, the sands directly overlying the bedrock of K26 are stained black by organic material, which potentially suggests hearth-building activity directly on the rock surface; however the exfoliation of the bedrock itself is not apparent.

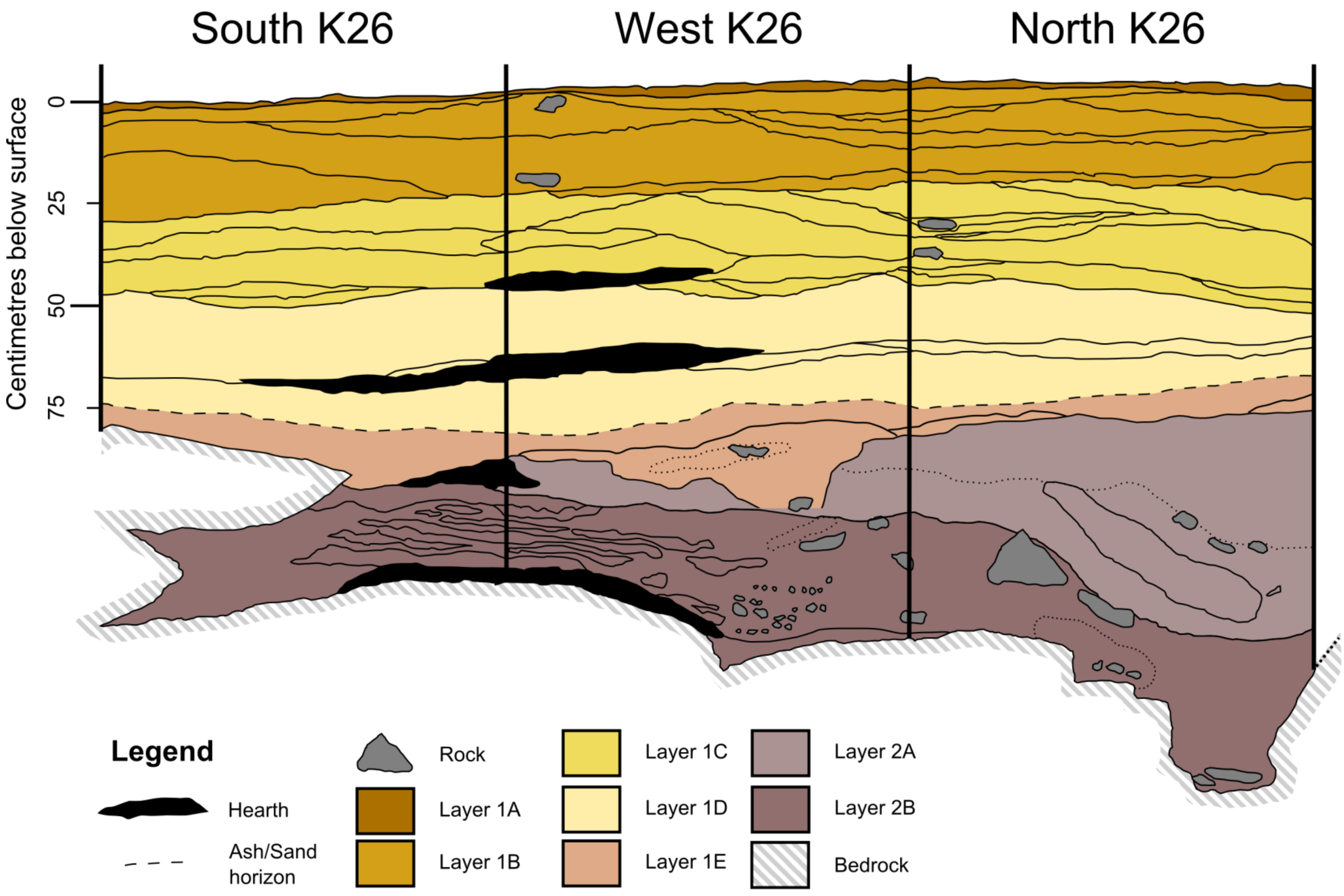


Figure 3.13 – Stratigraphic section of three of the walls of the square K26. Figure redrawn from original stratigraphic section diagram produced by Kim Newman.

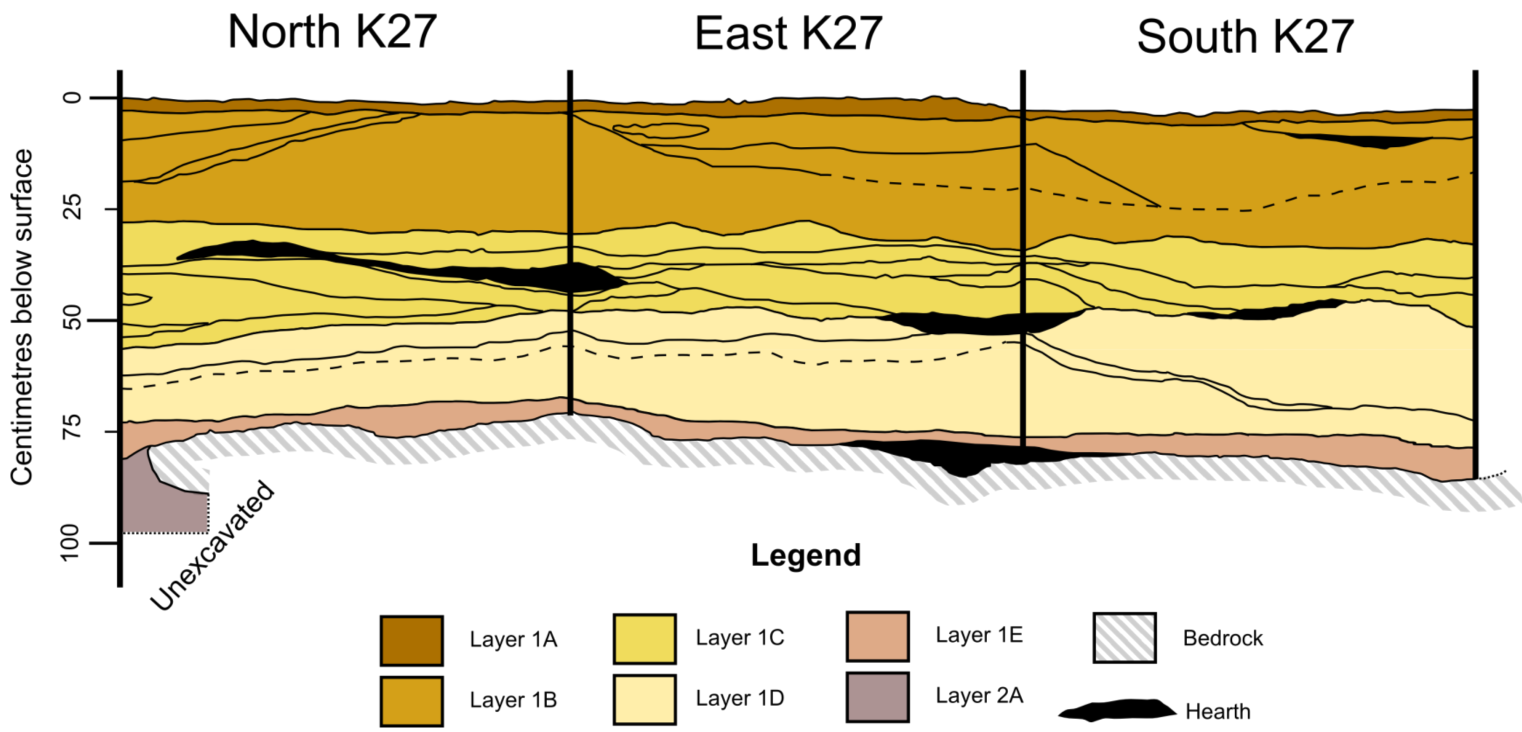


Figure 3.14 - Stratigraphic section of three of the walls of the square K27. Figure redrawn from original stratigraphic section diagram produced by Kim Newman.

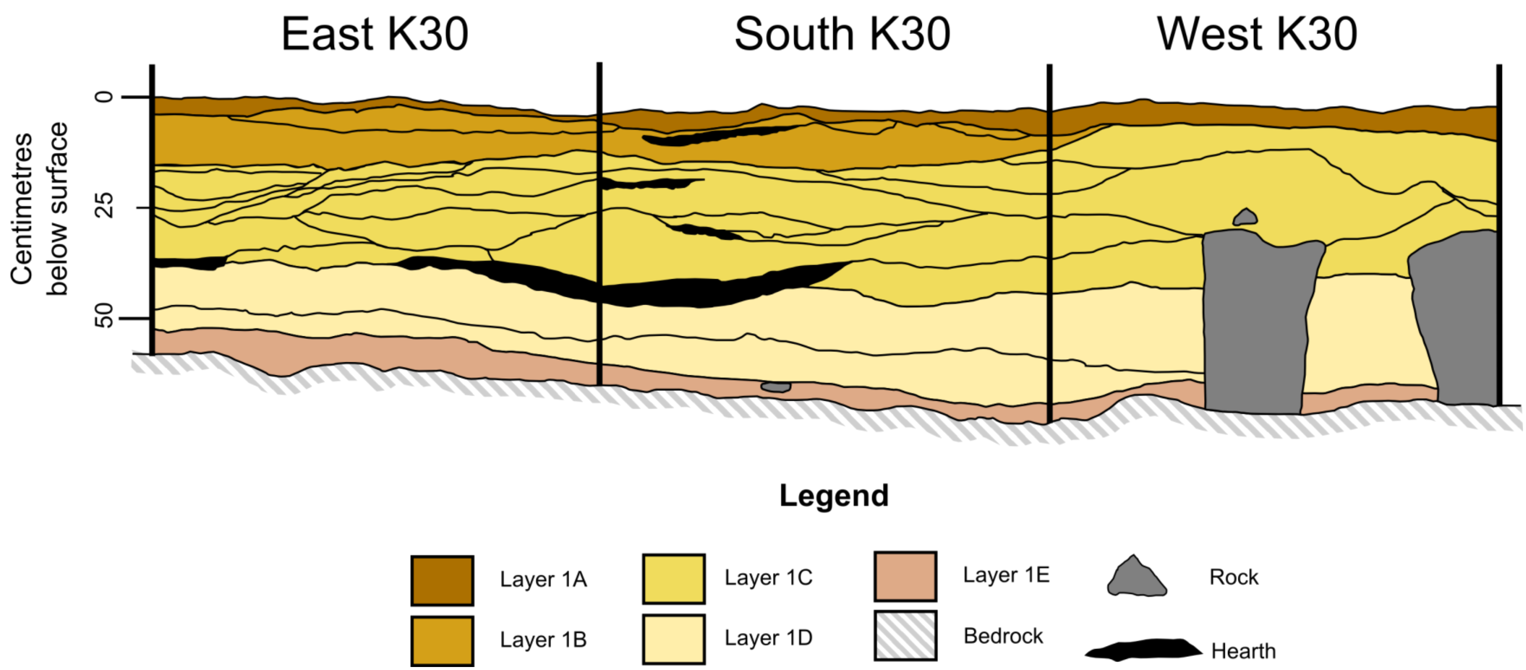


Figure 3.15 - Stratigraphic section of three of the walls of the square K30. Figure redrawn from original stratigraphic section diagram produced by Kim Newman.

Figure 3.16 - Western wall of square K26 showing clear distinction between Horizons 1 and 2. Note the shell-filled pit feature intruding into the brown sands from Horizon1 into Horizon 2.

S44

The small mounded midden to the east of the main rockshelter was also excavated, and the square labelled S44. From a surface view, the midden appeared comparable to the surface of the much larger deposit within the rockshelter with regards to species composition; dominated by *M. hiantina* and *T. granosa*. As well as this, the surface of this deposit was consolidated slightly with a thin algal coating. Upon excavation, the stratigraphic patterning observed seemed to mirror the patterning of

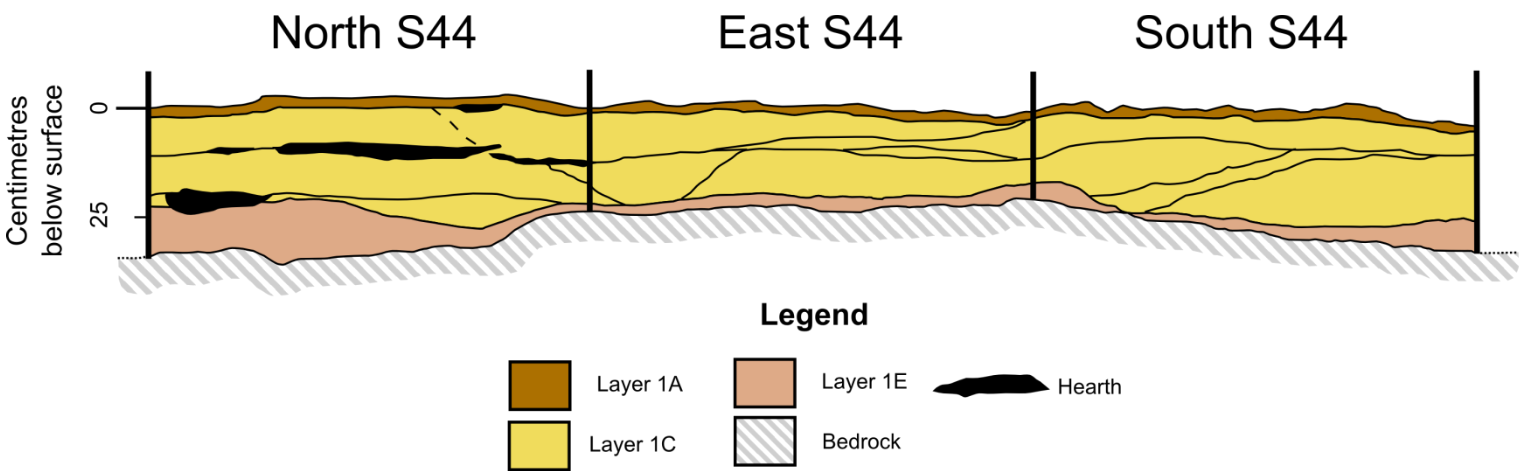


Figure 3.17 - Stratigraphic section of three of the walls of the square S44. Figure redrawn from original stratigraphic section diagram produced by Kim Newman.

Layer 1A of the squares excavated within the rockshelter, and described above – principally being dominated by shell midden material supported by an ash/silt matrix. Layers 1B, 1C and 1D, on the other hand, were not separately identified at S44. Interestingly, towards the lowest extent of S44, the sediments supporting the shell midden material coarsened, from ashy silts to medium sand, again similar to layers identified in the other squares; specifically Layer 2A. Exfoliation of the rock surface on which the midden was deposited generated by fire was not observed.

Chronology of Brremangurey

The preliminary radiocarbon dating program incorporated 20 specimens sampled from the Brremangurey excavations: 18 sourced from K26, and 2 from K27. No specimens from either K30 or S44 were sampled for dating. Furthermore, an additional 3 ages were generated using optically stimulate luminescence (OSL) dating using the quartz sands towards the lower extent of Horizon 2. The results of this dating program are presented in Table 3.1, and are discussed below. Radiocarbon dates were calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years applied on marine shell (Alan Hogg, pers. comm. 2014).

The archaeological material within the Brremangurey rockshelter can largely be differentiated into two distinct phases of deposition. The earliest material within the Brremangurey rockshelter was deposited in the late Pleistocene. These deposits, stratigraphically, accord with Horizon 2, and were deposited from approximately 14,200 and 12,700 cal. BP, as indicated by the oldest radiocarbon ages sampled from *in situ* hearth features within Horizon 2 and presented in Figure 3.18. The age of two samples, Wk-32411 and Wk-32410 respectively, were validated by OSL ages generated from quartz sands which returned age determinations of approximately 13,000 years BP.

#	Sample code	Material	Depth (cm. below surface)	Layer/ Horizon	^{14}C Age (uncal.)	Calibrated ^{14}C Age (1 sigma)	Calibrated ^{14}C Age (2 sigma)
1	**Wk-32405**[a]	Charcoal	8.6	1	493 ± 33	511 - 534	498 - 552 (99.4%) 614 - 617 (0.6%)
2	**OZQ-185**[b]	Charcoal	24.1 - 28.1 (Spit 6)	1	930 ± 25	796 - 834 (44.7%) 842 - 874 (37.8%) 893 - 909 (17.5%)	791 - 918
3	**OZQ-181**[b]	*T. granosa*	24.1 - 28.1 (Spit 6)	1	1,415 ± 25	853 - 950	785 - 988
4	**OZQ-188**[b]	*M. hiantina*	24.1 - 28.1 (Spit 6)	1	1,305 ± 25	729 - 840	695 - 892
5	**OZQ-191**[b]	*P.* c.f. *albina*	24.1 - 28.1 (Spit 6)	1	1340 ± 25	780 - 883	728 - 913
6	**Wk-32406**[b]	Charcoal	38.1	1	1,069 ± 28	934 - 982 (89.8%) 1035 - 1043 (10.2%)	930 - 1,008 (80.5%) 1,024 - 1,053 (19.5%)
7	**Wk-32407**[a]	Charcoal	57.6	1	1,896 ± 33	1,817 - 1,886	1,733 - 1,899 (98.9%) 1,913 - 1,920 (1.1%)
8	**OZQ-192**[b]	*P.* c.f. *albina*	64.4 - 69.9 (Spit 13)	1	2305 ± 25	1800 - 1906	1,730 - 1,954
9	**OZQ-186**[b]	Charcoal	75.9 - 80.3 (Spit 15)	1	2,210 ± 30	2,155 - 2,209 (48.4%) 2,223 - 2,270 (41.1%) 2,295 - 2,308 (10.6%)	2,148 - 2,319
10	**OZQ-182**[b]	*T. granosa*	75.9 - 80.3 (Spit 15)	1	2,615 ± 30	2,176 - 2,292	2,115 - 2,326
11	**OZQ-189**[b]	*M. hiantina*	75.9 - 80.3 (Spit 15)	1	2,495 ± 30	2,005 - 2,132	1,942 - 2,215
12	**OZQ-183**[b]	*A. spinosa*	75.9 - 80.3	1	2,565 ± 30	2,115 - 2,255	2,048 - 2,298
13	**WK-32408**[a]	Charcoal	90.5	1	2,444 ± 34	2,369 - 2,370 (0.4%) 2,377 - 2,497 (63.0%) 2,596 - 2,612 (9.0%) 2,637 - 2,685 (27.5%)	2,358 - 2,543 (60.2%) 2,559 - 2,618 (14.5%) 2,630 - 2,702 (25.3%)
14	**Wk-32409**[b]	Charcoal	91.0	1	3,394 ± 25	3,595 (1.1%) 3,607 - 3,646 (61.2%) 3,662 - 3,688 (36.9%)	3,579 - 3,694
15	**OZQ-187**[b]	Charcoal	91.0 - 95.9 (Spit 18A)	1	1,875 ± 25	1,742 - 1,754 (8.9%) 1,784 - 1,791 (5.2%) 1,810 - 1,871 (85.9%)	1,733 - 1876
16	**Wk-37137**[b]	*T. granosa*	91.0 - 95.9 (Spit 18A)	1	7,828 ± 25	8, 187 - 8,288	8,152 - 8,334
17	**OZQ-190**[b]	*M. hiantina*	91.0 - 95.9 (Spit 18A)	1	2,850 ± 30	2,462 - 2,618 (89.9%) 2,622 - 2,643 (10.1%)	2,375 - 2,682
18	**OZQ-184**[b]	*A. spinosa*	91.0 - 95.9 (Spit 18A)	1	2,745 ± 30	2,320 - 2,435	2,282 - 2,543
19	**Wk-32410**[b]	Charcoal	108.3	2	10,867 ± 39	12,708 - 12,760	12,694 - 12,801
20	**Wk-32411**[b]	Charcoal	125.5	2	12,303 ± 44	14,113 - 14,308	14,059 - 14,564

Table 3.1 – Ages of the intial radiocarbon dates of charcoal sourced from the wall of the excavation, and shell from excavated midden material post-excavation presented in stratigraphic order. Sample codes marked with superscript ‘a’ were analysed using conventional radiocarbon dating, whereas those marked with superscript ‘b’ used AMS. Where depths are marked with an asterisk, specimens were sampled directly from the wall of the square. Where a depth range is given, specimens were sampled from already excavated during the faunal analysis in the laboratory.

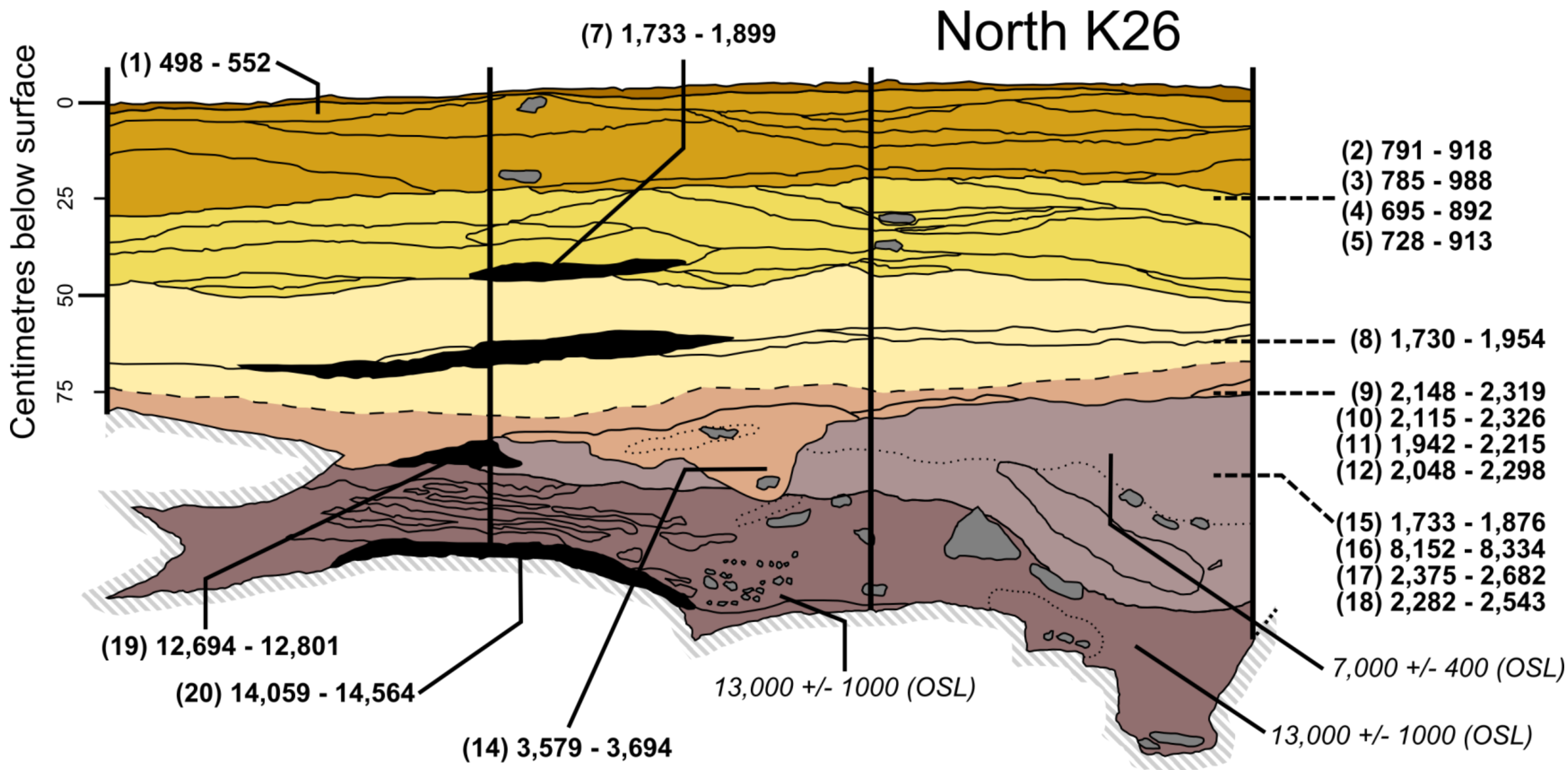


Figure 3.18 - Radiocarbon ages from K26, generated immediately post-excavation, placed in stratigraphic order from where the material was sampled from. Specimens for radiocarbon dating marked with a solid line were sampled directly from the wall of the trench during excavation. Specimens that were selected post-excavation from analysed midden material are indicated by a dashed-line at the approximate depth from which they were excavated.

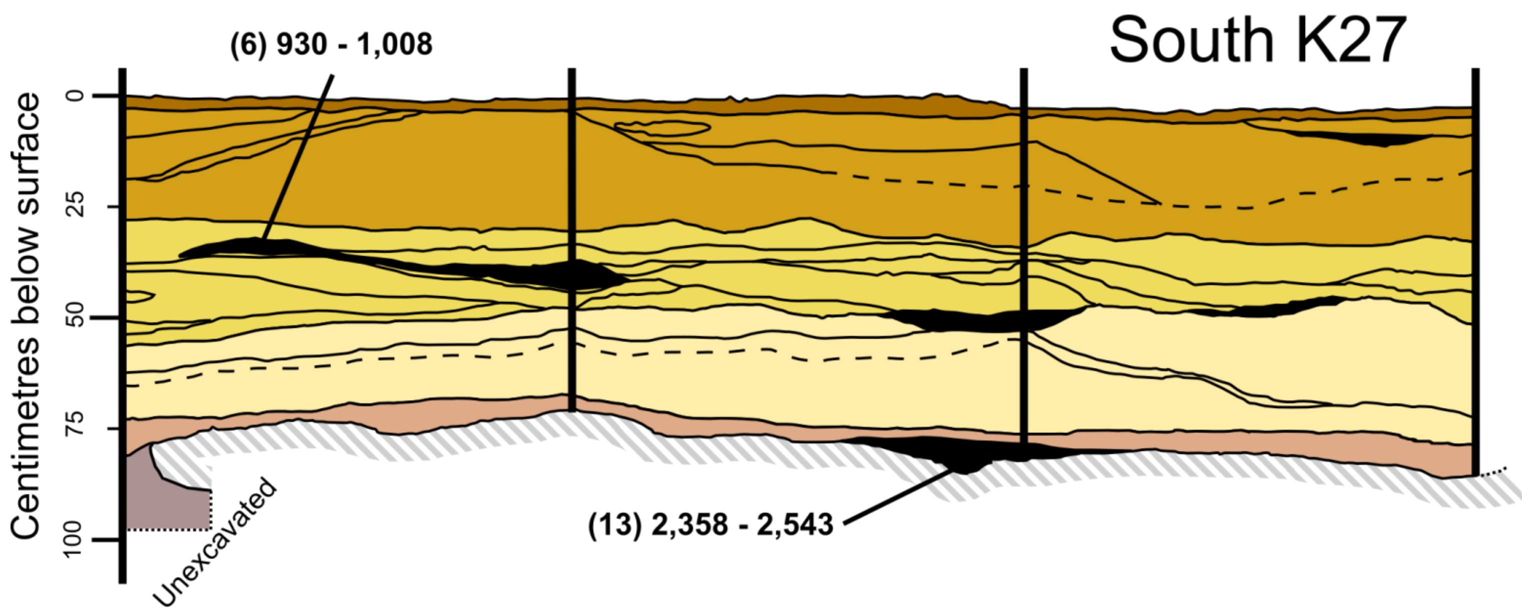


Figure 3.19 - Radiocarbon ages from K27, generated immediately post-excavation, placed in stratigraphic order from where the material was sampled from.

The Pleistocene/terminal Holocene ages of the sandsheet layer of Horizon 2 contrast with the largely younger ages of the overlying midden deposit of Horizon 1. Almost all of the radiocarbon ages across both marine shell and charcoal samples fall between approximately 3,600 and 500 cal. BP bracketing the most intensive period of midden deposition at Brremangurey. This pattern of late Holocene midden formation is not uncommon, and is rather typical of archaeological deposits of Australia's tropical north (e.g. Bailey 1977, Veitch 1999, Bourke 2012, Faulkner 2013). What is not typical of midden deposits in northern Australia is the age returned from a specimen of *T. granosa* (Wk-37137) dating to between 8,152 and 8,334 cal BP. This particular specimen was sampled from the same stratigraphic level as samples OZQ-184, OZQ-187, OZQ-190 and Wk-32409, yet all of these samples returned ages ranging from approximately 1,800 to 3,600 cal. BP. The implications of this early Holocene age from a *T. granosa* valve at Brremangurey, with specific regards to formation and transformation processes at Brremangurey, as well as subsequent interpretations of gathering practices of the prehistoric occupants of Brremangurey and their environment will be discussed towards the end of this chapter.

Faunal analysis of midden material excavated at Brremangurey

Approach to investigation

A total of 950.5 kg of shell material was excavated from all 4 squares at Brremangurey: ca. 325.5 kg from K26, ca. 364 kg from K27, ca. 157 kg form K30 and ca. 44 kg from S44. The strategy of sub-sampling the midden material evolved as excavation proceeded. Initially, a 100% sample was collected. As excavation progressed, it became clear that continuing with this approach would result in a logistically unfeasible quantity of midden shell, it was decided that a 50% sub-sample would be more appropriate. As some levels had already been excavated and transported off-site when this decision was made, the method in which a 50% sample was applied varied between sections of each square, and are summarised in Table 3.2 below. For the spits where 100% of the midden sample was already transported off-site, sub-sampling to 50% was conducted by weight in the laboratory prior to the material being sorted and quantified. For the spits that were not already excavated when the decision to reduce sample size was made, sub-sampling proceeded by volume, where the 1x1 m square was split into left east/west halves, with the material from one being kept for further analysis. The half that would not be kept was still sieved on-site and visually inspected for the presence of artefacts and other material culture.

Square	100% sample	50% by weight	50% by volume
K26	Spits 19 - 41	-	Spits 1 - 18B
K27	Spits 1 - 7	Spits 8 - 11	Spits 12 - 16
K30	-	Spits 1 - 13	-
S44	-	Spits 1 - 6	-

Table 3.2 - Sub-sampling data of squares excavated at Brremangurey

It should be noted that spits below Spit 18B in square K26, sampling was reverted back to 100%. At this level, the abundance of midden shell rapidly decreased in subsequent excavation units which resulted in the 100% sampling of midden shell to become feasible.

Following the excavations at Brremangurey, the midden shell was transported to the University of Wollongong's Zooarchaeology Laboratory for sorting, quantification, and further analysis. As K26 and S44 were the only squares to provide a complete cross-section of the archaeological deposits of Brremangurey, only the quantification results for these two squares will be presented here, and only the 5 mm sieved fraction has been analysed. Initial analyses involved separation and identification to the lowest possible taxonomic level, and isolation and quantification of non-repeating elements (NRE) to provide a minimum number of individuals (MNI) estimate for each taxon that contributed to the assemblage. Quantification of the total number of identified specimens present (NISP) for each taxon was also undertaken. The abundance of burnt shell specimens using the same NRE and NISP quantification methods was also established. The NRE selected for quantifying bivalves of the Brremangurey assemblage was both the left and right hinges, for gastropods the spire was selected, and for chitons both the anterior and posterior plates were individually quantified. In consideration of Grayson's 'division of aggregates' problem (1984), the totals of each NRE throughout the assemblage was tallied, and the higher of the two being used for individual excavation unit's MNI values. This will consequently under- rather than over-estimate MNI values. Charcoal separated from each spit's material during sorting was also quantified by weight to the nearest gram.

Results of quantification – K26

A total of 207 kg of shell excavated from the 5 mm sieved fraction was analysed as part of the quantification process of the Brremangurey midden. The weights of shell from each spit of K26 are presented in Figure 3.20.

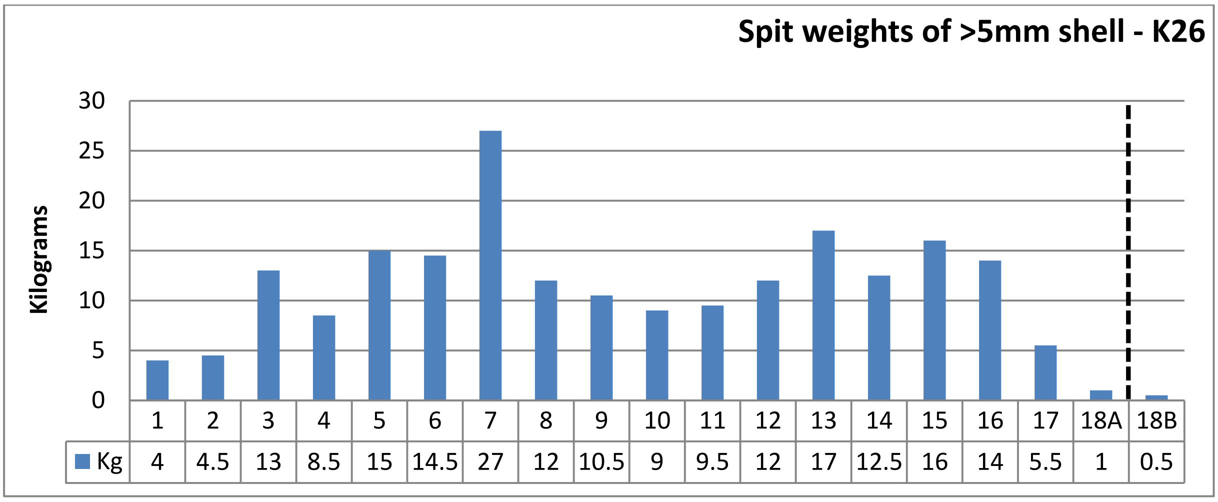


Figure 3.20 - Kilograms per spit of >5mm shell material excavated from K26. Weights of shell below spit 18B were too small to adequately display on this figure. Dashed line denotes transition from Horizon 1 to Horizon 2.

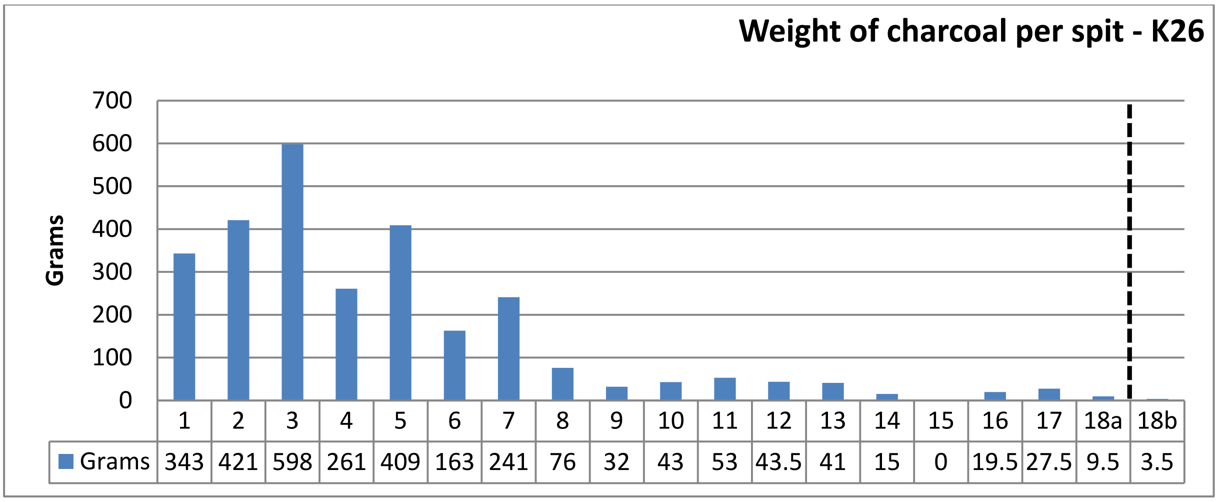


Figure 3.21 - Grams per spit of charcoal excavated from K26. Weights of charcoal below Spit 18B were too small to adequately display on this figure. Dashed line denotes transition from Horizon 1 to Horizon 2. Dashed line denotes transition from Horizon 1 to Horizon 2.

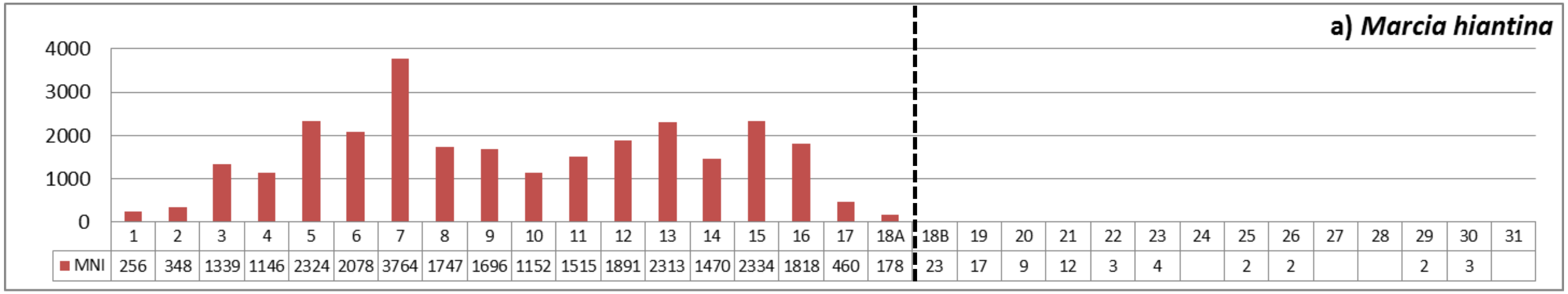
Across all of the analysed material, 86 separate taxa were identified in varying abundances. As can be seen in Table 3.3, bivalves dominated the assemblage. The soft-shore venerid *M. hiantina* was by a large margin the most abundant species present in the assemblage, comprising 70% of MNI and 81% of NISP counts in square K26. Much smaller quantities of the pearl oysters *Pinctada* cf. *albina* and *Isognomon ephippium* were identified representing 2.2% and 1.4% of total MNI counts respectively. In contrast to the typical shell accumulations reported in northern Australian archaeological research (e.g. Bailey 1977, Faulkner 2006, Veitch 1999; but see Cochrane 2014), the estuarine cockle *T. granosa* comprises only a small proportion of the overall assemblage with less than 1% of total MNI and NISP counts across all taxa present, despite the appearance of equal proportions of *T. granosa* and *M. hiantina* on the rockshelter's surface. The vast majority of shell material was concentrated within the upper midden layers of the site of Horizon 1, between Spits 1 and 18A, though minor instances of shell were discovered within the underlying sandsheet of Horizon 2. The summarised results of the quantification of the K26 midden material is presented in Table 3.3 below.

Bivalvia	MNI				NISP		
	Counts		% of total MNI	% MNI Burnt	Counts	% of total	% Burnt
Marcia hiantina	Left	27,706	69.6	7.2	259,556	81.1	13.0
	Right	27,906	70.1	6.9			
Pinctada c.f. *albina*	Left	748	1.9	0.8	27,831	8.7	3.1
	Right	878	2.22	2.7			
Isognomon ephippium	Left	564	1.4	1.1	4,082	1.3	2.5
	Right	570	1.4	1.6			
Tegillarca granosa	Left	308	0.8	11.7	2,192	0.7	42.1
	Right	316	0.8	8.9			
Septifer bilocularis	Left	258	0.7	1.2	952	0.3	2.1
	Right	250	0.6	0.4			
Saccostrea cucullata	Upper	24	0.1	-	220	>0.1	9.6
	Lower	13	>0.1	7.7			
Saccostrea cucullata (juvenile)	Upper	132	0.3	3.0	812	0.3	5.5
	Lower	135	0.3	3.0			
Circe sp.	Left	139	0.4	13.7	308	0.1	14.9
	Right	157	0.3	16.6			

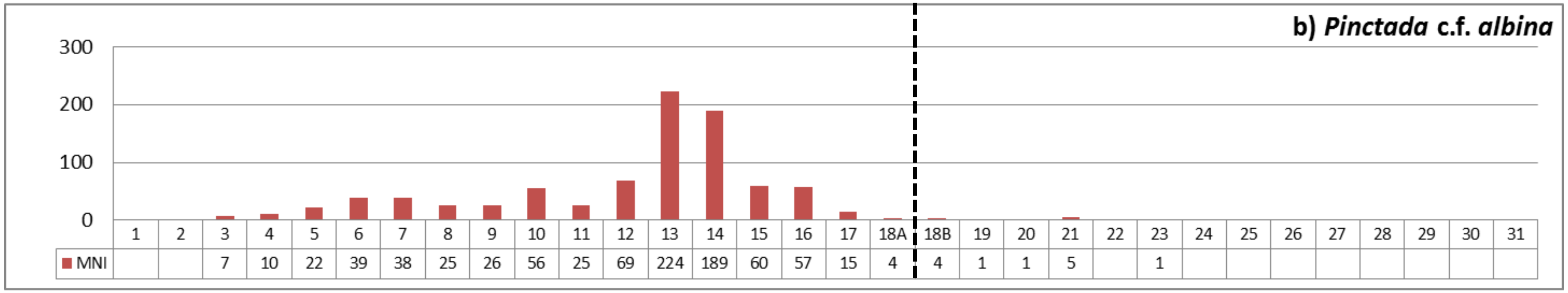
Gastropoda	MNI			NISP		
	Counts	% of total MNI	% MNI Burnt	Counts	% of total	% Burnt
Terebralia palustris	16	>0.1	6.3	1942	0.6	10.8
Telescopium telescopium	9	>0.1	22.2	375	0.1	15.2
Clypeomorus bifasciata	143	0.4	6.3	185	>0.1	6.0
Amplirhagada sp.	42	0.1	42.9	1278	0.4	35.1

Polyplacophora	MNI				NISP		
	Counts		% of total MNI	% MNI Burnt	Counts	% of total	% Burnt
Acanthopleura spinosa	Anterior	505	1.3	5.9	6,138	1.9	5.4
	Posterior	605	1.5	4.3			

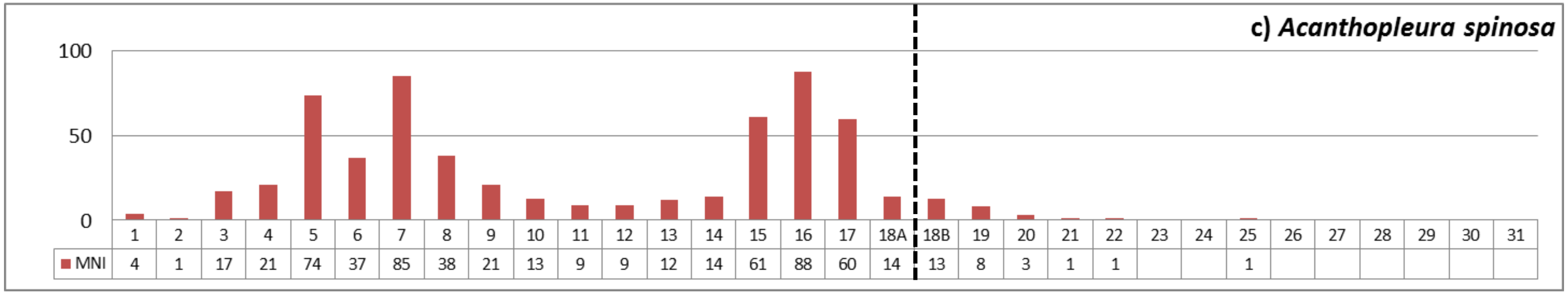
Table 3.3 - Summary of results of quantification of midden material excavated from K26 with specific species isolated. Note that *Amplirhagada* sp. is a terrestrial gastropod, unlike the other species represented which are all marine molluscs.



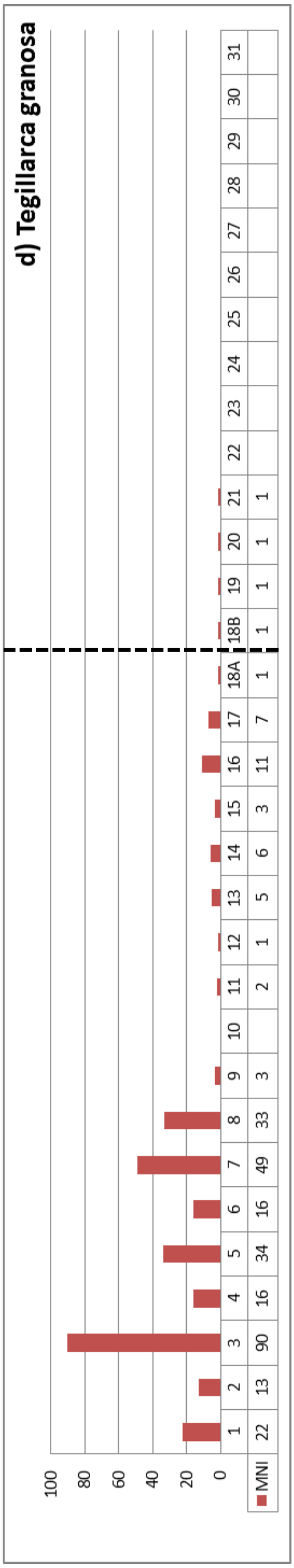
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18A	18B	19	20	21	22	23	24	25	26	27	28	29	30	31
MNI	256	348	1339	1146	2324	2078	3764	1747	1696	1152	1515	1891	2313	1470	2334	1818	460	178	23	17	9	12	3	4		2	2			2	3	

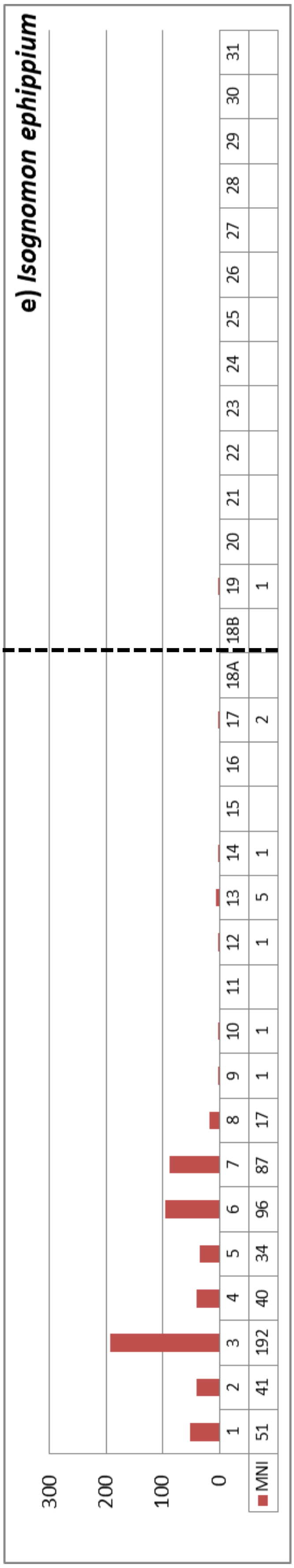


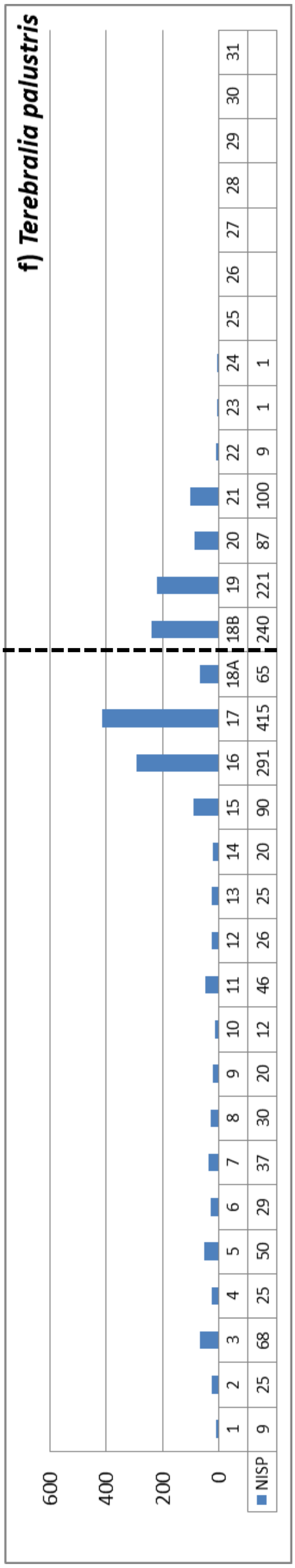
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18A	18B	19	20	21	22	23	24	25	26	27	28	29	30	31
MNI			7	10	22	39	38	25	26	56	25	69	224	189	60	57	15	4	4	1	1	5		1								



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18A	18B	19	20	21	22	23	24	25	26	27	28	29	30	31
MNI	4	1	17	21	74	37	85	38	21	13	9	9	12	14	61	88	60	14	13	8	3	1	1			1						


d) Tegillarca granosa
100
80
60
40
20
0
MNI
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18A 18B 19 20 21 22 23 24 25 26 27 28 29 30 31
22 13 90 16 34 16 49 33 3 2 1 5 6 3 11 7 1 1 1 1 1


e) Isognomon ephippium
300
200
100
0
MNI
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18A 18B 19 20 21 22 23 24 25 26 27 28 29 30 31
51 41 192 40 34 96 87 17 1 1 1 5 1 2 1


f) Terebralia palustris
600
400
200
0
NISP
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18A 18B 19 20 21 22 23 24 25 26 27 28 29 30 31
9 25 68 25 50 29 37 30 20 12 46 26 25 20 90 291 415 65 240 221 87 100 9 1 1

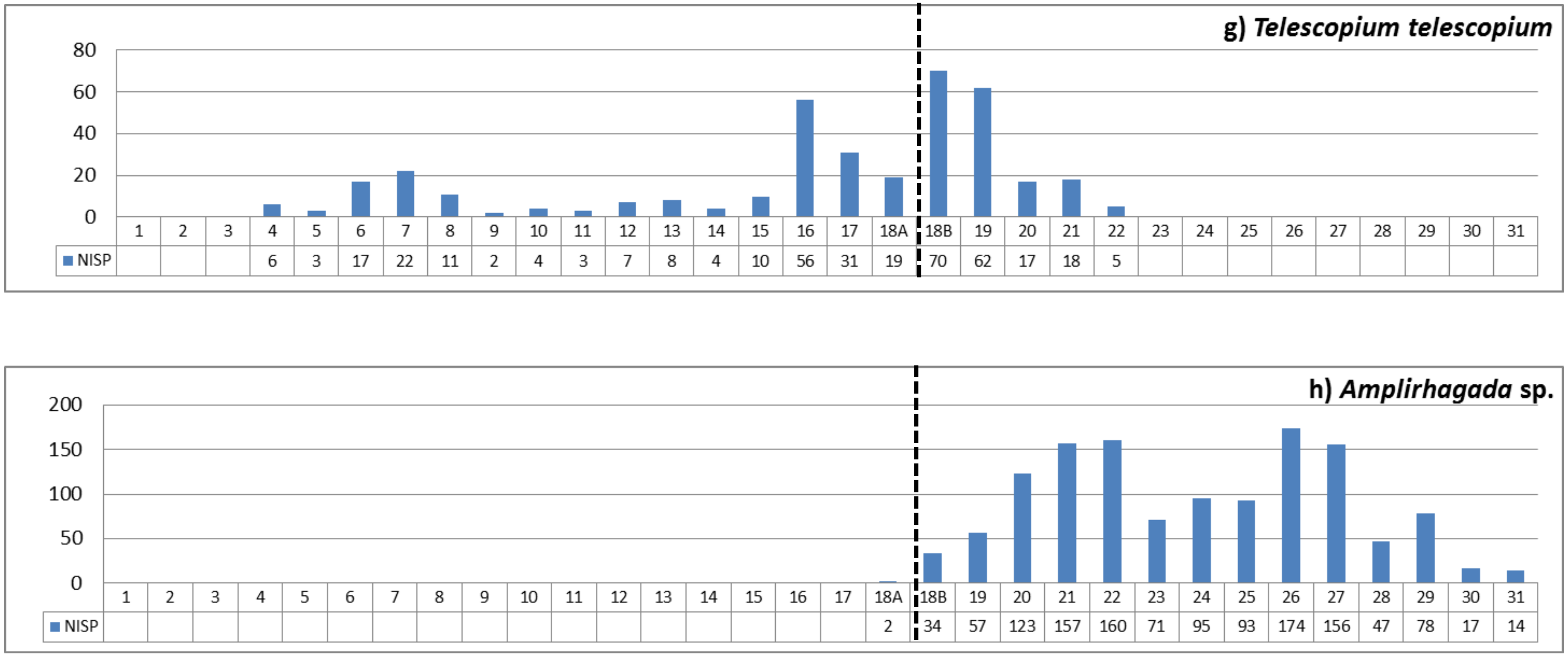
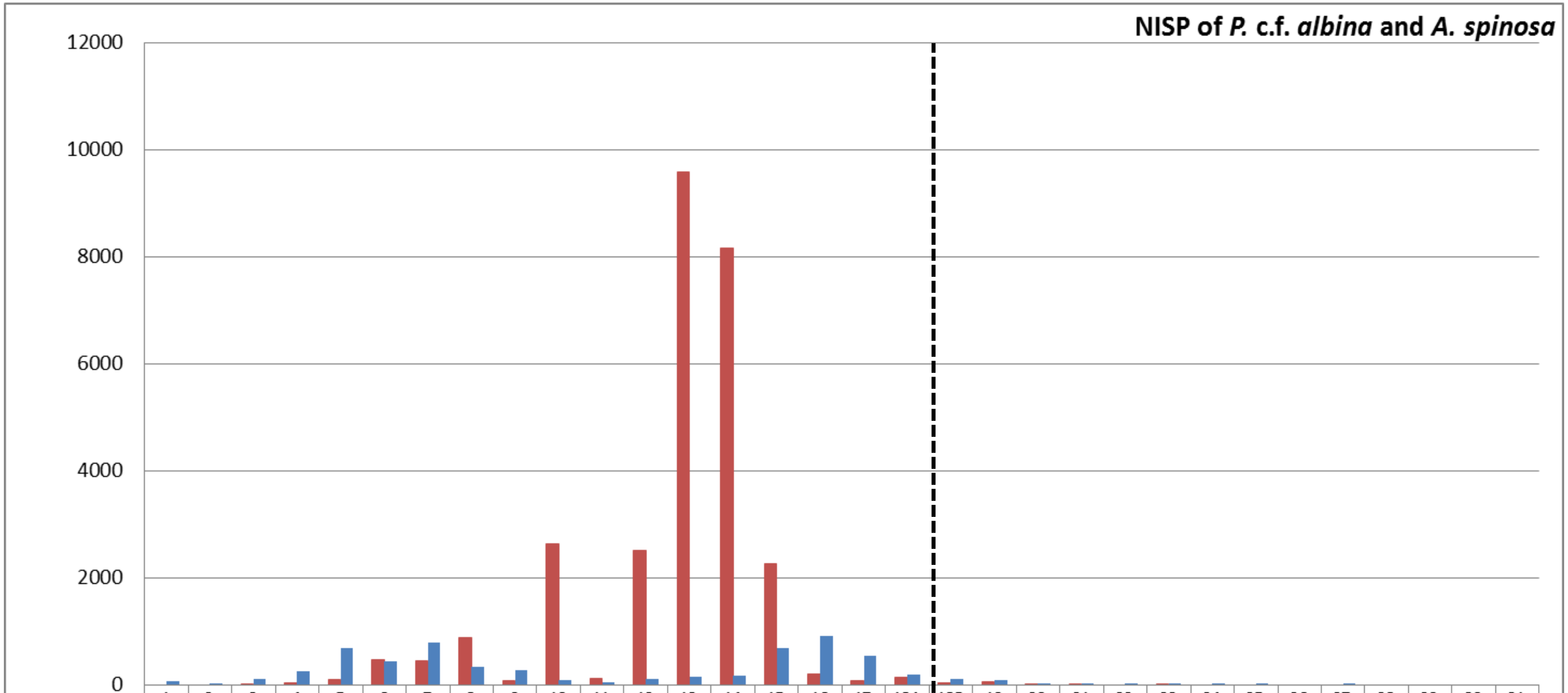
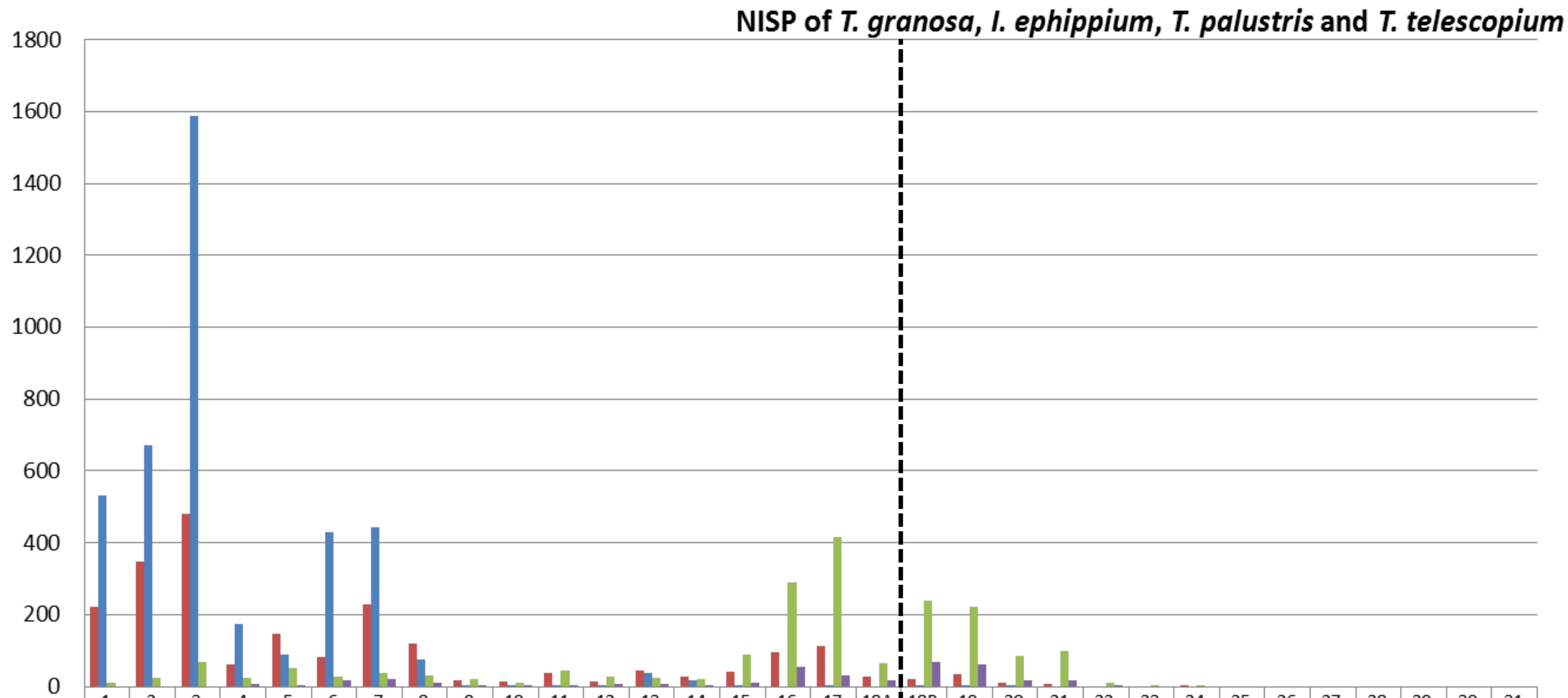


Figure 3.22a-h - Quantification results for specific species from the K26 excavated material. Excavation proceeded beyond Spit 31, however as no shell was found beyond this point, it is not factored into these figures. Dashed line denotes transition from Horizon 1 to Horizon 2.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18A	18B	19	20	21	22	23	24	25	26	27	28	29	30	31
P. albina			24	31	89	471	451	883	75	2639	118	2514	9580	8158	2271	209	76	133	27	66	8	7		1								
A. spinosa	70	12	116	255	681	430	799	343	271	78	52	108	155	160	683	918	543	199	99	95	23	34	8	2	1	1		2				

Figure 3.23 - Quantification results *P. c.f. albina* and *A. spinosa* from the K26 excavated material. Excavation proceeded beyond Spit 31, however as no shell was found beyond this point, it is not factored into this figure. Dashed line denotes transition from Horizon 1 to Horizon 2.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18A	18B	19	20	21	22	23	24	25	26	27	28	29	30	31
T. granosa	223	348	479	61	148	83	228	121	17	13	39	14	43	29	41	95	114	27	22	34	10	8			1							
I. ephippium	532	670	1586	175	88	429	442	76	5	2	4	4	39	16	4		5		3	1	1											
T. palustris	9	25	68	25	50	29	37	30	20	12	46	26	25	20	90	291	415	65	240	221	87	100	9	1	1							
T. telescopium				6	3	17	22	11	2	4	3	7	8	4	10	56	31	19	70	62	17	18	5									

Figure 3.24 - Quantification results specific species from the K26 excavated material. Excavation proceeded beyond Spit 31, however as no shell was found beyond this point, it is not factored into this figure. Dashed line denotes transition from Horizon 1 to Horizon 2.

Species name	MNI	NISP
Marcia hiantina	27906	259556
Pinctada c.f. *albina*	878	27831
Acanthopleura spinosa	605	6138
Isognomon ephippium	570	4082
Tegillarca granosa	316	2192
Septifer bilocularis	258	952
Circe sp.	157	308
Clypeomorus bifasciata	143	185
Saccostrea cucullata (juvenile)	135	812
Nerita spp.	110	597
Nerita balteata	100	560
Nerita undata	74	769
Amplirhagada sp.	43	1280
Thais echinata	42	239
Cantharus erythrostomus	39	141
Cardita variegata	35	117
Arca avellana	34	88
Anomalocardia squamosa	29	91
Calliostoma spp.	26	36
Saccostrea cucullata	24	220
Anadara setigericosta	22	76
Nerita polita	20	93
Chama iostoma	20	54
Terebralia palustris	16	1942
Pugilina cochlidium	13	129
Cerithium sp.	13	47
Planaxus sulcatus	13	27
Turbo cinereus	12	140
Dosinia scalaris	11	28
Pitar citrinus	11	18
Patelloida saccharina	11	15
Telescopium telescopium	9	375
Malleus sp.	9	24
Beguina semiorbiculata	6	20
Gafrarium tumidum	6	16
Cyclotellina remies	6	10
Hemitoma tricarinata	6	6
Tellina sp.	5	5
Cerithidea anticipata	4	78
Anadara antiquata	4	13
Siphonaridae	4	4
Fissurelidae	3	4
Melo sp.	2	53
Muricidae	2	43
Fasciolaridae	2	8
Ostrea sp.	2	5
Lunulicardia hemicardia	2	3
Nerita signata	2	3
Corbulidae	2	2

Species name (continued)	**MNI**	**NISP**
Littorina pintado	2	2
Non-calcareous opercula	2	2
Fish otolith	2	2
Barnacle fragment	≥1	2410
Calcareous worm cast fragment	≥1	147
Crustacean fragment	≥1	87
Austrocochlea sp.	≥1	27
Morula sp.	≥1	8
Cassidula angulifera	≥1	4
Siliquaria ponderosa	≥1	2
Nassarius sp.	≥1	2
Pectinidae	≥1	2
Cypraea sp.	≥1	2
Dentalium sp.	≥1	2
Chicoreus sp.	1	77
Polymesoda erosa	1	31
Trochus niloticus	1	7
Urchin fragment	1	5
Tellina scobanata	1	5
Placamen sp.	1	4
Ancilla c.f. *monolifera*	1	3
Lioconcha castrensis	1	3
Mactra achinata	1	2
Polinices sordidus	1	2
Mytilidae	1	1
Atactodea striata	1	1
Gafrarium divaricatum	1	1
Epitonium imperialis	1	1
Littoraria filose	1	1
Pleuroploca trapezium	1	1
Nucula sp.	1	1
Scalptia scalata	1	1
Gari sp.	1	1
Cerithidea sp.	1	1
Strombus sp.	1	1
Marinula patula	1	1
Puperita sp.	1	1
Cymatiidae	1	1
Cancellariidae	1	1
Undiagnostic nacre fragment	-	6917
Unidentified/Undiagnostic shell	-	683
Coral fragment	-	56

Table 3.4 - Complete list of species that comprise the faunal assemblage of K26. Species presented in order of descending MNI abundance.

As can be clearly seen in Figure 3.22a, *M. hiantina* is the most abundant species throughout the K26 assemblage. Despite this consistent dominance, a general trend can be determined across all of the taxa so far presented here. The results presented in Figures 3.22a-h of the marine molluscan taxa quantified as part of the K26 midden analysis reveal peaks of abundances at consistent stratigraphic depths. The first of these peaks occur between spits 1 to 9. Following this, a trough is noted as abundances fall, only to rise again between spits 14 to 18A. This pattern is also noted in the weights of shell excavated form K26, seen in Figure 3.20. It is likely that these two patterns are linked; that the greater the mass of shell being removed from excavation units will directly translate to increased taxon-specific abundances post-quantification. However this in itself says a story about the depositional patterning at Brremangurey. Based on the quantification data presented here, as well as the spit weights of shell, an argument can be made that the shell midden of K26 was deposited in two distinct phases of intensive deposition, with a relatively less intense deposition in between.

Comparing this interpretation to the results of the radiocarbon dating program presented in Table 3.1, a similar interpretation can be made. Radiocarbon specimens sampled from above Spit 10 (Wk-32405, OZQ-185, OZQ-181, OZQ-188, OZQ-191 and Wk-32406), ages range between approximately 500 to 1,000 cal. BP. The remaining radiocarbon ages sampled at lower stratigraphic levels are notably older, ranging from approximately 1,730 to 3,700 cal. BP; potentially adding weight to the interpretation of two distinct phases of midden deposition at Brremangurey.

Focussing on the abundances of *P.* c.f. *albina* seen in Figure 3.22b and Figure 3.23, a significant spike in both MNI and NISP counts is noticed between spits 12 and 14. This contained increase in abundance of a particular species is not shared amongst the other taxa identified at Brremangurey, and unlike the previously mentioned correlation between species abundance and spit weights, no significant increase in spit weights is noticed at this stratigraphic layer. This spike in *P.* c.f. *albina* numbers is more than likely a distinct depositional episode outside of the typical species being targeted by the inhabitants of Brremangurey at 1,730 - 1,954 cal. BP (OZQ-192 and Table 3.1).

During the excavation of the spits characterised by the increase in *P.* c.f. *albina* numbers, the pearl oysters did seem to form a distinctive carpet-like layer across the three squares within the Brremangurey rockshelter. There are two implications of this. Firstly, having *P.* c.f. *albina* concentrated within a relatively small vertical window suggest a degree of stratigraphic integrity within the deposit – at these levels at least. Secondly, this carpet-like layer of *P.* c.f. *albina* was noticed across all three squares within the Brremangurey rockshelter. This implies a relatively large spatial distribution, extending across 5 metres at least, likely much more. Finally, it is possible that this *P.* c.f. *albina* layer, assuming it is *in situ*, spatially separates the younger depositional phase towards the upper extent of the midden, from the older underneath.

Interestingly, towards the bottom-most extent of the midden deposit of K26, mangrove associated gastropods appear to increase in relative abundance. Both *T. palustris* and *T. telescopium* counts are at their highest between spits 16 (81.8 - 85.2 cm BS) and 21 (113.4 - 119.5 cm BS) where NISP counts of 73.1% for the former and 72.8% of the latter were identified (Figures 3.22f and 3.22g). Midden deposits dominated by mangrove gastropods, particularly *T. palustris*, have been discovered in archaeological sites along Western Australia's coast (e.g. Bowdler 1990a and 1990b, Lorblanchet 1992, Clune and Harrison 2009: 71) and are associated with mid-Holocene ages, when mangrove forests proliferated across the northern Australian coastline (Woodroffe *et al*. 1985 and 1988). Whether or not this is the case here and these specimens are representative of an early tradition of shellfish gathering focussing on mangrove ecologies is impossible to determine without dating these samples, which to date has not been done. It should be noted that the other mangrove associated species, the mangrove pearl oyster *I. ephippium*, does not mimic the patterns of *T. palustris* or *T. telescopium*. Rather, this particular species at Brremangurey is confined to the uppermost and youngest extent of the midden at K26, seen in Figure 3.22e.

From Spit 16 and for the next few spits, the presence of shell diminishes rapidly. From Spit 18B it can be argued that the midden deposit has completely transitioned to the sandsheet of Horizon 2.

Despite this, molluscan shell is still found, even towards the deeper extent of the sandsheet. The terrestrial snail *Amplirhagada* sp. is absent within the midden deposit, and is exclusively found in the underlying sandsheet, as seen in Figure 3.22h. These specimens are highly fragmented and exhibit a particularly higher proportion of burnt samples with approximately 42% of fragments indicating some degree of burning. Terrestrial snails of the Camaenidae Family are known to aestivate, or hibernate during periods of aridity by burying themselves in sheltered soft sediments (e.g. Köhler 2010, Criscione and Köhler 2016). With this in mind, it is difficult to determine whether the presence of *Amplirhagada* sp. within the Brremangurey assemblage is incidental and not related to deliberate human subsistence gathering, or whether these fragments are the result of targeted gathering by the Brremangurey inhabitants. Were these *Amplirhagada* sp. specimens aestivating by burying themselves within sediments, applying ages from adjacent samples is problematic, as the snails have effectively intruded their way into much older sediments and are therefore temporally disconnected form the sands in which they now lie.

Furthering on from this, a total of 1,010 fragments of *M. hiantina* were also found embedded within the sandsheet between Spit 18B (105.1 – 109.8 cm BS) and Spit 31 (155.2 - 156.7 cm BS). These fragments were in excellent condition, possibly facilitated by the relatively high pH of the Brremangurey deposits. As seen in Figure 3.19, these fragments were found in association with sediments dated to the late Pleistocene/early Holocene. As none of the specimens were directly dated, it is difficult to confidently ascertain their age.

Results of quantification – S44

A total of 56 kg of midden material was excavated from the S44 midden to the east of the Brremangurey rockshelter's principal entrance (Figure 3.10) and the excavation reached a total depth of 31.8 cm BS when bedrock was reached at the termination of Spit 6.

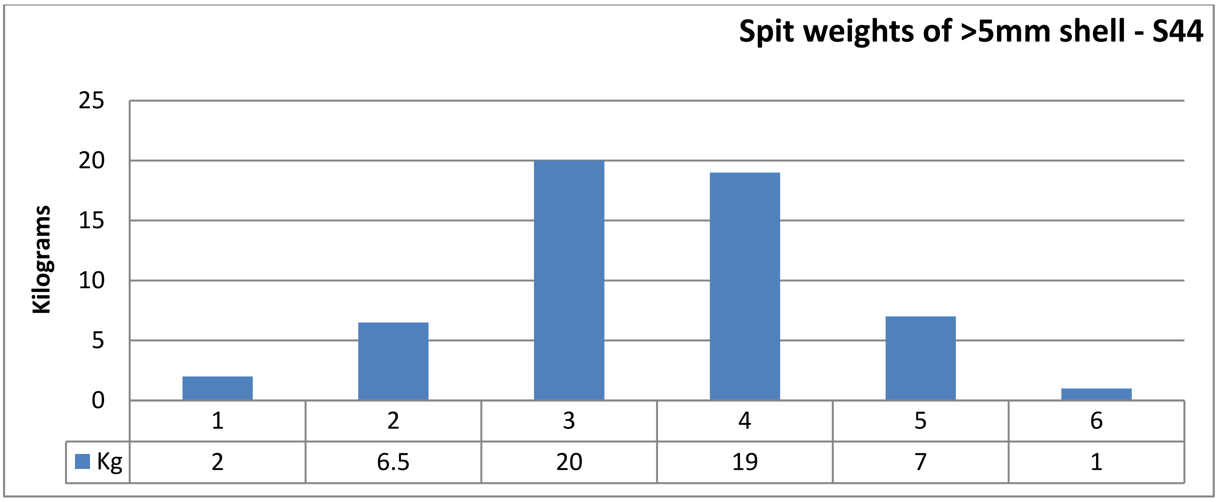


Figure 3.25- Weights of shell from >5mm sieve fraction excavated from S44.

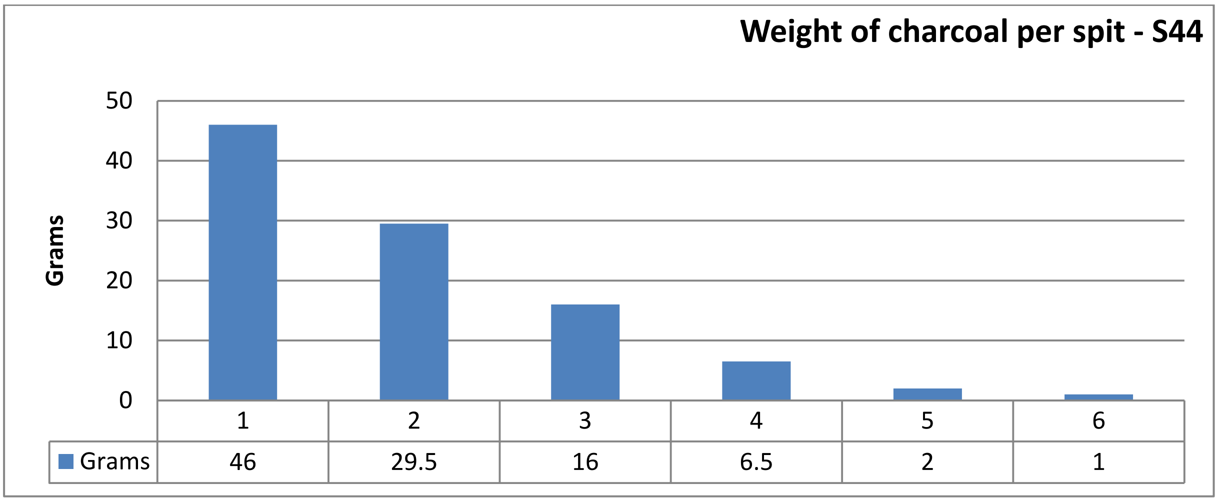


Figure 3.26 - Weights of charcoal excavated from S44.

A total of 44 distinct taxa were identified from the excavated material from S44. Compositionally, 94.3% of total NISP fragments excavated from S44 comprised of 7 taxa; *M. hiantina*, *T. granosa*, *A. spinosa*, *P. albina*, juvenile *Saccostrea cucullata,* and barnacle fragments. Like K26, *M. hiantina* dominates throughout the sequence.

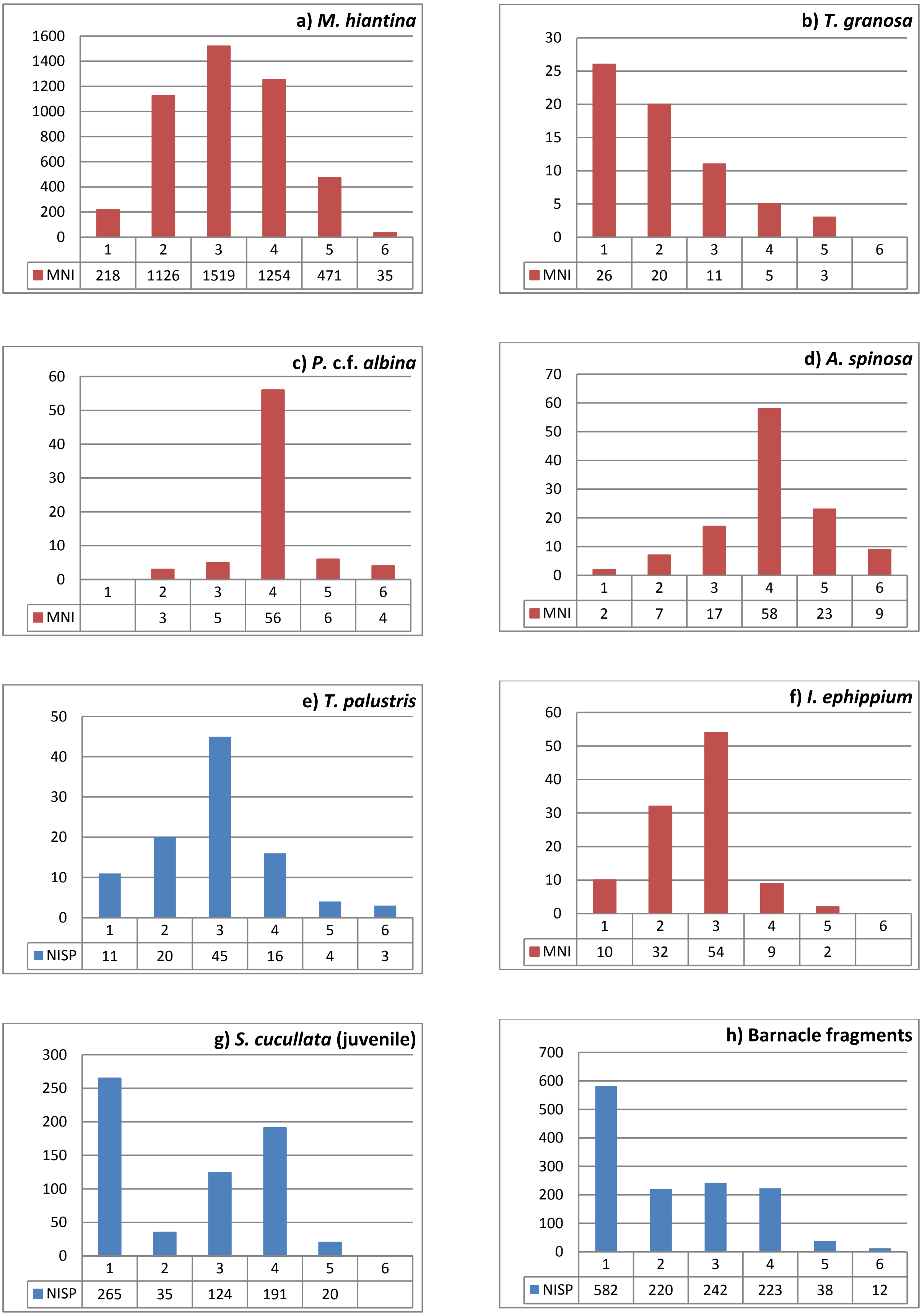


Figure 3.27a-h - Results of quantification of targeted species excavated from S44

Due to the shallow nature of the S44 deposit, with a total depth not exceeding 32 cm and only 6 spits in total, there is less room for patterns, trends, species shifts and transitions to manifest themselves when compared with K26. In saying this, however, some interesting trends can be isolated.

The patterns of abundance (Figure 3.27a-h) across nearly all of the species found at S44 follow a bell-shape, with MNI and NISP counts increasing in the upper levels of the deposit, reaching a maximum towards the middle, and falling at the deepest and oldest levels of the excavation. As with K26, this pattern of faunal abundance correlates with the weight of shell excavated from each spit (Figure 3.25) so it is likely that this is driving the increased numbers of specimens.

This is not true of all of the species at S44, though, as the uppermost Spit 1 recorded the highest number of MNI counts of *T. granosa* within S44, as counts for this species gradually decrease with depth. Interestingly, the same pattern is observed for NISP counts of both juvenile *S. cucllata* and fragments of barnacles, and the same pattern is observed in the weights of charcoal. If we assume that the increased presence of charcoal within these uppermost levels is indicative of a relative increase in fire-building activity, a possible scenario that accounts for the patterns seen in juvenile *S. cucullata* and barnacle fragments is that they were brought to the site accidentally, attached to firewood that was collected. However, following this scenario further, we would expect relatively increased incidences of burning with these taxa, which is not apparent (Table 3.9). It is possible that the degree of burning was enough to result in visual and tactile indicators for these specimens, however this is unlikely.

Another pattern that should be pointed out is the spike of *P.* c.f. *albina* numbers seen in Figure 3.27c in Spit 4. Comparing the this pattern between the two squares, much fewer *P.* c.f. *albina* valves were uncovered than at K26, and this apparent boom in abundance is only based on the relative proportion of the *P.* c.f. *albina* specimens of Spit 4 compared with the other spits. Of course the large-scale *P.* c.f. *albina* heavy layer identified within K26 cannot be compared with the potential feature of S44 due to the limited spatial extent of this auxiliary midden, and further undermined by the lack of a chronological framework for S44 outside of hypothesised stratigraphic projections, however the pattern should be noted.

Synthesis of the results of excavations at Brremangurey

In broad terms, the middens in which both K26 and S44 were situated are largely comparable. Both deposits are dominated by the same species (*M. hiantina*), and overall both exhibit very comparable faunal composition. Despite lacking a conclusive dating program incorporating material from S44, it can be assumed based on species representation and sedimentological characteristics compared with layers of K26 that both middens temporally overlap to some degree.

In describing the gathering behaviours of the inhabitants of an ancient Brremangurey, both middens can largely be discussed simultaneously. Live populations of all of the species identified in the archaeological context of the Brremangurey middens can be found in the varying coastal ecologies surrounding Brremangurey, described in Part 1 of this chapter. The overt dominance of *M. hiantina* suggests that it was the soft, sandy shorelines that were most intensively targeted for subsistence gathering, though it is clear that both rocky shorelines and mangrove contexts were also visited, as suggested by the consistent presence of species associated with these environments throughout each assemblage.

The exception to this, however, is *T. granosa*. The occurrence of modern populations of this species could not be confirmed in the area most likely to harbour live populations of *T. granosa* was deemed too dangerous to explore due to the prevalence of saltwater crocodiles in the area. In saying this, however, *T. granosa* is thought to be extinct in the area (Robert Vaughn personal communication). The extinction of *T. granosa* is a phenomenon that has been observed across almost the entire extent of tropical northern Australia (Bourke et al. 2007), though a definitive cause for this extinction has not been proposed.

The principal period of midden formation is confined to the late Holocene, interpreted from the radiocarbon chronology of K26 (Table 3.4), and assumed for S44. And while this largely accords with the typical model of midden construction across tropical northern Australia (e.g. Bailey 1977, Veitch 1999, Bourke 2012, Faulkner 2013), this does not entirely convey the complexity of the formation history of the Brremangurey midden.

One of the radiocarbon ages generated from material towards the bottom of the K26 midden deposit, a valve of *T. granosa* (Wk-37137), returned an age range of 8,152 - 8,334 cal. BP. As this was a direct date using the shell itself, and not based on associated material (an OSL age on adjacent sediments for example), this age reliably represents the earliest dated evidence of midden shell at this site; placing the initiation of midden formation occurring during the early Holocene at Brremangurey, and not the late Holocene as is so typically reported in tropical coastal middens in Australia. A number of other specimens of marine shell and one specimen of charcoal (OZQ-184, OZQ-187 and OZQ-190, seen in Table 3.4) sampled from the same spit as this valve of *T. granosa* generated significantly younger ages, within the late Holocene. The presence of samples presenting such contrasting ages within the same excavation unit raises significant questions regarding the temporality of the cultural material around it, as it is clear that some process of transformation has time-averaged previously distinct layers. The subsistence collection of mangrove and estuarine species during the terminal Pleistocene/early Holocene has been demonstrated at sites in the northern Kimberley prior to Brremangurey (O'Connor 1999), however specific instances of *T. granosa* have not been recorded.

With this in mind, and returning to the results of the faunal analysis, an intriguing connection can be drawn linking the presence of a significantly time-averaged unit and the increase in abundance of the mangrove gastropods *T. palustris* and *T. telescopium* (Figure 3.22f and 3.22g) at the lower portions of the K26 midden. Anthropogenic accumulations of these species have been reported to predate the typical soft sandy shore middens dating to the late Holocene (e.g. Bowdler 1990a and 1990b, Lorblanchet 1992, Clune and Harrison 2009: 71). Is this the case at Brremangurey? Without direct dating of the species themselves, we cannot know, however an envelope of time within these layers has been identified that renders this scenario as potentially plausible.

Furthermore, with an effective initiation age of midden formation of approximately 8,300 years BP, what interpretations can be made regarding the fragments of *M. hiantina* situated within the sandsheet underlying the midden at K26? Radiocarbon, as well as OSL ages dates the deposition of this sandsheet into the terminal Pleistocene at approximately 12,000 years BP. One course of action could be to assume contemporaneity between the shell fragments and the sediments in which they lie, however this age goes against the standard understanding of the antiquity of subsistence gathering of this species in northern Australia. The alternative is to assume post-depositional transformation and that these fragments are vertically displaced from the overlying midden. Unlike the *Amplirhagada* sp. found at this site (Figure 23.2h), aestivation is a far from likely scenario for *M. hiantina*. If we therefore assume that these fragments of *M. hiantina* are displaced, from what levels within the overlying midden did these specimens originate?

Finally, and most importantly, how do these patterns effect describing the behavioural patterning of deposition that resulted in the Brremangurey midden? As mentioned before, the spit weights of shell, combined with the faunal analysis point towards two phases of intensive midden deposition; three if the dense layer of *P.* c.f. *albina* is interpreted as a discrete event. However, the complexities of midden formation highlighted by the dating program utilising midden shell complicates this scenario, as the presence of a time-averaged deposit at the lowest extent of the midden deposit in K26 has likely obfuscated distinct phases of midden deposition. What we know is that the Brremangurey midden formed at a much earlier date than what is expected for soft-shore dominated middens in northern Australia. What we do not know, is the relative intensity of gathering practices of this time. This is not even considering the fragments of *M. hiantina* situated in older sediments underneath the midden deposit.

With the dating program enacted during the analysis of the Brremangurey midden material, questions regarding the stratigraphic integrity, as well as the behavioural patterning that resulted in the formation of the midden have been raised. For a more complete and reliable story to be told about the formation of this site, the behaviours of the people that created it, and a potentially changing environment, these questions need to be dealt with. Using the results of the excavation, the dating program and the faunal analysis only, these questions cannot be addressed without further analysis.

The following two chapters of this thesis focus on addressing these questions using the novel application of amino acid racemisation and midden shell to inform interpretations on site formation and transformation. Specifically, the following analyses will:

1) Isolate the temporality of the *M. hiantina* fragments found within the Pleistocene sandsheet layer underneath the midden deposit relative to the faunal assemblage above.
2) Disentangle the influence of time-averaging in the lower portions of the Brremangurey midden and potentially re-establish temporally distinct populations of midden shell.

Refine the patterns of deposition of midden shell at Brremangurey to tell a more detailed story regarding the behaviours of the people who inhabited the rockshelter.

Chapter 4 – Isolating downward displacement: The solutions and challenges of amino acid racemisation in shell midden archaeology

Statement of Author's Contribution

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We, the PhD candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution.

	Author	*% of contribution to the manuscript*
Candidate	Brent Koppel	90
Author	Katherine Szabó	8
Author	Mark Moore	2

MM oversaw the excavations (undertaken by MM and BK) that generated the material to be analysed
BK and KS conceptualised the manuscript
BK and KS planned the analysis, which was conducted by BK
BK and KS interpreted the data
BK drafted the manuscript which was reviewed by KS
MM offered comments on final draft of manuscript

Name of Candidate: Brent Koppel

Name/title of Principal Supervisor: A/Prof. Katherine Szabó

Candidate Date: 31/03/17

Principal Supervisor Date: 31/03/17

Introduction

Archaeological deposits are constantly being influenced by environmental and cultural processes that can add, remove or redistribute material (Schiffer 1996). These processes can result in the distortion or complete disassociation of the original spatio-temporal connections that artefacts and sediments (Bailey 2007). This is a major complication, especially considering that researchers constantly rely on assumptions of spatial and temporal relationships between materials in archaeological deposits to build interpretations regarding the ancient behaviours and palaeoenvironments represented within the deposit (e.g. Burleigh 1974: 79, Taylor and Bar-Yosef 2014). Recognising that the potential exists for material within an archaeological deposit to be displaced is therefore critical for any interpretations or subsequent analyses to carry any form of accuracy or relevance. Resolving these ambiguities, however, can present methodological problems.

Radiocarbon dating is by far the most widely used absolute chronological tool in archaeological in archaeological investigation, however issues regarding site integrity and patterns of disturbance still have the potential to greatly skew results and interpretations (Burleigh 1974). The development of AMS techniques facilitated the direct dating of archaeological material (e.g. Rick *et al.* 2005, Wild *et al.* 2005, O'Connor *et al.* 2010). The key advantage of this practice is that the assumption that spatial association represents temporal association is circumvented by attributing an age to the artefact or ecofact itself rather than relying on the chronology of the surrounding material. Despite its prolific use in archaeological research, the radiocarbon method as we know it today is most effective on a small scale of chronological inquiry; dating one specific event or artefact (see Lucas 2005: 45, 49, Sullivan 2008). In answering larger site-scale questions, such as assessing the spatial and temporal relationships between populations of artefacts and material, one single age determination is insufficient. While two radiocarbon ages can at times be enough to identify a disturbed deposit (see O'Connor *et al.* 2010: 37-38), such minimal data can rarely pinpoint the degree or nature of disturbance. Many individual samples are required to reliably identify disturbed deposits and go beyond the mere label of 'disturbed'. Only then can researchers actually assess the relative contributions of units of temporally distinct sediments, ecofacts and artefacts in a time-averaged deposit and build reliable interpretations of site transformation.

Shell middens are ubiquitous archaeological features across the globe, and are particularly susceptible to post-depositional transformation (Stein 1992). This is largely due to their generally coarse and porous composition that allows material held within to be freely displaced, removed or altered by environmental and cultural processes (e.g. Specht 1985, Dwyer *et al* 1985, Wandsnider 1988, Rick 2002, Robins and Robins 2011, Szabó 2012). Considering the significant potential that shell middens have in contributing to important issues in archaeological research (e.g. Bailey 1977, Cannon 2000, Lombardo *et al.* 2013), it is critical that the identification of displaced material within a shell midden is identified. Unfortunately, few methodologies are currently utilised that can unambiguously identify and isolate displaced shell in middens, especially on a larger scale (but see Villagran *et al*. 2009, Villagran *et al*. 2011a and 2011b for a microscale perspective). While an intensive dating program using the radiocarbon method and multiple samples would identify temporally disconnected, but spatially associated shells, the financial costs associated with so many radiocarbon age determinations generally make this approach unrealistic.

Amino acid racemisation (AAR) is a relative dating method that has had a long history of use in archaeological investigation (e.g. Wehmiller 1977, Masters and Bada 1977, Parfitt *et al*. 2005, Bateman *et al.* 2008, Ortiz *et al*. 2009, Demarchi *et al.* 2011). Rather than providing numerical values, AAR results tell us which samples are more or less racemised and thus, broadly, older or younger. While AAR experienced some negative perception in the discipline of archaeology in the late 20th century as a result of anomalous ages being generated (Bada *et al.* 1974, see also Johnson and Miller 1997: 276), refinements in the method have yielded consistently reliable results (e.g. Kaufman and Manley 1998, Penkman *et al.* 2008, Demarchi *et al.* 2013a, Demarchi *et al.* 2013b). The technique carries with it major advantages compared with more conventional dating methodologies such as radiocarbon and OSL. Firstly, AAR allows for a substantial number of samples to be analysed for the same cost as a single radiocarbon age determination. This cost effectiveness creates the opportunity for a much more intensive dating program incorporating many more samples than relying on radiocarbon dating alone. A second key advantage is that the archaeological material is being directly targeted and not sediments argued to be in association, as with OSL dating. This removes a layer of inference which would otherwise have the potential to skew results due to post-depositional movement of sediments and archaeological material. The relatively low cost coupled with the ubiquity of dateable material in shell midden archaeology, results in AAR being perfectly suited for intensive dating programs to ascertain a much broader understanding of the ages of materials present within a deposit.

Chronology

The chronology of ancient *M. hiantina* collection and deposition at Brremangurey largely parallels late Holocene high intensity shell collection across tropical northern Australia as observed in other sites such as Blue Mud Bay (Faulkner 2013), the western Admiralty Gulf (Veitch 1999), Darwin (Bourke 2012) and Weipa (Bailey 1977, but see Morrison 2014). Initial AMS radiocarbon ages derived from whole valves at the lowest excavation unit from which shell was recovered suggests that the large-scale gathering of *M. hiantina* commenced at 2,375 – 2,682 cal. years BP (OZQ190) (Table 1). A fragment of charcoal (Wk-32405) sampled from the wall of square K26 post-excavation from a depth of 8.6 cm below surface returned an age of 498 – 552 (99.4%) cal. years BP which provides an indication of the time of cessation of midden building at Brremangurey. An AMS radiocarbon date from a pit feature identified at approximately 91 cm below surface (Wk-32409) was also obtained, and returned an age of 3,579 – 3,694 cal. years BP.

Sample code	Sampling location	Material	Depth (cm. below surface)	Layer/ Horizon	Radiocarbon age (uncalibrated)	Calibrated age
Wk-32405	Trench wall	Charcoal	8.6	1	493 ± 33	498 - 552 (99.4%) 614 - 617 (0.6%)
OZQ-188	Excavated material	*Marcia hiantina*	24.1-28.1 (Spit 6)	1	1,305 ± 25	695 - 892
OZQ-185	Excavated material	Charcoal	24.1-28.1 (Spit 6)	1	930 ± 25	791 - 918
Wk-32407	Trench wall	Charcoal	57.6	1	1,896 ± 33	1,733 – 1,899 (98.9%) 1,913 – 1,920 (1.1%)
OZQ-189	Excavated material	*Marcia hiantina*	75.9 - 80.3 (Spit 15)	1	2,495 ± 30	1,942 – 2,215
OZQ-186	Excavated material	Charcoal	75.9 - 80.3 (Spit 15)	1	2,210 ± 30	2,148 – 2,319
OZQ-190	Excavated material	*Marcia hiantina*	91.0-95.9 (Spit 18A)	1	2,850 ± 30	2,375 – 2,682
OZQ-187	Excavated material	Charcoal	91.0-95.9 (Spit 18A)	1	1,875 ± 25	1,733 - 1876
Wk-32409	Trench wall	Charcoal	91.0	1	3,394 ± 25	3,579 – 3,694
Wk-32410	Trench wall	Charcoal	108.3	2	10,867 ± 39	12,694 – 12,801
Wk-32411	Trench wall	Charcoal	125.5	2	12,303 ± 44	14,059 – 14,564

Table 4.1 Ages of the initial AMS radiocarbon dates of charcoal sourced from the wall of the excavation and shell from excavated material during preliminary midden analysis. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

In summary, the chronological patterning of Brremangurey can largely be separated into two distinct depositional phases; firstly a sand dominated deposit dating to the terminal Pleistocene, and secondly, intensive episodes of shellfish gathering and deposition through the late Holocene that resulted in the formation of the shell midden series seen in the upper extent of the deposit.

Midden analysis

Molluscan shell dominated the deposit at Brremangurey to a far greater extent than the initial observations of the midden's surface suggested. Of the total 1.79 m^3 that was excavated from square K26, 1.53 m^3 contained culturally deposited shell. The 50% sample of this total volume retained for analysis yielded 207 kg of culturally deposited shell material, with 205 kg coming from the upper most 0.455 m^3 of the square.

A brief summary of the results of the molluscan faunal analysis from Chapter 3 is presented here. The soft-shore venerid *Marcia* (=*Tapes* =*Katelysia*) *hiantina* was the most abundant species present in the assemblage, comprising 70% of MNI (n = 27,906) and 81% of NISP (n = 259,556) counts in square K26. Much smaller quantities of the pearl oysters *Pinctada* cf. *albina* and *Isognomon ephippium* were identified, representing 2.2% (n = 878) and 1.4% (n = 570) of total MNI counts respectively. Belying surface observations, *T. granosa* comprised only a small proportion of the overall assemblage, at less than 1% (n = 316) of total MNI and NISP counts across all analysed material (see Chapter 3). This small proportion of the mudflat inhabiting *T. granosa* is in contrast to the typical archaeological shell mound deposits reported across Australia's tropical north (e.g. Bailey 1977, Veitch 1999, Faulkner 2013, Bourke 2012; but see Cochrane 2014) where it is by far the most dominant species. MNI and NISP counts of all species drop dramatically at approximately 96 cm below surface which marks the lower limits of the midden unit. Below this level relatively small quantities of shell, particularly fragmented *M. hiantina* (n = 1,010), were found between a depth of 96 and 156 cm below surface.

These fragments were in remarkably good condition considering the difference in age between the late-Holocene midden above and the terminal Pleistocene sandsheet below, raising questions about the stratigraphic integrity of the lowermost shell fragments. Do these 1,010 fragments of *M. hiantina* found within terminal Pleistocene sands represent of late Pleistocene shell gathering, or are they Holocene fragments that are *ex situ*? Early Holocene shellfish gathering has been demonstrated in this site (see Table 4.3.1) but at present this is confined to the species *T. granosa*. Do these stratigraphically-deeper fragments of *M. hiantina* represent an even older shell-gathering tradition at the site? The alternative explanation is that these shell fragments infiltrated into the older sandsheet from the younger midden deposit in Unit 1. Visually, texturally and taphonomically, there was nothing distinguishing *M. hiantina* fragments found within the Holocene midden deposit from the fragments found in the terminal Pleistocene sandsheet underneath. A zone of subsidence is noted towards the centre of the rockshelter and is potentially the result of water flowing into the rear of the shelter during periods of abundant rainfall, such as during the annual summer monsoons (Robert Vaughan personal communication 2011). Therefore the scenario of water flowing into the site, interacting with the midden shell and redistributing fragments into the lower and older portions of the site is a possibility. Nevertheless, if this occurred it must have been low energy to not leave visually distinctive taphonomic traces on shell surfaces.

Radiocarbon dating of fragments found within the terminal Pleistocene sands would conclusively define their temporality, especially when these dates are then compared with those already determined from material sourced from the Holocene midden deposit above. Due to the costs of individual age determinations, dating these potentially displaced fragments using the radiocarbon method is unfeasible. Constraining the dating program to only a few age determinations in order to reduce the costs narrows the scope and scale of questions that can be asked of the deposit (see Sullivan 2008: 33), and may not adequately determine the whole range of dates. A greater number of age determinations will allow a greater understanding of the range of ages represented within the sandsheet-sourced shell fragments which will subsequently increase the chance of identifying temporally separate groups of shell.

To determine whether the shell fragments of *M. hiantina* found in the Pleistocene sands have been displaced downwards from the Holocene midden deposit above, an intensive dating program centred on the AAR technique was undertaken that assessed the D/L values of shell sourced from the two stratigraphic locations to establish relative ages. If the fragments from the sandsheet were *in situ*, their D/L values would be distinctively separated from the D/L values of shell from the midden deposit above. Conversely, should a displaced population of shell be identified, their D/L values would be equivalent to shells sourced from the midden deposit. Below, the results of the AAR analysis on *M. hiantina* are discussed, with the implications of these, as well as a comparison with a complementary radiocarbon dating program. The approach presented in this study is then critiqued, with the current challenges facing this method and its potential contributions to the discipline of archaeology considered.

Approach to investigation

As a dating method, AAR measures the proportional abundances of amino acids in their two forms. During life, amino acids are maintained in the laevorotary (L) form. Post mortem, the L-form amino acid molecules are rearranged into their dextrorotary (D) form with increasing proportional abundance through time: a process termed racemisation (Johnson and Miller 1997, Wehmiller and Miller 2000). Racemisation occurs until the ratio of D and L form amino acids reaches equilibrium and both forms occur in equal abundance, after which equilibrium is maintained through time. In short, the higher the D/L value the greater time since the organism's death. In an ideal, closed system, racemisation is primarily influenced by temperature. A number of other factors, however, can influence the rate of racemisation of amino acids such as pH, the presence of metal ions and microbial alteration to name a few (e.g. Bada 1972, Bada and Schroeder 1975, Child 1995, summarised in Penkman 2005: 33-38). Recent research has identified a small proportion of proteins that are encapsulated within individual calcium carbonate crystals that form molluscan shell (Sykes *et al.* 1995, Penkman *et al.* 2008). Once isolated, these intracrystalline proteins have proven to act as a closed system, and unlike the intercrystalline protein component of the shell matrix, are not influenced by contamination and exchange of non-indigenous proteins as well as the other aforementioned environmental factors. Targeting the products of intracrystalline protein diagenesis (IcPD) for use in AAR has subsequently provided more precise and reliable results (Penkman *et al.* 2008), and these techniques are applied in this study.

AAR has had a long history of application in shell midden archaeology (e.g. Masters and Bada 1977, Bateman *et al.* 2008, Ortiz *et al*. 2009), however the method has largely been applied in a supplementary fashion to other techniques such as radiocarbon dating (but see Wehmiller 1977, Demarchi *et al*. 2011). In contrast, geological and geomorphological research routinely uses AAR, and specifically aminostratigraphy, as a method for understanding patterns of deposition and post-depositional transformation (e.g. Miller *et al.* 1979, Kennedy *et al.* 1982, Hearty *et al.* 1986). Aminostratigraphy centres on the comparison of 'aminozones', which are groupings of similarly aged specimens. It is important to note that aminozones are established by temporality alone irrespective of spatial positioning of each sample. Following the identification of aminozones, a comparison between temporal patterning and spatial positioning allows interpretations regarding site formation and transformation processes to be made (Miller and Hare 1980). A high resolution and broad AAR aminostratigraphic analysis will result in similarly aged fragments of shell clustering together in a scatterplot, whereas temporally distinctive populations of samples will separate from each other. Comparing these clusters with the relative spatial positioning of each sample stratigraphically will provide insights into how populations of similarly aged materials have moved through a site subsequent to initial deposition.

By comparing the aminozones identified using samples of *M. hiantina* sourced from the younger shell midden deposits and the older terminal Pleistocene sands of Brremangurey, the relative temporality of shells from both sampling locations should become clear. The IcPD method of AAR also accounts for the various taphonomic factors so prevalent in archaeological deposits. Based on the results, additional radiocarbon samples from shell fragments already dated using AAR provide a numerical age through which to anchor and further interpret results.

Methods

Sampling methodologies

To properly establish the aminostratigraphy of the midden deposit, shell specimens for AAR analysis were evenly sampled from all spits. In total, 72 specimens of *M. hiantina* were assayed. Fifty-seven specimens were sampled from the surface down to a depth of approximately 104 cm. This represents the first 19 spits of the excavation, as well as the entire extent of the dense Holocene midden in the Brremangurey rockshelter. Three shell specimens from each spit were selected for analysis. Only specimens that had no visible signs of burning or other taphonomic alterations were selected. A further 3 shell fragments were sampled from spit 21 (112-118 cm below surface), spit 23 (121 to 124 cm below surface), spit 25 (125 to 128 cm below surface) and spit 30 (150 to 154 cm below surface). Where possible, a complete right valve was selected to avoid the potential for sampling opposing valves of the same animal. While whole vales of *M. hiantina* were abundant within midden layer, the shell within the sandsheet was fragmented and sampling both left and right valves as well as fragments was unavoidable. Furthermore, the specimens of *M. hiantina* that were selected for the initial radiocarbon determinations were also incorporated into this study. This provided a paired radiocarbon age to the D/L value generated.

Sample preparation

Sample preparation was conducted as per Lachlan (2011). In summary, shell fragments were thoroughly cleaned of adhering dirt and sediments through a series of rinses and sonication episodes in ultrapure Millipore water and mild abrasion using a rotary drill. Following this, whole shells were subsampled and the exterior and interior face abraded. A soak in 2M hydrochloric acid (HCl) was undertaken to remove the outermost surface of the shell which is the area of shell most likely to contain contaminants. Following Sykes *et al.* (1995), the shell fragments were then powdered and exposed to a 12.5% sodium hypochlorite bleach solution (NaOCl) to oxidise and destroy the intercrystalline protein component of the mollusc shell structure. The intracrystalline proteins are then isolated by dissolving the mineral calcium carbonate in 8M HCl. The vials are then filled with nitrogen gas and sealed, and then placed into an oven at 110˚ Celsius for 22 hours to induce hydrolysis of the peptide bonds. The solution was then completely desiccated and rehydrated using a solution of 0.01mM L-Homoarginine + 0.01M HCl + 0.77mM sodium azide – with L-Homoarginine acting as an internal laboratory standard. Sample analysis was conducted using a reverse phase high pressure liquid chromatograph (RP-HPLC). Instrument procedures follow the method of Kaufman and Manley (1998) and refined by Kaufman (2000), summarised in Lachlan (2011: 345-347). Samples were run in duplicate and averages given.

Results

Out of the 72 samples analysed during this study, all but one provided useable results. Sample number UWGA10340 underwent an incomplete injection in the RP-HPLC and did not provide assessable results. Only the results of aspartic and glutamic acids are presented here. While 8 amino acids are isolated and quantified in the RP-HPLC, only the results of aspartic (Asx) and glutamic acid

(Glx) are presented here[1] (Table 4.1). Aspartic acid was selected because of its abundance in molluscan shell, but also because of the balance it offers between temporal resolution and time-depth. Glutamic acid was also selected due to the high degree of covariance with Asx, which allows taphonomically affected samples to be identified through the deviation from this covariance (Kaufman 2006).

The initial bivariate scatter plot showing the D/L values of Asx and Glx (Figure 4.1) of all specimens analysed in this study reveal three main groupings of specimens, further defined by k-means cluster analysis. The two densest clusters, labelled clusters A and B in Figure 4.1, contain the majority of the shell specimens used in this study. Cluster C contains the remaining 5 samples, and these exhibit the greatest extent of racemisation. Cluster C is also considerably more scattered when compared to clusters A and B with results covering a much greater range of D/L values.

Highlighting the shell fragments sampled from the Pleistocene sands underneath the Holocene shell midden, seen in Figure 4.2, the temporality of these specimens become clear. All but one of these shell fragments exhibit D/L values consistent with specimens contained within Cluster B which dates to the early Holocene. The implication of this grouping as a result of the AAR analysis utilising spatially separated specimens becomes clear – the shell fragments are of identical age to those found in Cluster B and have therefore been spatially displaced through some process over time. The identification of the driving process or processes behind the displacement of these specimens is ongoing.

[1] Throughout this thesis, the use of the abbreviation Asx refers to the combination of native aspartic acid within a sample, as well as the aspartic acid that is generated as a result of the deamidation of asparagine in the preparation process. This is also the case for Glx, glutamic acid and glutamine (Hill 1965).

Lab code (UWGA)	Spit	Layer/ Horizon	D/L Asx	Sample variance	D/L Glx	Sample variance	Radiocarbon lab code	Radiocarbon age (cal. BP)
10325	1	1	0.2405	± 0.001	0.12	± 0.002		
10326	1	1	0.307	±0.002	0.132	0	Wk-40860	295 - 462
10327	1	1	0.208	-	0.101	-		
10328	2	1	0.301	0	0.137	0		
10329	2	1	0.2775	± 0.001	0.1405	± 0.001		
10330	2	1	0.261	± 0.004	0.1155	± 0.001		
10331	3	1	0.2415	± 0.003	0.108	0		
10332	3	1	0.2035	± 0.001	0.1265	± 0.001		
10333	3	1	0.3305	± 0.003	0.259	0		
10334	4	1	0.2305	0	0.1155	± 0.001		
10335	4	1	0.196	± 0.004	0.1125	± 0.001	Wk-40861	639 - 774
10336	4	1	0.234	0	0.106	0		
10337	5	1	0.257	-	0.084	-		
10338	5	1	0.2325	± 0.007	0.0185	± 0.003		
10339	5	1	0.221	-	0.026	-		
10340	6	1	-	-	-	-		
10341	6	1	0.270	0	0.0595	± 0.115		
10342	6	1	0.240	0	0.103	0		
10496	6	1	0.362	± 0.002	0.1485	± 0.001	OZQ-188	695 - 892
10343	7	1	0.2235	± 0.003	0.1065	± 0.001		
10344	7	1	0.2385	± 0.001	0.1185	± 0.001		
10345	7	1	0.212	0	0.1105	± 0.001		
10346	8	1	0.3265	± 0.001	0.1735	± 0.005		
10347	8	1	0.3265	± 0.001	0.176	0		
10348	8	1	0.3545	± 0.001	0.164	0		
10349	9	1	0.4435	± 0.003	0.2195	± 0.001		
10350	9	1	0.342	0	0.1375	± 0.001		
10351	9	1	0.419	0	0.2055	0		
10352	10	1	0.425	± 0.002	0.2155	± 0.001		
10353	10	1	0.480	0	0.2375	± 0.003		
10354	10	1	0.387	0	0.1785	± 0.003		
10355	11	1	0.4235	± 0.001	0.1795	± 0.001		
10356	11	1	0.389	-	0.179	-		
10357	11	1	0.4075	± 0.001	0.206	± 0.002		
10358	12	1	0.6195	± 0.003	0.2935	± 0.001		
10359	12	1	0.4325	± 0.002	0.232	0		
10360	12	1	0.573	0	0.269	± 0.008		
10361	13	1	0.466	± 0.002	0.2035	± 0.001		
10362	13	1	0.4285	± 0.003	0.195	0		
10363	13	1	0.399	-	0.191	-		
10364	14	1	0.3735	± 0.005	0.198	0		
10365	14	1	0.4445	± 0.001	0.1965	± 0.001		
10366	14	1	0.4215	± 0.007	0.1945	± 0.003		
10367	15	1	0.4265	± 0.001	0.2235	± 0.001		
10368	15	1	0.364	± 0.002	0.202	± 0.004		
10369	15	1	0.4025	± 0.001	0.1985	± 0.003		
10497	15	1	0.4335	± 0.021	0.214	± 0.004	OZQ-189	1,942 – 2,215
10370	16	1	0.4225	± 0.001	0.2235	± 0.001		
10371	16	1	0.4095	± 0.001	0.1925	± 0.003		
10372	16	1	0.3965	± 0.003	0.190	0		
10373	17	1	0.3875	± 0.001	0.191	0		
10374	17	1	0.3825	± 0.001	0.211	0		
10375	17	1	0.3625	± 0.003	0.145	± 0.002		
10376	18A	1	0.774	± 0.006	0.6845	± 0.003	Wk-40863	1,983 – 2,247
10377	18A	1	0.407	± 0.002	0.153	± 0.002		
10378	18A	1	0.423	0	0.2135	± 0.001		
10498	18A	1	0.4265	± 0.019	0.1905	± 0.003	OZQ-190	2,375 – 2,682
10379	18B	2	0.543	0	0.3655	± 0.001	Wk-40862	2,756 – 2,962
10380	18B	2	0.411	± 0.002	0.189	± 0.002		
10381	18B	2	0.412	0	0.2315	0		

10410	21	2	0.4195	± 0.001	0.2445	± 0.001	
10411	21	2	0.485	0	0.2385	± 0.005	
10412	21	2	0.422	± 0.002	0.2185	± 0.003	
10413	23	2	0.3405	± 0.001	0.1595	± 0.011	
10414	23	2	0.415	± 0.010	0.2305	± 0.003	
10415	23	2	0.3855	± 0.003	0.2085	± 0.013	
10416	25	2	0.386	0	0.189	0	
10417	25	2	0.4485	± 0.001	0.214	± 0.002	
10418	25	2	0.4375	± 0.001	0.236	± 0.006	
10419	30	2	0.3635	± 0.001	0.1545	± 0.003	
10420	30	2	0.6845	± 0.001	0.5375	± 0.009	
10421	30	2	0.4065	± 0.003	0.203	± 0.002	

Table 4.2 - Results of the AAR analysis. Each sample was run in duplicate and averaged. UWGA lab code issued by the Amino Acid Racemisation Laboratory at the University of Wollongong. AMS radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

	Amino acid	Centroid mean	Cluster range	Standard deviation
Cluster A	Asx	0.2421	0.196 – 0.307	0.03
	Glx	0.1022	0.0185 – 0.1405	0.033
Cluster B	Asx	0.4031	0.326 – 0.485	0.038
	Glx	0.2	0.1375 – 0.259	0.028
Cluster C	Asx	0.6388	0.543 – 0.774	0.093
	Glx	0.43	0.269 – 0.6845	0.177

Table 4.3 - Results gathered from k-means cluster analysis utilising the Brremangurey AAR samples. Centroids refer to the average D/L values of Asx and Glx for each cluster.

Figure 4.1 - Bivariate plot combining D/L ratios of both Asx (x-axis) and Glx (y-axis) for each sample analysed in this study. The results of the k-means cluster analysis are also incorporated. Specimens that have been circled have been interpreted to have been affected by burning or exposure to high heat. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

The similarity in D/L values exhibited between specimens from the lower extent of the midden layer and the displaced specimens sampled from the Pleistocene sand layer is further demonstrated in Figure 4.3 which compares D/L of Asx with location of sampling. Specimens from spits 8 to the lowest level of sampling at spit 30 exhibit a restricted and consistent range of D/L values through the sequence. Contrasting to this are the specimens sampled from the upper portion of the midden unit between spits 1 and 7, which show an equally lesser extent of racemisation, yet a similar restricted and consistent range of values. Applying the results of the k-means cluster analysis, presented in Figure 4.1, the specimens in Cluster A were all sourced from the upper most extent of the midden layer between spits 1 and 7. Similarly, clusters B and C are spread through the lower excavation units, from spits 8 to 30.

In drawing together the results of the relative dating program using AAR, along with the spatial positioning of each of the specimens utilised in this study, interpretations regarding episodes of deposition of shell at Brremangurey can be formed. The close concordance of relative age exhibited within Cluster A of Figure 4.1 with the samples' restriction to the 7 uppermost spits of the midden, seen in Figure 4.3, suggests a distinct episode of shellfish deposition at the site. The same interpretation can be made of the samples of Cluster B. This is in stark contrast to Cluster C, which contains only 5 specimens, yet covers a much greater range of D/L values than clusters A and B. Relying solely on the results of the AAR analysis in interpreting the very different pattern observed in Cluster C compared to the other clusters, an argument of a far less intensive period of shellfish deposition over a much longer period of time can be made. Whereas clusters A and B imply rapid deposition of a large amount of shell at the site, Cluster C suggests a more ephemeral and punctuated depositional behaviour of the occupants of Brremangurey.

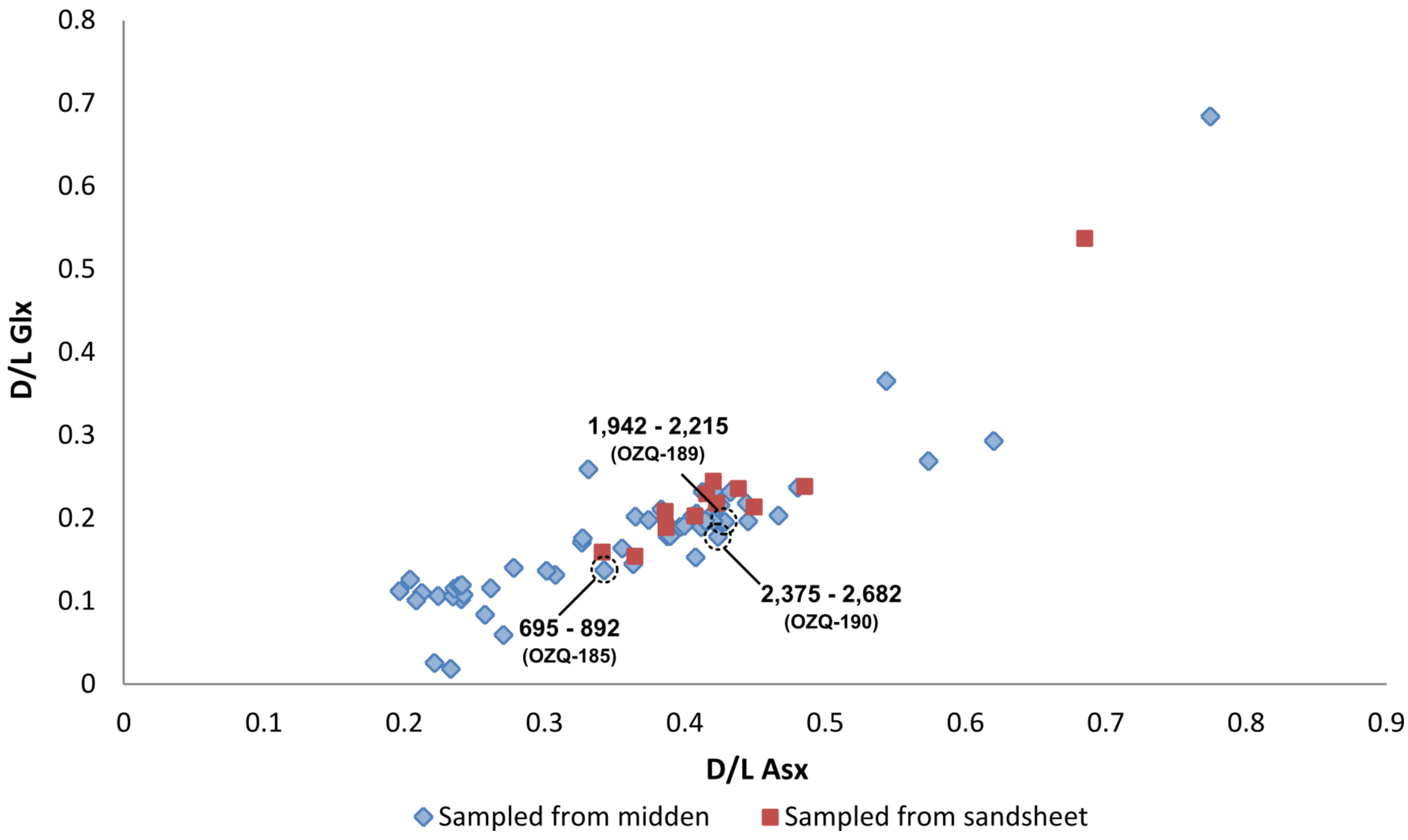

Figure 4.2 - Bivariate plot combining D/L ratios of both Asx (x-axis) and Glx (y-axis) for each sample analysed in this study. Sampling locations, either from the late Holocene midden deposit or Pleistocene sandsheet, have been demarcated.

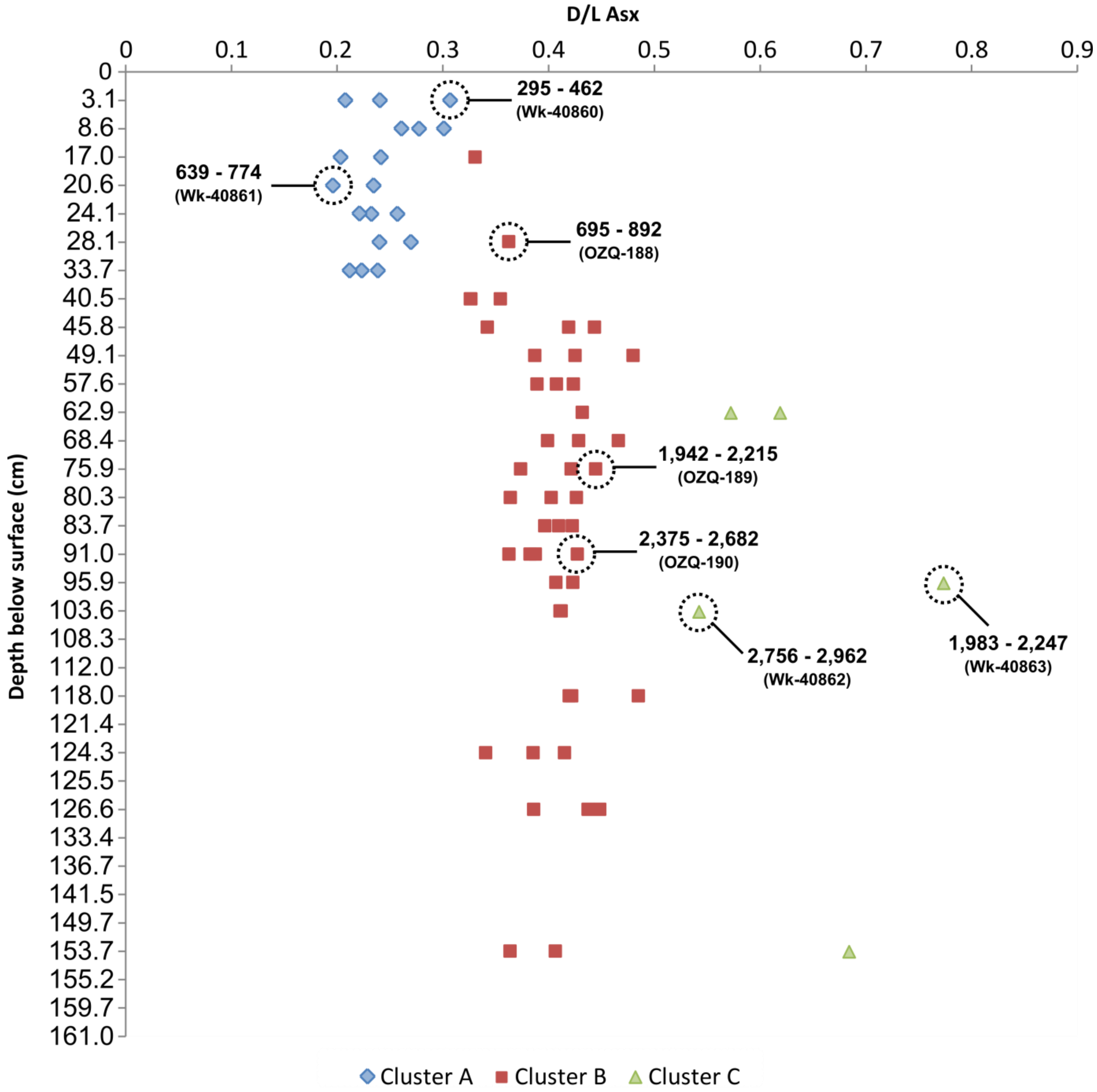

Figure 4.3 - D/L values (x-axis) of Asx compared with excavation units that shells were sampled from. Note increasing D/L value to the right of the figure implies older age.

Sample code	UWGA Sample code	Material	Depth (cm. below surface)	Layer/ Horizon	Radiocarbon age (uncalibrated)	Calibrated Age
Wk-40860	10326	*Marcia hiantina*	0 – 3.1 (Spit 1)	1	800 ± 20	295 - 462
Wk-40861	10335	*Marcia hiantina*	17.0 – 20.6 (Spit 4)	1	1,211 ± 20	639 - 774
Wk-40862	10379	*Marcia hiantina*	95.9 – 103.6 (Spit 18B)	2	3,151 ± 20	2,756 – 2,962
Wk-40863	10376	*Marcia hiantina*	91.0-95.9 (Spit 18A)	1	2,512 ± 20	1,983 – 2,247

Table 4.4 - Results of additional AMS radiocarbon analyses on shell specimens selected as a result of the AAR analysis (see Figure 4.1). Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

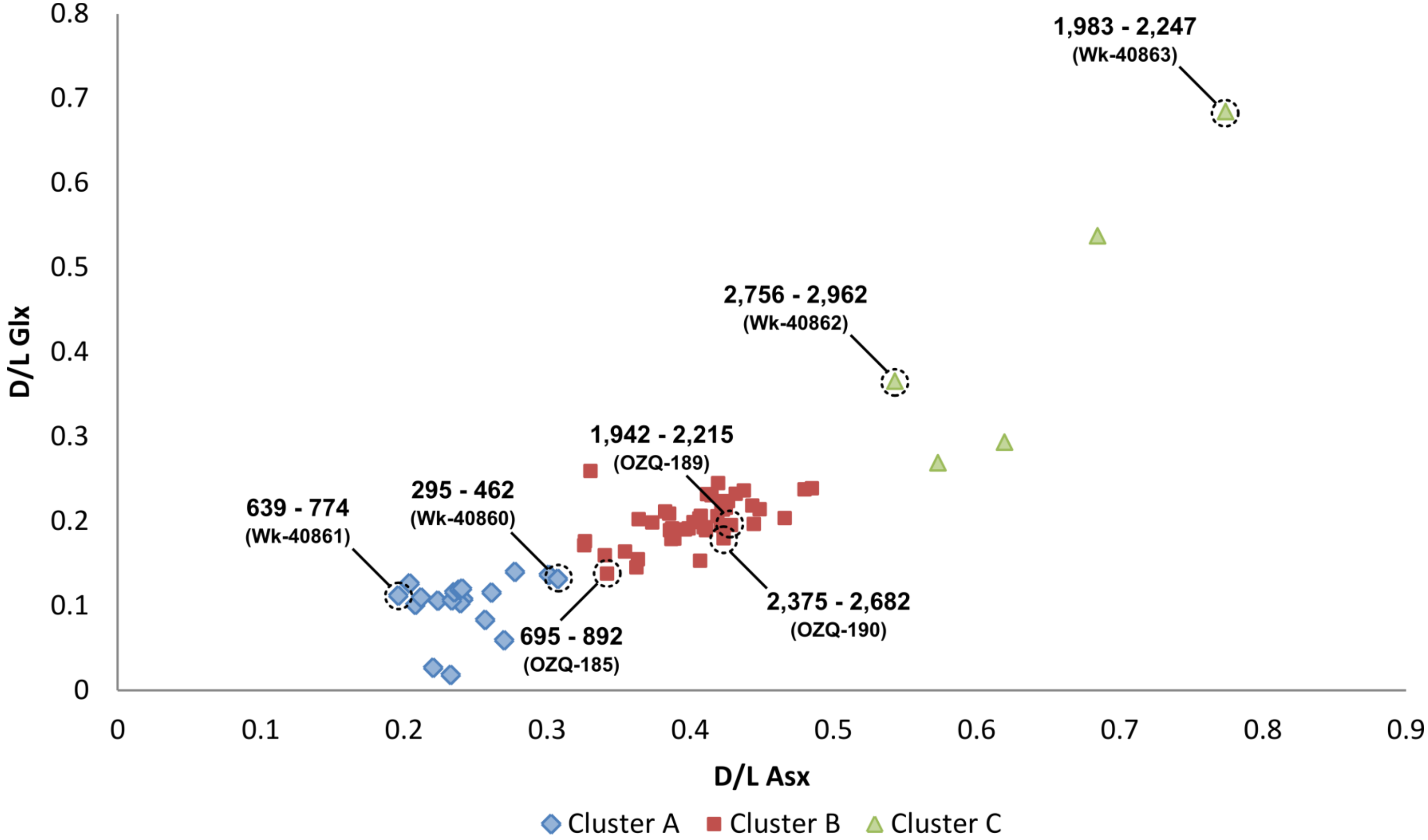

Figure 4.4 - Bivariate plot combining D/L ratios of both Asx (x-axis) and Glx (y-axis) for each sample analysed in this study compiled with all radiocarbon age determinations generated for this study.

To test whether the specimens observed in Cluster C of Figure 4.1 are representative of an older tradition of shell gathering, as well as establishing a more complete chronological framework to anchor the results of the AAR analysis, a further program of AMS radiocarbon dating was undertaken. Using the range of relative ages established using AAR, 4 additional specimens of *M. hiantina* were selected for dating, and the results are presented in Table 4.4. Plotting all of the radiocarbon ages used in this study with the paired D/L values generated in this study, seen in Figure 4.4, major, fine-grained complications arise. In some instances, multiple age reversals are identified where AMS radiocarbon ages do not conform to the samples' relative D/L values – meaning "younger" specimens according to the AAR analysis were determined to be older according to the radiocarbon dating program, and vice versa. For example, specimen Wk-40862 presented an extent of racemisation roughly half of Wk-40863, and yet recorded a radiocarbon age approximately 800 calibrated years older. A similar reversal is observed for samples Wk-40861 and Wk-40860, while samples OZQ-190 and OZQ-189 present nearly identical D/L values yet are separated by approximately 500 calibrated radiocarbon years.

The results of the additional radiocarbon dating program undertaken after the AAR analysis have effectively nullified the hypothesis that Cluster C is a depositional episode temporally distinct from clusters A and B. Despite exhibiting a substantially greater extent of racemisation, the radiocarbon ages do not reveal a similar distinction in numerical age. While AAR was able to reintegrate the shell midden temporally in terms of broad depositional episodes, the finer grained details are problematic. Exactly why this may be the case is considered below.

Discussion

Taken on its own, the program of intensive relative dating of midden shell using AAR reported in this study conclusively identified shell material that was spatially separated as being chronologically contemporaneous, and therefore identified vertical displacement in a shell midden. However, on a more fine-grained level, a lack of correlation between paired AAR and radiocarbon dating methodologies was noted. Chapter 5 presents a similar study, albeit focussing on *T. granosa* rather than *M. hiantina*, and yielded successful results including a positive correlation between AAR and paired radiocarbon ages. Why one study found no issues in the correlation of AAR and radiocarbon ages while the other encountered problems raises immediate questions regarding this new application of the long-standing AAR method.

AAR has traditionally been utilised alongside or as a substitute for radiometric methods such as radiocarbon and OSL dating. While sometimes this is out of necessity due to a lack of dateable material or samples being beyond the limit of radiocarbon dating (e.g. Parfitt *et al*. 2005), in other examples it is not (e.g. Bada 1985, Cann *et al*. 1991). Despite AAR being a relative dating technique, its use as an alternative for numerical dating methods has driven developments to 'calibrate' the racemisation reaction to allocate projected numerical ages (Johnson and Miller 1997: 269). Through a combination of independent radiometric ages, coupled with modelling the species-specific rate of racemisation, an absolute age can be determined from the D/L value of a sample (e.g. Wehmiller *et al.* 1995, Clarke and Murray-Wallace 2006, Kosnik *et al.* 2008). This contrasts with the calibration of radiocarbon ages, where independent proxies such as tree rings and speleothems, match radiocarbon to calendrical years (Stuiver 1982). This is an important distinction between the calibration of radiocarbon age determinations and the "calibration" of D/L values as the former is absolute, and the latter is much less strongly anchored and remains susceptible to many other external influences.

It is precisely these external influences which may result in a lack of congruence between radiocarbon and AAR results. The temporal and spatial scale of geological contexts, where AAR is most commonly used, is generally much larger and coarser in resolution than those of archaeological contexts. Because of this, distortions in the results of AAR analyses are muted purely due to the relatively larger scale of the investigations being undertaken and questions asked. Archaeological contexts are of much smaller and fine-grained spatial and temporal scale (Lock and Molyneaux 2006), and as such the influence of analytical error has a much greater impact on overall interpretations. As well as this, the additional influence of anthropic factors, such as the potential thermal influence of small scale camp-fires, adds an additional layer of complexity to AAR in archaeological contexts. With this in mind, can the traditional assumptions which underpin the "calibration" and use of AAR be directly applied to archaeological contexts without reformulation? The complications identified in this study suggest that a rethink is required.

The racemisation reaction, and more specifically the rate of racemisation, which underpins this particular dating methodology is influenced by many factors (Schroeder and Bada 1976, Johnson and Miller 1997). In attempting to identify the reason behind the lack of correlation between what should be complementary dating methods, four different possibilities are hypothesised here: human and machine error, intraspecies variations in racemisation rates due to biological and metabolic processes, and taphonomic influences including variations in thermal histories.

Both human and machine error during the process of analysis was quickly ruled out. The samples that presented a lack of agreement between extent of racemisation and radiocarbon age determinations were reanalysed twice, and in all instances resulted in statistically identical D/L values. The exact samples of shell that were submitted for radiocarbon dating were also returned and subjected to AAR analysis, also resulting in statistically identical D/L values. Intraspecies variations in the rate of racemisation have also been observed. Different areas within the same shell specimen have resulted in varying D/L values (e.g. Hare 1963, Goodfriend and Weidmen 2001). Similarly, protein composition and amino acid abundance has been identified to vary between different microstructures in molluscan shell (e.g. Kobayashi and Samata 2006). Due to the consistency of sampling locations in the shell valves utilised in this study, along with the focus on one particular species, the effects of intraspecies variations in AAR determinations should not be apparent. The infiltration of non-endogenous proteins is also not a possibility as the IcPD approach to AAR utilised in this study completely destroys the non-intracrystalline protein fraction. With these possibilities ruled out, one factor remains as arguably the most parsimonious explanation for the lack of congruence between the results of the AAR and AMS radiocarbon dating programs utilised in this study.

The greatest variable of the rate of the racemisation reaction is temperature. Increasing temperatures increases the rate at which racemisation occurs (Miller and Brigham-Grette 1989). The Brremangurey rockshelter is located in the tropics (Latitude - 14˚ 32' S), thus little seasonal fluctuation in mean average temperature is observed. Similarly, the squares from which the midden material was excavated are permanently protected from the radiant heat of sunlight because of the shade generated by the rockshelter itself. These two features of Brremangurey result in a largely consistent ambient air temperature year round. Should the cause for the age inversions between AAR and radiocarbon be thermal in origin, it would not be on an environmental scale, but rather smaller and more isolated events such as campfires and hearths; features that are abundant throughout the Brremangurey rockshelter and midden deposit sequence (Moore 2011). It is a distinct possibility that the heat generated by these small scale fires would hasten protein diagenisis, with little impact upon radiocarbon ages generated from the same specimen.

Identifying the influence of heating using AAR has been an area of limited research (Brooks *et al.* 1991). Heating experiments, in this case exposure to temperatures of 200-230˚ Celsius for one hour, revealed that the rate of racemisation of Glx was preferentially hastened. This resulted in D/L values of Glx exhibiting an increased extent of racemisation in comparison to the usually faster racemising Asx. While the experiments presented by Brooks *et al.* (1991) were focussed on ostrich eggshell, similar patterns of relatively advanced racemisation of Glx interpreted to have been the result of anthropic heating have been identified in molluscan shell (Demarchi *et al.* 2011: 120). Preferentially advanced racemisation of Glx was not observed in the results of this study, and as such the identification of anthropic heating as the driver of the anomalous ages presented above remains unresolved. Experimental work to date has only tested the effects of heat; however it is possible that combustion and oxidation, as well as the high and sometimes unstable temperatures associated with fires, may play an equally influential role in the overall effects of fire in the AAR reaction. This requires further experimental work if AAR methods are to be refined and prove useful in fine-grained archaeological interpretations.

Conclusion

The results of the AAR analysis presented in this study, when treated independently, neatly and efficiently identified that the majority of *M. hiantina* fragments found within the terminal Pleistocene sands at Brremangurey to have undergone significant vertical displacement and be of a late Holocene age. Without the need for numerical calibration, AAR was able to firmly establish two major phases of *M. hiantina* deposition that formed Brremangurey's Holocene midden, and it is from the older of these two phases that the displaced fragments originated. The results of the subsequent confirmatory radiocarbon dating program, however, produced ages not strictly in accordance with the relative ages generated here using AAR.

The exact cause of these inversions between radiocarbon and D/L values remains unknown. Methods of sample preparation and analyses specifically designed to negate taphonomic influences that distort AAR results were undertaken, and no indication of the influence of anthropic heating was detected. The forces that have resulted in the non-alignment of what should be two complementary dating methodologies remain elusive.

Despite this obstacle, the potential of this new application of the well-established AAR dating technique is clear. AAR is undergoing a renaissance in archaeological research, and like the developments through time in both radiocarbon and OSL dating, the method is becoming more refined and reliable. In saying this, however, issues do need to be resolved; particularly centred on archaeocentric hazards to AAR such as burning. This is but one of a number of anthropic processes not typically encountered by geochronologists, and thus remains underdeveloped methodologically. Further experimentation is therefore required to bring this method up to speed with other dating techniques and into the chronological toolkit of archaeological researchers across the world.

Chapter 5 – Untangling time-averaging in shell middens: Defining temporal units using amino acid racemisation

Statement of Author's Contribution

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We, the PhD candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution.

	Author	*% of contribution to the manuscript*
Candidate	Brent Koppel	90
Author	Katherine Szabó	8
Author	Mark Moore	2

MM oversaw the excavations (undertaken by MM and BK) that generated the material to be analysed
BK and KS conceptualised the manuscript
BK and KS planned the analysis, which was conducted by BK
BK and KS interpreted the data
BK drafted the manuscript which was reviewed by KS
MM offered comments on final draft of manuscript

Name of Candidate: Brent Koppel

Name/title of Principal Supervisor: A/Prof. Katherine Szabó

Candidate Date: 31/03/17

Principal Supervisor Date: 31/03/17

Introduction

Archaeological sites are not frozen in time. Rather, environmental and cultural processes act on deposits to add, remove and redistribute archaeological material (Ascher 1961, 1968; Schiffer 1972, 1996). One particular product of these transformations is the creation of a palimpsest: an agglomeration of previously separated material into one homogenised unit (Bailey 2007). This mixing of originally spatially separated material creates the illusion of contemporaneity during excavation with obvious implications regarding initial interpretations and subsequent analyses utilising the time-averaged material. It is therefore critical that a time-averaged deposit be identified as such. Establishing that a unit is time-averaged allows restructuring of the scale of questions being asked of the deposit to account for the expanded bracket of time represented. By establishing the time range represented within an assemblage, relevant information can still be gathered from material representing a much greater timespan, however the possibility to tackle themes on a smaller temporal scale is lost (Bailey 1981, 1983, Lucas 2005: 45, 49, Stern 2008: 134, Sullivan 2008).

Compositionally, shell midden deposits are usually dominated by large amounts of molluscan shell with smaller proportions of sediments such as sand, silt and ash. Middens tend to be extremely permeable due to the relatively large size of the abundant shells that facilitates the free movement of water, which can subsequently influence materials within the midden itself (Stein 1992). Lighter elements such as sand, ash, small fish bones and charcoal, can be blown away by wind, leading to deflation of the deposit, or washed away either through the matrix or away from the deposit (Rick 2002, see also Wandsnider 1988). Animals also act as agents of transformation within midden deposits. Among others, bowerbirds (Dwyer *et al* 1985), ants and termites (Robins and Robins 2011), crabs (Specht 1985, Szabó 2012) and earthworms (Stein 1983) have all been identified as adding, removing, and redistributing midden material in archaeological sites. Finally, human activity can greatly contribute to the movement of midden shell through processes such as trampling, pit digging and other activities associated with various cultural behaviours (Schiffer 1996).

Recognising a significantly time-averaged unit in a shell midden during excavation is troublesome due to the coarse nature of the shell dominated matrix and frequent compositional homogeneity. Increasing the number of chronometric age determinations obtained can increase temporal resolution and suitably bracket the age of a deposit (Kowalewski *et al.* 1998: 291), although this can be a costly exercise. Cost means that the dating of shell middens often only involves a handful of age determinations for the entire sequence, and rarely more than one per stratigraphic unit (Stein *et al.* 2003). The implication of this is that the acknowledged temporal range of a time-averaged unit will be severely underrepresented, or indeed not be identified at all.

The problem of time-averaging in shell dominated deposits is not confined to archaeology and has been addressed in the geomorphological and palaeontological literature (e.g. Fürsich and Aberhan 1990, Kowalewski *et al.* 1998, Flessa and Kowalewski 1994, Fujiwara *et al.* 2004 and Kidwell *et al*. 2005). Indeed, within some of these disciplines, time-averaged deposits are considered the norm (Krause *et al.* 2010: 428). While the same limitations regarding the costs involved for radiometric dating techniques carry over into geological and palaeontological research, these latter disciplines have utilised alternative dating methodologies to tackle the issue of time-averaged, carbonate-dominated deposits in a cost effective way; most notably in the application of amino acid racemisation (AAR) (e.g. Wehmiller *et al.* 1995, Goodfriend and Stanley 1996, Carroll *et al.* 2003 and Krause *et al.* 2010). The cost-effectiveness of AAR allows a large number of samples to be analysed, with multiple samples from the same stratigraphic unit being tested to establish a range of ages for time-averaged deposits (Kowalewski *et al.* 1998). While the processes that result in time-averaging in the earth sciences often differ from those that are occur in the archaeological record (e.g. Hughes and Lampert 1977, Schiffer 1996: 47), the principles and implications of time-averaging remain the same.

Amino acid racemisation (AAR) is a dating method that has had a long history of use in archaeological investigation (e.g. Wehmiller 1977, Masters and Bada 1977, Parfitt *et al*. 2005, Johnson and Miller 1997, Bateman *et al.* 2008, Ortiz *et al*. 2009, Demarchi *et al.* 2011). While the method his principally been used to replace or supplement ^{14}C dating as a chronological device to understand broad site chronology (e.g. Bada and Protsch 1973, Parfitt *et al.* 2005, Kosnik *et al*. 2008), AAR has been utilised for other ends: for example acting as a range finder for shell midden units (Demarchi *et al.* 2011: 123), potentially identifying anthropic heating (Demarchi *et al.* 2011: 120) and using amino acids to taxonomically identify shell fragments (e.g. Andrews *et al*. 1985) and artefacts (Demarchi *et al.* 2014). The potential exists for AAR to address issues of post-depositional transformation in archaeological deposits utilising the concept of 'aminostratigraphy' developed within the earth sciences (e.g. Miller *et al.*1979, Kennedy *et al.* 1982, Hearty *et al.* 1986) which at present remains unexplored (but see Demarchi *et al.* 2011: 123). We do not intend that increasing the resolution of our understanding of how middens are deposited and over what range of time using AAR is a way to deconstruct middens to mealtimes. Rather, our approach intends to identify conflated deposits, provide a guide as to the temporal ranges encapsulated within and 'unravel the palimpsest into its constituent parts' (Bailey 2007: 216). The principal aim is to refine a time-averaged deposit into smaller scale of episodes appropriate and relevant for the scale of investigations, such as changes in environment and gathering behaviours, we ask of archaeological sites (Sullivan 2008: 33).

To test the applicability of an aminostratigraphic approach to isolating time averaging in middens, we have undertaken an intensive dating program on midden material excavated from Brremangurey rockshelter in the northwest Kimberley, Western Australia (Figure 3.1). Our aim was to identify zones of time-averaged midden and identify and quantify the extent of time-averaging that had occurred through the deposit's history. We further elaborate on the implications of the results, which substantially change our understanding of the accretion of midden at Brremangurey.

Chronology

The initial charcoal radiocarbon ages obtained post-excavation at Brremangurey presented in Table 5.1 (see Table 3.1 for the results of all ages analysed using material from Brremnagurey) reveal intensive midden deposition throughout the later stages of the Holocene from approximately 2,500 years cal. BP, with the cessation of deposition occurring at approximately 500 cal. years BP. Other key north Australian shell midden deposits such as Weipa (Bailey 1977, but see Morrison 2014), Blue Mud Bay (Faulkner 2013), Darwin (Bourke 2012) and the Admiralty Gulf (Veitch 1999), show a parallel chronological spread that would seem to accord with the dates for Brremangurey.

A second series of dates yielded an early Holocene age of 8,152-8,334 cal. BP on a valve of *Tegillarca granosa* (Wk-37137) from the lower extent of the midden, and this prompted a chronological rethink. Sourced from spit 18A (91-95.9 cm below surface), this shell was taken from the same spit as an adjacent fragment of charcoal that returned an age of 1,733-1876 cal. years BP (OZQ-187); a difference in age of over 6,000 calibrated years BP . Obviously, questions have to be asked regarding stratigraphic integrity. This result has significant repercussions for interpretations of both the material culture found in association with the shells, as well as having clear implications regarding the formation history of the shell midden. If these results mean that a conflated deposit has been identified in the Brremangurey assemblage, what proportion of shell specimens are similarly temporally obscured? Conventional dating methods such as radiocarbon could resolve this issue, however the number of individual age determinations required to adequately bracket the extent of time-averaging within the conflated deposit renders this approach unfeasible. This conundrum provided a good opportunity to test an application of an alternative chronological method - amino acid racemisation.

Sample code	Sampling location	Material	Depth (cm. below surface)	Layer/ Horizon	Age (uncalibrated)	Calibrated Age
Wk-32405	Trench wall	Charcoal	8.6	1	493 ± 33	498 - 552 (99.4%) 614 - 617 (0.6%)
OZQ-181	Excavated material	*Tegillarca granosa*	24.1-28.1 (Spit 6)	1	1,415 ± 25	785 - 988
OZQ-185	Excavated material	Charcoal	24.1-28.1 (Spit 6)	1	930 ± 25	791 - 918
Wk-32407	Trench wall	Charcoal	57.6	1	1,896 ± 33	1,733 – 1,899 (98.9%) 1,913 – 1,920 (1.1%)
OZQ-182	Excavated material	*Tegillarca granosa*	75.9-80.3 (Spit 15)	1	2,615 ± 30	2,115 – 2,326
Wk-37137	Excavated material	*Tegillarca granosa*	91.0-95.9 (Spit 18A)	1	7,828 ± 25	8,152 – 8,334
OZQ-187	Excavated material	Charcoal	91.0-95.9 (Spit 18A)	1	1,875 ± 25	1,733 - 1876
Wk-32409	Trench wall	Charcoal	91.0	1	3,394 ± 25	3,579 – 3,694
Wk-32410	Trench wall	Charcoal	108.3	2	10,867 ± 39	12,694 – 12,801
Wk-32411	Trench wall	Charcoal	125.5	2	12,303 ± 44	14,059 – 14,564

Table 5.1 - Ages of the initial AMS radiocarbon dates of charcoal sourced from the wall of the excavation and shell from excavated material during preliminary midden analysis. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

Approach to investigation

Amino acid racemisation (AAR) is a dating technique that centres on the two chiral forms of amino acids. During life, amino acids are almost solely maintained in the laevorotary (L) form. After death, these L-amino acids convert to their dextrorotary (D) forms; a process called racemisation. Over time, the proportion of D-amino acids relative to L-amino acids increases until equilibrium is reached. By establishing the ratio of D- to L-amino acids allows the time since the organism's death can be identified. In summary, the larger the D/L ratio, the more time passed since the death of the organism. The primary variable that affects the rate of racemisation is temperature, however a number of different environmental factors can influence the rate of racemisation, such as pH, presence of metal ions and microbial alteration to name a few (Penkman 2005: 33-38). Recent research has identified a small proportion of proteins that are encapsulated within individual calcium carbonate crystals that form molluscan shell (Sykes *et al.* 1995, Penkman *et al.* 2008). These intracrystalline proteins have been proven to act as a closed system, insulated from external taphonomic processes that have the potential to obscure or skew results. Isolating the products of intracrystalline protein diagenesis (IcPD) for use in AAR has subsequently provided more precise and reliable results. The IcPD approach to AAR dating has been utilised here.

Geomorphological studies have routinely used AAR as a means of assessing the depositional history of a deposit by establishing the relative ages of carbonate sediments, including molluscs and foraminifera, with comparable D/L values; a concept called aminostratigraphy (e.g. Miller *et al.* 1979, Murray-Wallace *et al.* 1991, Bates 1993, Hearty and Kaufman 2000, Wehmiller and Miller 2000, Penkman *et al.* 2007, 2013, Meijer and Cleveringa 2009). By establishing clusters of specimens exhibiting similar D/L ratios, called aminozones, then comparing extent of racemisation with spatial positioning allows interpretations to be made regarding both site formation as well as post-depositional transformation. Substantially time-averaged deposits are immediately identified as spatially associated specimens return D/L values belonging to different aminozones (e.g. Kowalewski *et al.* 2000, Kidwell *et al.* 2005, Kosnik *et al.* 2007). While the agents and processes that drive deposition and transformation in geomorphological settings frequently differ to those of archaeological contexts, the principles of recognising the temporality of deposition and transformation processes remain the same, and this approach is especially applicable to shell middens. As applied to the Brremangurey shell midden we aimed 1) to isolate any major instances of time-averaging within the midden, and 2) establish a more accurate chronostratigraphic interpretation for such layers.

Methods

Sampling methodology

Shells were sampled from all excavation units (spits) from which shell midden was recovered. This approach allowed the results to portray clustering without the bias associated with preferential sampling of one excavation unit over another. A total of 42 valves of *T. granosa* were sampled from both the dense midden overlying the sandsheet from spits 1 to 21 (surface to 118 cm below surface). Two valves were selected from the excavated and sorted midden material of each spit, except for spits 10 and 12 where only one whole left valve was found. No whole valves of *T. granosa* were found in spit 11 (a full list of samples, their codes, and relevant excavation data is presented in Table 5.2). To remove the possibility of dating the same animal twice, only the left valves were selected for analysis. Specimens that had no visible signs of burning or other taphonomic influence such as acid dissolution were selected. Where possible, the same shells that were sampled for AMS radiocarbon dating were incorporated into the AAR programme to provide a direct link between D/L values and radiocarbon age (samples OZQ-181 and OZQ-182).

Sample preparation

Preliminary sample preparation followed the process described by Lachlan (2011). Shell specimens were cleaned of adhering sediment using a soft-bristled brush. Following this, using a dental drill, the surfaces of the interior and exterior regions near the umbo were abraded. A small subsample of the shell was removed from near the umbo. Already fragmented shells were not subsampled further, but were simply cleaned and abraded. All specimens were then sonicated in purified (Millipore) water for 5 minutes. This sonication step was repeated at least three times until the water post-sonication was clear, replacing the water after each cycle. Specimens were then air dried in sterile covered plastic dishes.

The shell fragments were accurately weighed and subjected to a 2M HCl etch at 0.0033mL of acid per milligram of shell. Fragments were then rinsed thoroughly in purified water. The fragments were once again air dried and then crushed to a fine powder using an agate mortar and pestle. Following methods outlined by Sykes *et al.* (1995) and Lachlan (2011), the powdered shell was then exposed to a bath of 12.5% sodium hypochlorite (NaOCl) for 24 hours and agitated regularly. The NaOCl solution was then poured off and the powdered shell was rinsed using purified water at least four times. A rinse of methanol was also used to ensure the neutralisation of the NaOCl, and was then followed by a final Millipore rinse.

Following the method outlind by Kaufman and Manley (1998), preparation for hydrolysis began with dissolving the powdered shell in a sterile vial using 8M HCl at 0.02mL of acid per milligram of shell. This destroys the crystalline component of the shell releasing the proteinaceous material contained within. The vials were then filled with nitrogen (N_2) gas and sealed. The vials were placed into an oven at 110˚C for 22 hours to induce hydrolysis of the peptide bonds. Following this process, samples were dried in a vacuum desiccator and then rehydrated using a solution 0.01mM L-HomoArginine + 0.01M HCl + 0.77mM sodium azide and L-HomoArginine acting as a an internal lab standard. Sample analysis was conducted using an Agilent 1100 reverse phase high pressure liquid chromatograph (RP-HPLC). Two analyses per shell sample were run to account for systematic machine error, and the results of each shell sample averaged.

Results

Of the 42 shells that were utilised for this study, one sample (UWGA10495) was lost when the vial was not sufficiently sealed prior to the 110˚C oven stage of sample preparation. All other specimens provided useable results. Only the results of aspartic (Asx) and glutamic (Glx) acids are presented here. Of all of the amino acids that can be analysed, aspartic acid was selected because of its abundance in molluscan shell, but also because of the balance it offered between temporal resolution and time-depth it provided. Glutamic acid was also selected due to the high degree of covariance with aspartic acid, which allows taphonomically affected samples to be identified through the deviation from this covariance (Kaufman 2006).

An initial observation of the results of this study is a clustering of specimens circled in Figure 5.1. The D/L values of these specimens (UWGA10472, UWGA10403, UWGA10407, UWGA10408 and UWGA10409) match patterns that are thought to result from burning, or exposure to fire. As mentioned previously, aspartic acid undergoes racemisation at a faster rate than glutamic acid, and subsequently equivalent D/L values between each amino acid should not be identified until equilibrium. Similar patterns are observed and described by Crisp (2013: 181-182), Demarchi *et al.* (2011: 120), and Brooks *et al*. (1991) who were able to demonstrate that exposure to high temperatures for a short period of time preferentially affected aspartic acid D/L values over other, slower racemising amino acids, such as glutamic acid. While none of the shells selected exhibited any visual signs of burning, the thermal influence of campfires has to be expected in a site like Brremangurey, especially considering the abundance of charcoal, hearth features and other evidence of anthropogenic fire within the archaeological material. As these specimens have been taphonomically altered, these samples have not been incorporated in further analyses and interpretations of this study.

Lab code (UWGA)	Spit	Layer/ Horizon	D/L Asx	Sample variance	D/L Glx	Sample variance	Radiocarbon lab code	Radiocarbon age (cal. BP)
10470	1	1	0.201	± 0.001	0.1115	± 0.0005	Wk - 40856	326-496
10471	1	1	0.3395	± 0.0015	0.12	± 0		
10472	2	1	0.543	± 0.006	0.6195	± 0.005		
10473	2	1	0.3485	± 0.0005	0.141	0	Wk - 40857	387-525
10474	3	1	0.35	± 0.001	0.148	0		
10475	3	1	0.346	± 0.008	0.1345	± 0.0015		
10476	4	1	0.356	±0.003	0.1335	± 0.0005		
10477	4	1	0.4025	± 0.0065	0.159	0		
10478	5	1	0.35	± 0.010	0.1275	± 0.0015		
10479	5	1	0.394	± 0.001	0.1485	± 0.0005		
10480	6	1	0.3755	± 0.0005	0.150	0		
10481	6	1	0.4185	± 0.0065	0.1535	± 0.0005		
10494	6	1	0.413	± 0.017	0.155	± 0.001	OZQ - 181	785-988
10482	7	1	0.428	± 0.0105	0.1665	± 0.0035		
10483	7	1	0.4365	± 0.0105	0.185	± 0.001		
10484	8	1	0.496	± 0.002	0.214	0		
10485	8	1	0.405	± 0.011	0.156	± 0.004		
10486	9	1	0.463	0	0.1975	± 0.0005		
10487	9	1	0.393	± 0.010	0.1505	± 0.0025		
10488	10	1	0.5165	± 0.0115	0.2255	± 0.0005		
10489	12	1	0.5765	± 0.0075	0.2655	± 0.0005		
10490	13	1	0.5605	± 0.0185	0.2505	± 0.0015		
10491	13	1	0.309	± 0.001	0.127	0		
10492	14	1	0.514	± 0.016	0.2115	± 0.0015		
10493	14	1	0.5095	± 0.0095	0.2265	± 0.0005		
10495	15	1	-	-	-	-	OZQ - 182	2,115-2,326
10394	15	1	0.514	-	0.263	-	Wk - 40858	2,139-2,330
10395	15	1	0.5095	± 0.0065	0.2705	± 0.0015		
10396	16	1	0.541	± 0.010	0.303	± 0.001		
10397	16	1	0.5245	± 0.0045	0.273	± 0.003		
10398	17	1	0.806	± 0.005	0.5425	± 0.0005	Wk - 40859	2,844-3,080
10399	17	1	0.5695	± 0.0045	0.2875	± 0.0005		
10400	18A	1	0.410	± 0.005	0.1815	± 0.0005		
10401	18A	1	0.9715	± 0.0205	0.856	± 0.013	Wk - 37137	8,208-8,365
10402	18B	2	0.5585	± 0.0005	0.3145	± 0.0005		
10403	18B	2	0.5395	± 0.0105	0.618	± 0.004		
10404	19	2	0.6525	± 0.0045	0.4625	± 0.0015		
10405	19	2	0.597	± 0.001	0.4145	± 0.0045		
10406	20	2	0.441	± 0.002	0.2245	± 0.0015		
10407	20	2	0.5105	± 0.0075	0.5355	± 0.0035		
10408	21	2	0.566	± 0.001	0.565	± 0.002		
10409	21	2	0.4785	± 0.0005	0.776	± 0.003		

Table 5.2 Results of the AAR analysis. Each sample was run in duplicate and averaged. UWGA lab code issued by the Amino Acid Racemisation Laboratory at the University of Wollongong. AMS radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

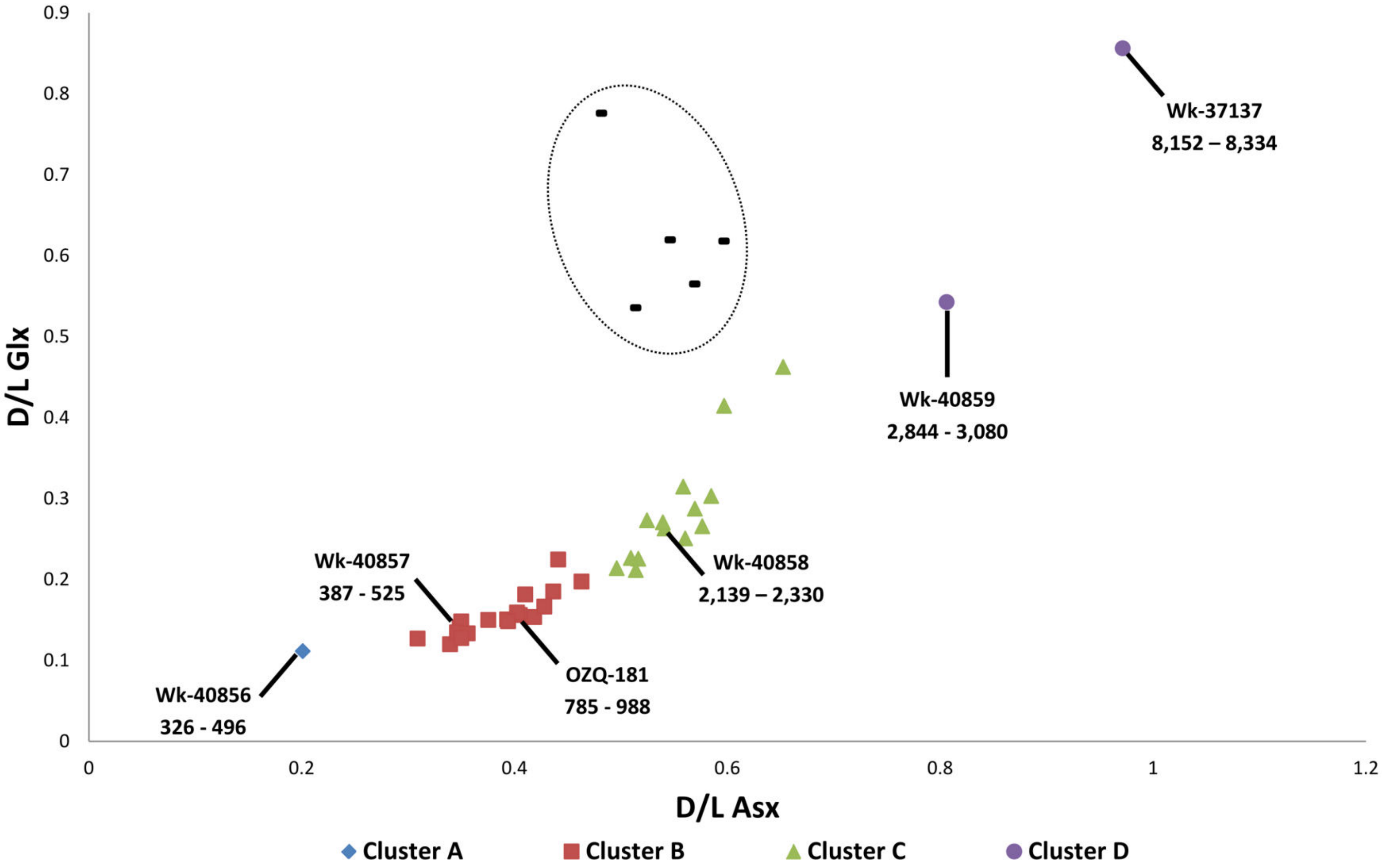


Figure 5.5 - Bivariate plot combining D/L ratios of both Asx (x-axis) and Glx (y-axis) for each sample analysed in this study. The results of the k-means cluster analysis are also incorporated. Specimens that have been circled have been interpreted to have been affected by burning or exposure to high heat. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

Looking to the rest of the dataset, the pattern observed in the bivariate analysis of aspartic acid versus glutamic acid (Figure 5.1) reveals a steady increase in the extent of racemisation in the shells analysed which, when the previously run radiocarbon ages are included, correspond well with increasing age. Generally, there is little clustering between samples seen in Figure 3 with a very regular increase in D/L ratios being observed. K-means cluster analysis statistically isolated 4 distinct clusters, shown in Figure 5.1. Cluster A is a single specimen (UWGA10470) exhibiting a much lower D/L value when compared to the rest of the sequence. Cluster B is a dense grouping of shells, comparable to cluster C, although cluster C exhibits a more advanced extent of racemisation. In contrast, cluster D exhibits the greatest extent of racemisation by a substantial margin (for example centroid of cluster D of Glx D/L value is 0.699 compared to 0.284 for the centroid of cluster C, seen in Table 5.3).

	Amino Acid	Centroid Mean (D/L)	Cluster Range (D/L)	Standard Deviation
Cluster A	Asx	0.201	-	-
	Glx	0.1115	-	-
Cluster B	Asx	0.387	0.309 – 0.463	0.042
	Glx	0.1558	0.120 – 0.2245	0.027
Cluster C	Asx	0.5529	0.496 – 0.6525	0.042
	Glx	0.2844	0.2115 – 0.4625	0.073
Cluster D	Asx	0.8888	0.806 – 0.9715	0.117
	Glx	0.6993	0.5425 – 0.856	0.222

Table 5.3 - Results gathered from k-means cluster analysis utilising the Brremangurey AAR samples. Centroids refer to the average D/L values of Asx and Glx for each cluster.

When comparing D/L values of each specimen with their spatial positioning during excavation (Figure 5.2), Clusters A and B are almost entirely comprised of shells sourced from spits 1 through to 7 (surface to 40.5 centimetres below surface). Such a pattern is not seen in the lower portion of the midden as little correlation between stratigraphic level and relative D/L values are observed. This is further depicted in Figure 5.2, which plots stratigraphic depth of each sample and Asx D/L values. While a positive correlation between depth and D/L value is seen in the upper and younger portion of the midden, the lower and older extent of the midden, particularly from spit 13 onwards, does not continue this trend. Instead, a much more variable pattern is apparent with very different ages being associated with the same spit, and regularly younger shell specimens being stratigraphically below older ones (for example shell specimens from spit 19 compared with spits 17 and 18A in Figure 5.2 and Figure 5.3). These patterns present a strong indication that time-averaging has occurred in the lower extent of the Brremangurey midden.

A further four shells were selected for radiocarbon dating based on their relative positioning derived from the results of the AAR analysis to properly bracket the age range of the deposit, as well as identify when punctuations in deposition occurred (Table 5.4). When these ages are marked on the bivariate plot, the numerical ages derived from the radiocarbon analysis coincide very neatly with the D/L values and relative ages of this study, seen in Figure 5.1.

Discussion

While the initial radiocarbon dating program suggested the presence of a time-averaged deposit, the AAR analysis presented here was able to expand on the story of deposition and disturbance within the Brremangurey midden. A population of shells exhibiting a substantially more advanced extent of racemisation (Cluster D in Figure 5.1) than the majority of shell specimens that form the main bulk of the shell midden has become apparent. The close agreement of the extent of racemisation established using AAR on the shell specimen also AMS radiocarbon dated to over 8,000 cal. years BP (Wk-37137), as well as its position relative to the other amino-ages generated, further reinforces the position that this shell is genuinely older than those surrounding it, and not a product of some process that skews age determinations such as the marine reservoir effect in radiocarbon dating.

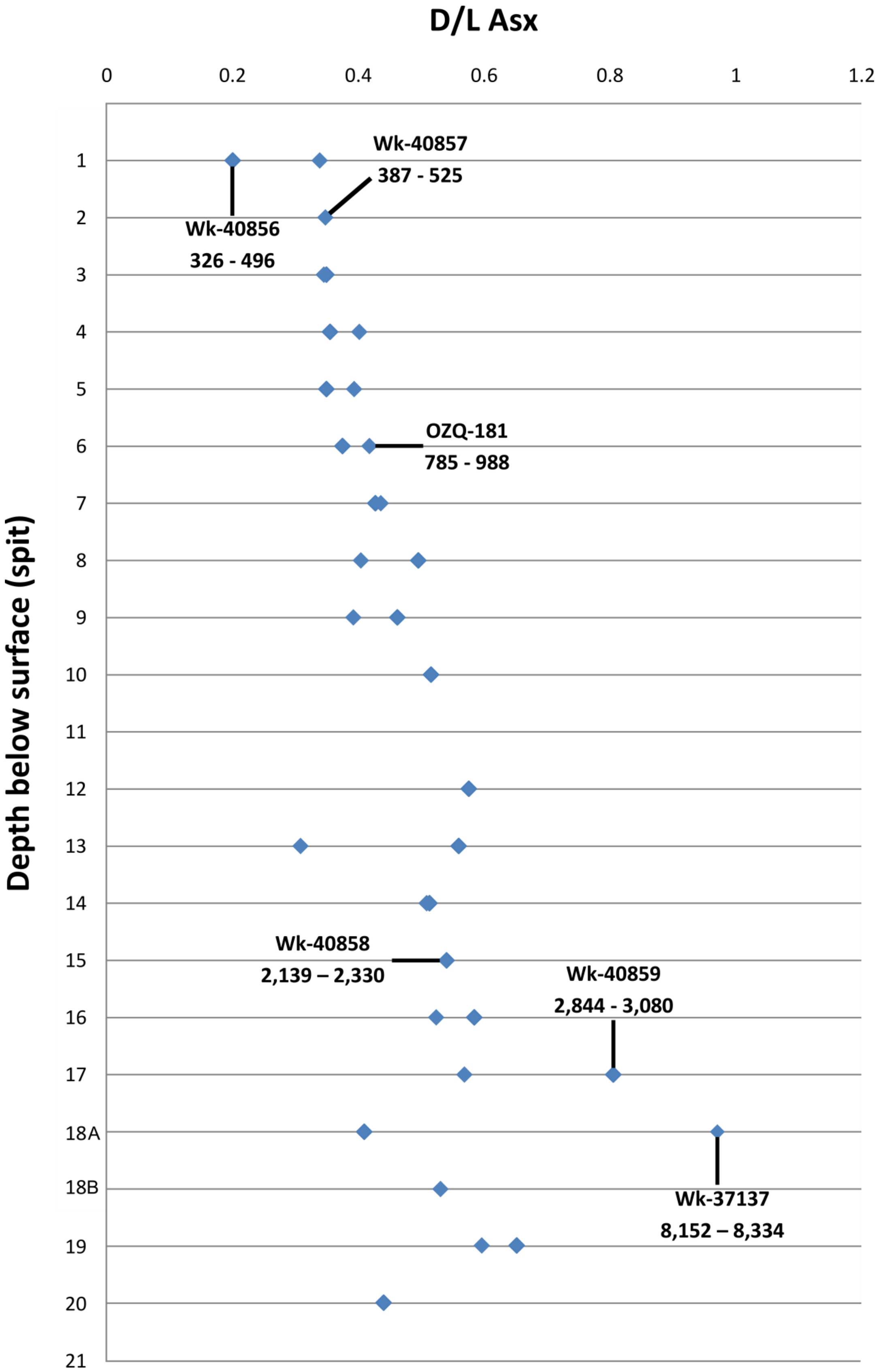


Figure 5.2 - D/L values (x-axis) compared with excavation units that shells were sampled from. Note increasing D/L value to the right of the figure indicates older age.

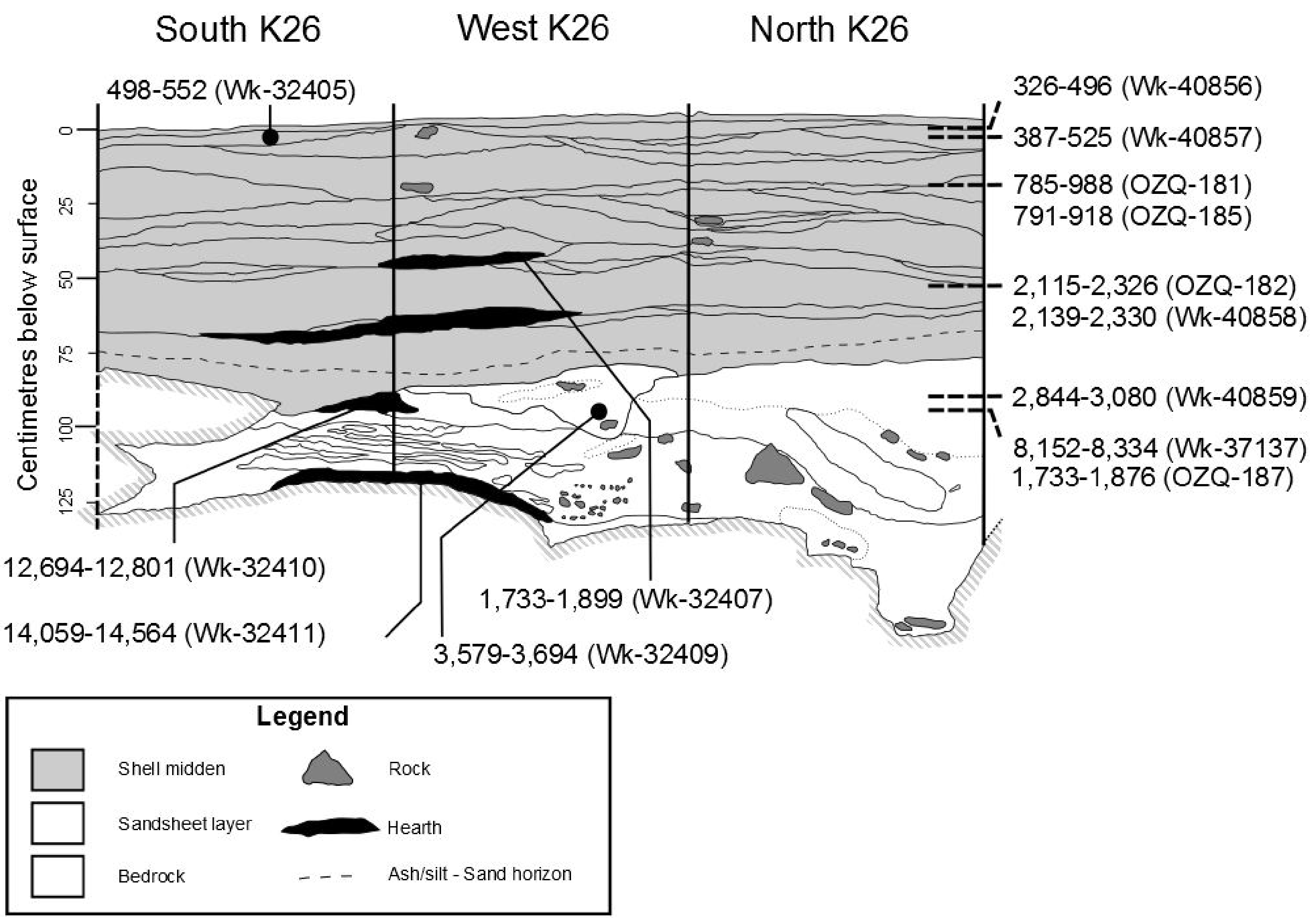


Figure 5.7 - All radiocarbon ages presented in this study placed in stratigraphic order from where the material was sampled from. Specimens for radiocarbon dating marked with a solid line were sampled directly from the wall of the trench during excavation. Specimens that were selected post-excavation from analysed midden material are indicated by a dashed-line at the approximate depth from which they were excavated.

Sample code	UWGA Sample code	Method	Material	Depth (cm. below surface)	Layer/ Horizon	Age (uncalibrated)	Calibrated Age
Wk-40856	10470	AMS Radiocarbon	*Tegillarca granosa*	0 – 3.1 (Spit 1)	1	851 ± 20	326 - 496
Wk-40857	10473	AMS Radiocarbon	*Tegillarca granosa*	3.1 – 5.4 (Spit 2)	1	882 ± 20	387 - 525
Wk-40858	10394	AMS Radiocarbon	*Tegillarca granosa*	75.9-80.3 (Spit 15)	1	2,631 ± 20	2,139 – 2,330
Wk-40859	10398	AMS Radiocarbon	*Tegillarca granosa*	83.7 – 90.1 (Spit 17)	1	3,232 ± 20	2,844 – 3,080

Table 5.4 – Results of additional AMS radiocarbon analyses on shell specimens selected as a result of the AAR analysis (see Figure 5.1). Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

The implication of this result, is that an older deposit of shell has become conflated into the younger shell deposit, as highlighted in Figure 5.2 and Figure 5.3. Comparing the younger shell deposit to the older and far less abundant deposit, the extent of time bracketed by each grouping of shell is an obvious distinction. The primary grouping of shell (clusters B and C seen in Figure 5.1) represent the bulk of the shell material present in the Brremangurey midden deposit, and covers a time range of approximately 2,300 to 350 cal. years BP. The much more scattered grouping of shell specimens (cluster D in Figure 5.1) covers a considerably larger time range from approximately 8,300 years cal. BP. With the oldest and youngest material dated, the effective range of shell midden accumulation observed in the Brremangurey midden assemblage extends throughout the Holocene, from approximately 8,300 to 350 cal. years BP.

While this conclusion in itself reveals a critical part of the history of the Brremangurey deposit, the refining of the chronology of the Brremangurey assemblage presents new opportunities for investigation. The results of the AAR analysis reveal a considerable difference in the proportional abundance of shell specimens between the various groupings of shell identified. The vast majority of midden shell specimens are restricted to the younger grouping (Clusters B and C in Figure 5.1), and by comparison the oldest grouping of shell (Cluster D in Figure 5.1), represents a much smaller population of shell specimens. Two interpretations can be offered; 1) the proportional abundances between the groupings are reflective of the relative depositional patterns that created them and thus the original level of deposition of *T. granosa* was low; or 2) the quantified abundances of *T. granosa* do not reflect the original scale of deposition and the earlier deposits have undergone a significant degree of loss of midden material over time. The first assumption closely aligns the Brremangurey midden with Bailey's description of a 'cumulative palimpsest' (2007: 207), where no (or little) material evidence is lost between two units when both are conflated – they are simply mixed. The second is closer to a 'true palimpsest' (Bailey 2007: 205) that involves some or total loss of material evidence through time.

Depending on which form of palimpsest is present in the Brremangurey midden assemblage, the overall interpretations of behavioural practices at Brremangurey change. Assuming that the abundance of shell present in the excavated assemblage is a reasonable reflection of the nature of *T. granosa* deposition in the past, we observe a substantial shift in gathering practices through time. The deposition of shell midden was initially rather sporadic and ephemeral with relatively small quantities of shell brought back to the rockshelter through most of the Holocene from approximately 8,300 to 2,500 years cal. BP. Patterns in midden deposition then changed, as gathering strategies focussing on shellfish increased in intensity with much larger quantities of shell being deposited in the rockshelter. This interpretation has further implications for the intensity and frequency of site use through time.

The alternative scenario is that a substantial amount of midden material has been lost through some process, mechanical or chemical, resulting in an underrepresentation of the true abundance of shell brought into the shelter in earlier phases of midden accumulation. Chemical dissolution has the potential to destroy carbonates in a deposit through slightly acidic water percolating through the site, however this process leaves traces in the form of reprecipitated minerals (e.g. Beck 2007, Villagran *et al.* 2011); something that was not observed during excavation or analysis of the midden material. Similarly, none of the shells selected for AAR analysis exhibited signs of low-level acid dissolution signalled by of rounded margins and muted sculpture and a chalky texture (Claassen 1998: 59-60). Mechanical removal of midden is a definite possibility, however once again evidence associated with this process was not found during excavation or analysis (e.g. Glover 1979: 306-7 on remnant midden-bearing breccias on cave walls). It is possible that evidence exists of the mass movement of shell within the talus slopes at the entrance of the rockshelter (see Figure 3.9) that could provide further insights into mechanical processes of shell removal at Brremangurey.

Without any lines of evidence from the analysed material that suggest a chemical or mechanical explanation of the removal of midden shell at Brremangurey, the most parsimonious explanation is that the shell excavated from the rockshelter is an adequate reflection of the depositional behaviours practiced over time and that the proportion of shell present in the midden is indicative of the amount of shell midden deposited in the early-mid Holocene. Thus, the change in proportional abundances of shell between the primary clusters of shell specimens and the oldest grouping of shell (cluster D in Figure 5.1) has been interpreted to be the result of a behavioural shift in shellfish gathering practices. Initially, shellfish collection and shell deposition followed a low intensity, ephemeral and very episodic pattern from approximately 8,300 cal. years BP. Rather suddenly, shellfish gathering behaviours became more focussed and intensive and this ultimately underpinned the formation of the very dense shell midden that accumulated from approximately 2,300 cal. years BP to 350 cal. years BP.

Conclusion

The key aims of this study were to refine the chronology of the Brremangurey midden assemblage and to isolate any potential time-averaged deposits, which have been achieved. Initial radiocarbon dates gathered using material excavated from Brremangurey were fortunate in likely identifying a time-averaged deposit, however the number of AMS radiocarbon ages presented in this study is unusual when compared to the typical approaches to midden chronology. Despite this, the true extent of time-averaging remained hidden. Similarly, shifts in shellfish gathering intensity through time would have remained masked. It was only with the intensive use of AAR presented here that the extent of time-averaging and changing gathering intensities could be further expanded. By isolating appropriate temporal units, the scale of questions we can now appropriately ask of the Brremangurey assemblage can be refined, allowing investigation of changes in the depositional behaviours practiced by Brremangurey’s ancient occupants on a resolution that would have been previously impossible.

Shell middens are always going to be beset with issues associated with time-averaging across a range of temporal, spatial and quantitative scales, largely due to their large constituent parts and complex and often fine-grained formation processes. While methodological advancements in standard chronometric techniques continue to allow for ever-finer resolution of dates, reducing a shell midden down to the individual mealtimes will remain impossible and arguably unnecessary considering the questions we as archaeologists ask of an assemblage. Refining the chronology enough to isolate temporal disjuncture and conflation in time-averaged deposits is necessary to establish the actual temporal envelope that brackets the archaeological material, and rationally reframe our scale of enquiry to engage with the processes behind the material which will provide a much more accurate and complete story of the deposit as a whole through time.

This study has shown that not only can temporal ranges be elucidated, but that changing patterns of deposition can be brought into sharper focus. It is also not unreasonable to assume that the hidden issues in the Brremangurey deposit are not also present in other midden deposits around the world. This study has, using the novel adaptation of a well-established dating method, presented a new approach to how we analyse midden material.

Chapter 6 – What really happened in the Holocene?: An intra-regional comparison of shellfish deposition in Kimberley shell middens, northern Western Australia

Introduction

The results of the aminostratigraphic analysis applied to the shell midden material excavated from within the Brremangurey rockshelter, presented in Chapters 4 and 5, went a long way to successfully disentangling the complex post-depositional processes that had redistributed archaeological shell throughout the deposit to reveal detailed insights into the site's formation history. The majority of the midden material, dominated by the softshore bivalve *Marcia hiantina*, was identified to have been deposited during the late Holocene from approximately 3,000 years BP to the relatively recent date of 300 years BP. An earlier tradition of the gathering of the mudflat species *Tegillarca* (=*Anadara*) *granosa* was also isolated, with specimens sampled form the site dating from approximately 8,200 years BP through to the cessation of midden building. Punctuation in shellfish deposition was also noticed, with results revealing clusters of similarly aged shell across the datasets of both *M. hiantina* and *T. granosa* separated by gaps in the aminostratigraphic profile.

The question that now arises is how representative the patterns of deposition identified at Brremangurey are of middens across a regional context? Around the Admiralty Gulf, three other large middens have been identified; Goala, Wundadjingangnari, and Idayu (Veitch 1999a: 75), seen in Figure 6.1. Brremangurey and these other Admiralty Gulf middens share distinct outward characteristics. Excavations and dating at these three sites place their formation in the late Holocene (seen in Table 6.1) concurrent with the younger, intensive periods of deposition at the Brremangurey midden nearby (Koppel *et al.* 2016, 2017). All but one of the ages determined from the midden material excavated by Veitch are younger than 2000 cal. years, with the remaining

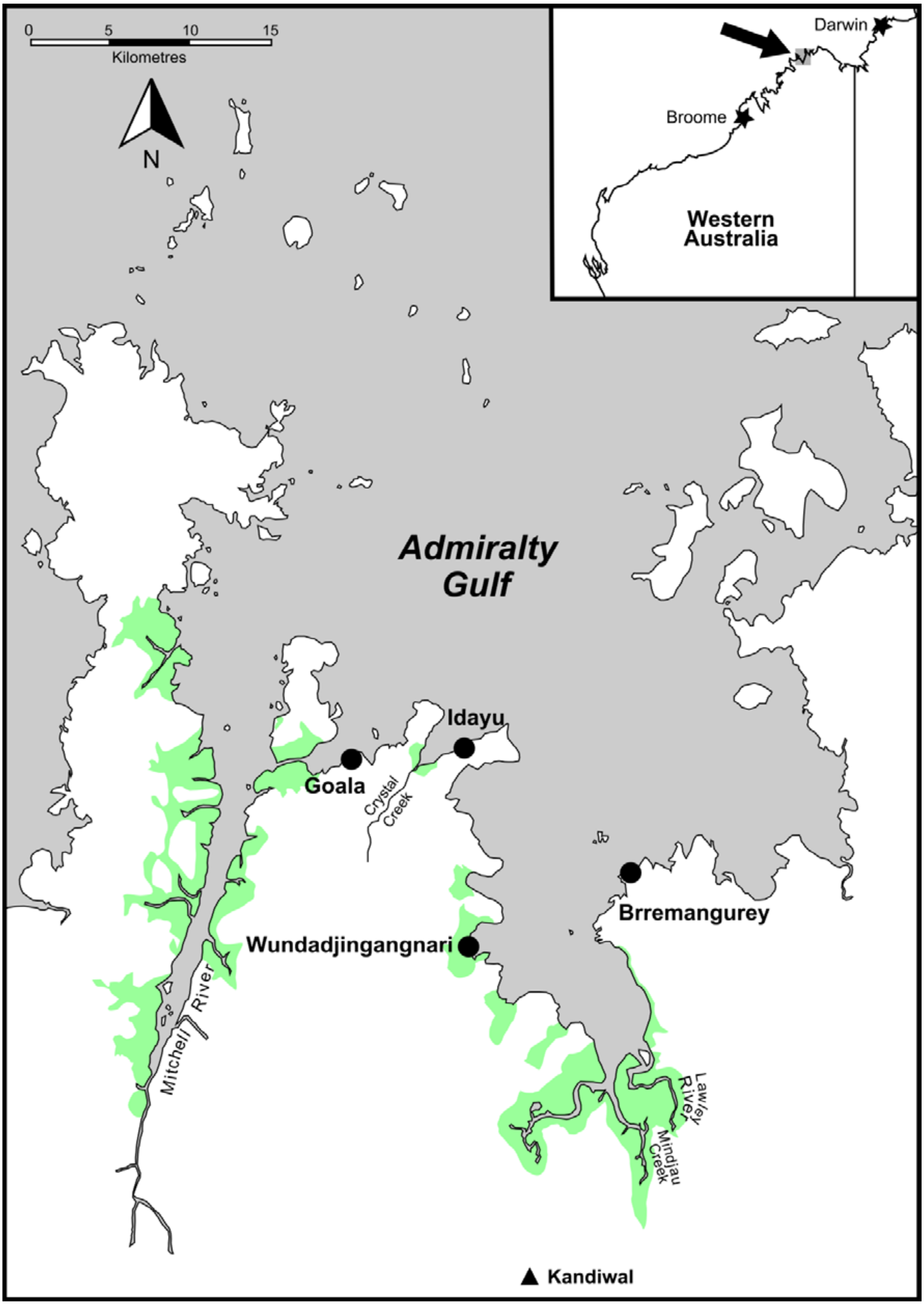


Figure 6.1 - Map of part of the Admiralty Gulf coast showing locations of midden sites mentioned in text. Green shaded areas are the approximate extent of extant mangrove stands. Adapted from Veitch 1999a: 38.

sample dating to a maximum age of 2991 cal. years. All of these ages lie within the periods of intensive deposition of midden material identified at Brremangurey. Compositionally, and like the Brremangurey midden, each site is dominated by soft shore bivalves. At Goala, *M. hiantina* is the most abundant species throughout the deposit, and at Wundadjingangnari, *T. granosa* is dominant throughout the site. Both of these sites, as well as Brremangurey, accord with the typical form and composition of shell middens in tropical northern Australia: they principally exhibit a late Holocene initiation and are compositionally dominated by a single species of bivalve. Idayu, however, exhibits a transition in dominant species abundance: from *M. hiantina* in the lower portions of the midden, to *T. granosa* in the younger, upper extent of the deposit.

<table>
<tr><th>Site</th><th>Sample code</th><th>Material</th><th>Depth (cm. below surface)</th><th>Age (uncalibrated)</th><th>Calibrated Age</th></tr>
<tr><td rowspan="2">Idayu</td><td>Wk-1619</td><td>T. granosa</td><td>45 – 50 (Spit 10)</td><td>2010 ± 50</td><td>1354 - 1657</td></tr>
<tr><td>Wk-1618</td><td>T. granosa</td><td>60 – 65 (Spit 13)</td><td>2090 ± 50</td><td>1439 - 1760</td></tr>
<tr><td rowspan="2">Goala</td><td>Wk-3675</td><td>M. hiantina</td><td>Surface</td><td>1170 ± 50</td><td>551 - 776</td></tr>
<tr><td>Wk-1621</td><td>M. hiantina</td><td>90 – 95 (Spit 19)</td><td>2090 ± 50</td><td>1439 - 1760</td></tr>
<tr><td rowspan="2">Wundadjingangnari</td><td>Wk-3676</td><td>T. granosa</td><td>Surface</td><td>640 ± 50</td><td>1 - 30 (3%)
40 - 330 (97%)</td></tr>
<tr><td>Wk-1620</td><td>T. granosa</td><td>90 – 95 (Spit 19)</td><td>3130 ± 50</td><td>2726 - 2991</td></tr>
</table>

Table 6.1 - Radiocarbon ages generated of three Mitchell Plateau middens excavated prior to this study by Veitch (1999a). Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years applied on marine shell (Alan Hogg, pers. comm. 2014), and presented at 2σ confidence.

In discussing this shift in species dominance, Veitch eschews large scale causes for a more local interpretation. He argues that the fact that Goala and Wundadjingangnari did not exhibit a switch in species dominance suggests that large scale drivers of ecological transformation, such as climate change, could not be attributed as a cause to the species shifts seen at Idayu. Rather, he suggests a more localised cause, specifically “changes in local sedimentary mechanics of the Crystal Creek area” (Veitch 1999a: 150). Veitch does not elaborate on this hypothesis.

Species transitions in northern Australian middens have been previously identified. Through the early to mid-Holocene, mangrove and rocky shore species dominated midden deposits prior to the proliferation of *M. hiantina* and *T. granosa* sites (e.g. Schrire 1982, Kendrick and Morse, 1982, Woodroffe *et al*. 1985, O'Connor 1999, Przywolnik 2005). Transitions in individual sites have also been observed, with middens of the mangrove gastropod *Terebralia palustris* underlying culturally-deposited *T. granosa* units across the northern Western Australian coast (e.g. Bowdler 1990a and 1990b, Lorblanchet 1992, Clune and Harrison 2009: 71). The rise and proliferation of mangrove gastropod dominated midden sites (e.g. Cribb 1986, Woodroffe *et al.* 1988, Przywolnik 2005, Clune and Harrison 2009) is attributed to the stabilisation of sea levels and a more humid climate, facilitating mangrove propagation which supported populations of these molluscs (Jennings 1975, Semeniuk 1982, Woodroffe *et al*. 1985). This was followed by a substantial reduction or loss of mangrove environments, as climatic variability tending towards increasing aridity could not support extensive mangrove stands and the faunal communities associated with this ecology (Chappell and Grindrod 1984, Woodroffe *et al* 1985, Shulmeister 1999: 86). Midden deposits across northern Australia reflect this shift, as *M. hiantina* and *T. granosa*-dominated sites began to characterise the coastal archaeological record (e.g. Bailey 1977, Bourke 2012, Faulkner 2013, Cochrane 2014).

Despite the isolation and impact of these large-scale environmental changes, late Holocene shifts in shell midden composition are relatively rare. Typically midden deposits dating to this period in northern Australia are dominated by a single species with relatively minor contributions from other taxa, so why does Idayu deviate from this norm? Idayu follows the same chronological pattern of midden formation that typifies midden deposits in northern Australia. This interpretation, however, is based on only a broad chronological framework of five radiocarbon ages. Whether or not these few ages are enough to properly bracket the more subtle patterns of midden formation remains inconclusive.

To adequately answer this question, a strong understanding of the formation processes of the Idayu midden deposit is required. Having a firm grasp on the timing and relative rates of deposition over the course of the site's history is critical prior to tackling broader issues relating to shell middens in northern Australia. The Brremangurey rockshelter midden, despite initially fitting the mould of the typical tropical Australian Holocene midden, revealed complex patterns of formation and transformation that obscured a much older date of initiation than first identified. Similarly, significant post-depositional movement of midden material both time-averaged temporally distinct units and vertically displaced midden shell. Considering that rockshelters are thought to be more protected and less susceptible to post-depositional alteration compared to open sites (Ulm 2013: 10-12), has the open Idayu deposit been affected and to what extent?

In this study, using the same methods as applied to the Brremangurey midden previously, patterns of deposition and the effects of post-depositional transformation at Idayu will be investigated using an aminostratigraphic approach. This method allows a robust relative chronology of midden material throughout the deposit to be established through the incorporation of a far greater number of samples than would be possible using conventional methodologies such as radiocarbon dating. With the aminostratigraphy of the Idayu midden identified, similarities and differences in the depositional patterning observed at the nearby Brremangurey rockshelter will be discussed. This comparison between two Mitchell Plateau middens will allow the beginnings of a regional discussion of shellfish gathering and deposition to commence. Possible implications and further questions regarding shell middens and late Holocene shellfish gathering across the broader context of top end Australia will also be discussed.

Background to Site and Sample

Idayu, a series of open shell middens, is located 1.5 km north of Crystal Creek, and approximately 250 m from the present day coastline of the Admiralty Gulf (Figure 6.1). A number of oval shaped shell mounds overlie a storm-deposited beach ridge of washed sands, corals, pumice and fragmented shell (Veitch 1999a). This beach ridge is found on the landward side of a mangrove forest, with extensive intertidal mudflats on the seaward extent of the forest. A detailed report of the surrounding area and the, including the results of species quantification is presented by Veitch (1999a: 133-137).

Of the shell mounds found at Idayu, two were excavated 1988, and only the excavated material from 'Mound 1' was retained for analysis and eventual publication (Veitch 1996, 1999a, 1999b). Excavation of 'Mound 1' revealed approximately 80 cm of culturally deposited shell overlying natural beach sand and coral grit. The uppermost extent of the mound, from the surface down to approximately 50 cm, is dominated by *T. granosa* while the lower 30 cm is dominated by *M. hiantina* (Veitch 1999a: 139). Other molluscs including *Terebralia palustris*, *Telescopium telescopium* and *Nerita* spp. were also found in much smaller abundances, as well as associated marine fauna such as the mud crab *Scylla serrata*.

An adapted stratigraphic drawing of the Idayu excavations is presented in Figure 6.2. Summarising Veitch (1999a: 139-140), apart from the transition between mollusc species dominance, compositionally there is little evidence of stratification of distinction between individual units in the Idayu deposit. A colour change was identified across four broad horizons through the deposit.

1. A dark grey unit extends from the surface of the deposit to approximately 23 cm below, characterised by abundant *T. granosa* and charcoal.
2. Underneath this, a lighter white/grey unit. Calcium carbonate fragments were found in association with, as well as attached to shells.
3. The unit immediately underlying the unit described above is very similar in colour, and also contains numerous fragments of calcium carbonate. The distinction that separates this unit form the one above is increasing abundances of *M. hiantina*. This unit extends to approximately 55 cm below surface.

4. A darker unit than the previous two, but slightly lighter than the upper-most unit extends down to approximately 85cm below the surface where the contact between midden and sterile beach ridge layer is reached.

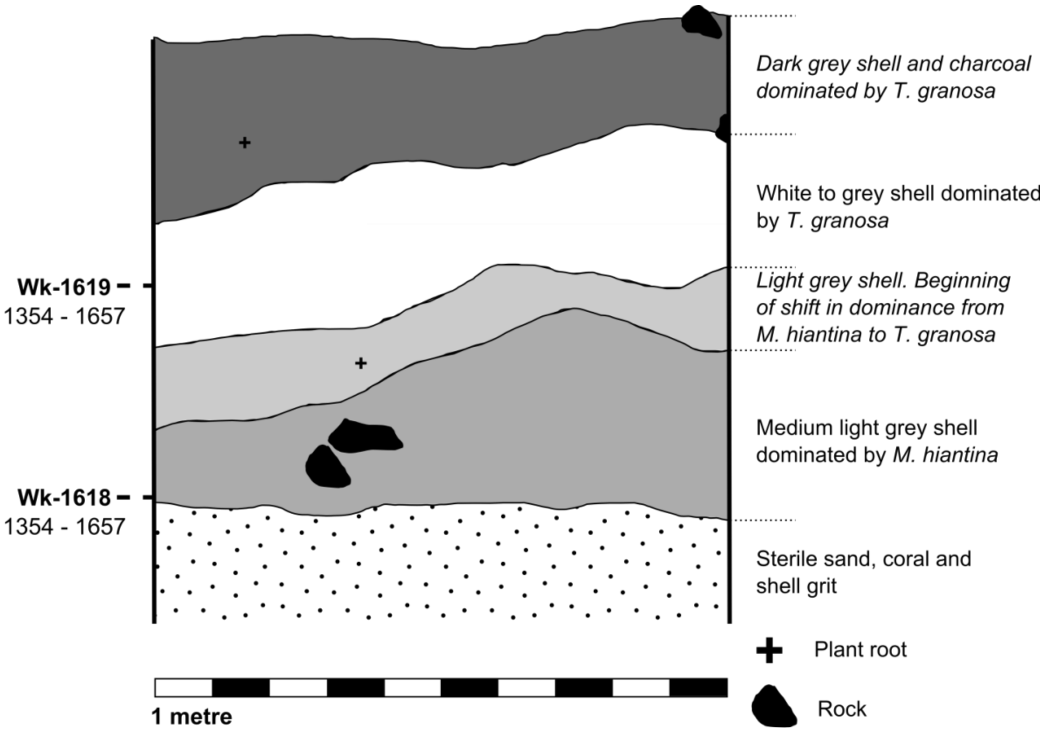
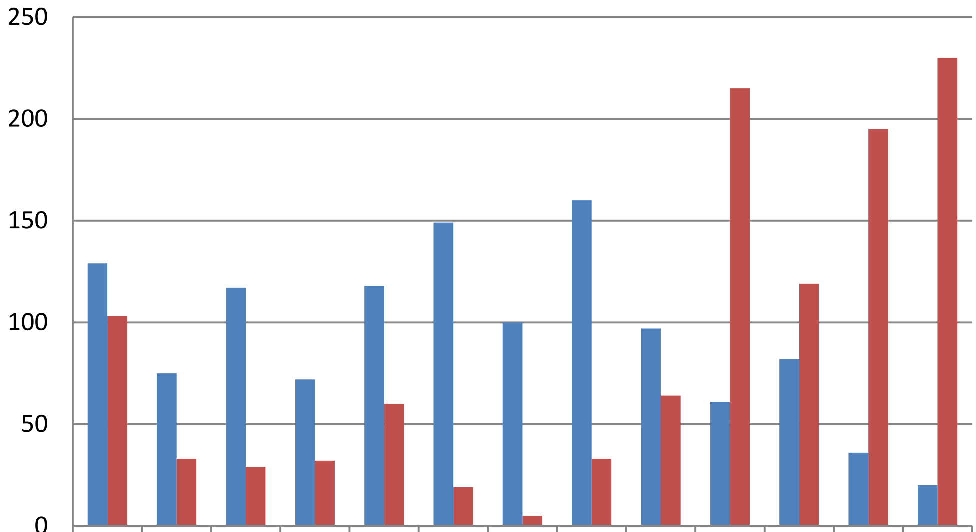


Figure 6.2 - North face of Mound 1 of the Idayu shell middens. Ages on the left are aligned with the approximate depth form which *T. granosa* valves were sampled for radiocarbon dating, seen in Table 6.1. Figure adapted from Veitch 1999a: 141).

Upon inspecting the midden material from Idayu, Veitch noticed that no difference in cultural content, aside from the shift in species dominance, could be detected. The change in colour was attributed to the presence and relative abundance of charcoal and ash interacting with percolating water, as well as sediments becoming stained by precipitated carbonates (Veitch 1999a: 142).

During the excavations conducted by Veitch, a 10 x 10 cm section of each excavation unit was retained as a bulk sample. This sub-sample was reanalysed by the author to provide the quantification data absent from Veitch's subsequent publications centred on the Idayu material. The results of this reanalysis corroborate Veitch's findings in that a species dominance change from *M. hiantina* to *T. granosa* at the interface of spits 9 and 10 (Figure 6.3 below).



	1	2	3	4	5	6	7	8	9	10	11	12	13
T. granosa (MNI)	129	75	117	72	118	149	100	160	97	61	82	36	20
M. hiantina (MNI)	103	33	29	32	60	19	5	33	64	215	119	195	230

Figure 6.3 - MNI counts of *T. granosa* and *M. hiantina* throughout Mound 1 of the Idayu shell middens. Data generated from the reanalysis of Veitch's excavated material from Idayu by Koppel.

Chronology

As part of the initial analysis of the Idayu midden material, Veitch sampled two valves of *T. granosa* for conventional radiocarbon dating – one from the basal level of the cultural deposits at 60-65 cm below surface (Wk-1619), and another from the spit where the transition from *M. hiantina* to *T. granosa* occurs at 50-55 cm below surface (Wk-1618). Both samples produced very similar results (Table 6.1), and when calibrated to 2σ confidence, exhibit nearly identical ages of approximately 1500 years BP with Wk-1618 being the marginally younger of the two.

A further three valves were sampled for AMS radiocarbon dating. Samples OZQ-193 and OZQ-194 are both *T. granosa* valves sampled from 10-15 cm below surface and 50-55cm below surface respectively. One valve of *M. hiantina,* Wk-42635, was also sampled from 15-20 cm below surface. All three specimens were subsampled from a whole valve of each of the species. The remainder of the valves were incorporated into the AAR dating program, presented below, to provide a numerical age by which to anchor the relative ages AAR analyses generates.

Specimens OZQ-193 and Wk-42635 resulted in close to identical ages of 1291 – 1498 and 1295 – 1490 years BP. Considering both specimens were sampled from adjacent excavation units, this result bodes well for interpretations of stratigraphic integrity and minimal post-depositional movement. However, these are two samples of many, and may not necessarily provide an accurate representative sample of the overall population. OZQ-194 provided an age of 1482 – 1710 years BP, which neatly accords with one of Veitch's original ages (Wk-1619) of 1439 – 1760 years BP. To summarise, less than 300 years separates the maximum ages of the youngest and oldest samples analysed from the Idayu midden material.

Sample code	Species	Spit (approximate cm. depth below surface)	Age BP (uncalibrated)	Age BP (calibrated)
OZQ-193*	*T. granosa*	3 (10 – 15)	1900 ± 30	1291 - 1498
Wk-42635*	*M. hiantina*	4 (15 – 20)	1900 ± 20	1295 - 1490
Wk-1619	*T. granosa*	10 (45 – 50)	2010 ± 50	1354 - 1657
OZQ-194*	*T. granosa*	11 (50 – 55)	2085 ± 30	1482 - 1710
Wk-1618	*T. granosa*	13 (60 – 65)	2090 ± 50	1439-1760

Table 6.2 - Compiled radiocarbon ages of shell sampled from Idayu. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years applied on marine shell (Alan Hogg, pers. comm. 2014), and presented at 2σ confidence. Samples marked with an asterisk were sampled by the authors of this study during the reanalysis of the Idayu material. The remaining samples (Wk-1618 and Wk-1619) were sampled and published by Veitch (1999a).

An immediate question that arises is how representative these five radiocarbon age determinations are of the Idayu midden deposit as a whole. The Brremangurey analysis demonstrated that substantial vertical displacement of midden shell in a sheltered midden deposit. It is feasible that equal, if not a greater degree of disturbance has occurred at the open Idayu site – however this is impossible to conclusively determine using only the radiocarbon dating program presented here.

Approach to Investigation

In identifying the formation processes of shell middens and in particular the intensity of deposition of shellfish, a firm understanding of chronology is required. Modern approaches to dating shell middens, however, fall short as the small number of age determinations that are typically utilised in shell midden archaeology are unable to detect anything but the most general of temporal trends (Stein *et al.* 2003). Recent studies have highlighted the effectiveness of using AAR, specifically the aminostratigraphy of shell middens, in collaboration with the more conventionally utilised technique of radiocarbon dating (Koppel *et al*. 2016 and 2017). This method allows a large number of samples to be analysed utilising AAR, the relative ages of which are then anchored with the precision of numerical radiocarbon dating. The result is a much stronger understanding of the finer, more detailed patterns of shellfish deposition. The same aminostratigraphic approach to shell midden analysis, as used by Koppel *et al.* (2016 and 2017) and the methods employed therein is used in this study.

This study aims to:

1) Establish the aminostratigraphy of the Idayu midden deposit to isolate a robust relative chronological framework of the midden as a whole
2) Compare the patterns of deposition with those identified at Brremangurey to determine if similarities or differences can be teased identified
3) Discuss whether these patterns can potentially contribute to interpretations regarding late-Holocene species transitions in Mitchell Plateau middens

Methods

Sampling methodologies

To appropriately establish the aminostratigraphy of the Idayu midden deposit, specimens of both *A. granosa* and *M. hiantina* were sampled evenly from all excavation units. In total, 52 valves were selected. From each of the 13 Spits, two valves each of *T. granosa* and *M. hiantina* were selected. Only shells presenting no visual evidence of burning or other taphonomic alteration were chosen for this study. Where possible, only left valves were chosen to avoid the possibility of analysing both valves of the same animal. As mentioned before, the valves of *T. granosa* and *M. hiantina* that were previously utilised for radiocarbon dating (OZQ-193, OZQ-194 and Wk-42635) were also incorporated to provide a paired radiocarbon age to the D/L values generated.

Sample preparation

Sample preparation was conducted as per Lachlan (2011: 345-347). To summarise, shell samples were initially cleaned of adhering sediments using a soft-bristled brush and clean water, followed by repeated sonications in ultrapure Millipore water. To minimise the potential for contaminants adversely affecting results, the outer- and inner-most surfaces of each valve were also lightly abraded using a rotary drill, which was followed by an acid etch using 2M hydrochloric acid (HCl). Each valve was then subsampled through the removal of a small fragment of shell located near the umbo. A detailed description of the methods used in the AAR analysis is presented in Chapter 4.

Results

Of the 52 specimens selected for analysis, all provided usable results as presented in Tables 3 and 4. Eight samples of *M. hiantina* underwent incomplete injections in the RP-HPLC and could not be properly analysed, however because individual specimens were run in duplicates, one successful amino acid ratio determination per specimen was still possible. Samples of inter-laboratory controls

Tegillarca granosa							
Lab code (UWGA)	**Spit**	**D/L Asx**	**Sample variance**	**D/L Glx**	**Sample variance**	**Radiocarbon lab code**	**Radiocarbon age (cal. BP)**
10578	1	0.55	± 0.016	0.318	0		
10579	1	0.4645	± 0.0045	0.2735	± 0.0005		
10580	2	0.519	-	0.312	-		
10581	2	0.539	-	0.284	-		
10582	3	0.518	-	0.263	-		
10583	3	0.4945	± 0.0015	0.2495	± 0.0055	OZQ-193	1291 - 1498
10584	4	0.5275	± 0.0005	0.2925	± 0.0005		
10585	4	0.5275	± 0.0005	0.3095	± 0.0005		
10586	5	0.5335	± 0.0025	0.3075	± 0.0025		
10587	5	0.5115	± 0.0005	0.2995	± 0.0055		
10588	6	0.5485	± 0.0015	0.33	± 0.004		
10589	6	0.6925	± 0.0035	0.5355	± 0.0035		
10590	7	0.5215	± 0.0055	0.7755	± 0.0035		
10591	7	0.5485	± 0.0005	0.3135	± 0.0005		
10592	8	0.554	-	0.282	-		
10593	8	0.5565	± 0.0035	0.2845	± 0.0035		
10594	9	0.5265	± 0.0015	0.307	± 0.001		
10595	9	0.5555	± 0.0015	0.282	± 0.001		
10596	10	0.5975	± 0.0035	0.3295	± 0.0005		
10597	10	0.518	± 0.002	0.271	± 0.001		
10598	11	0.5575	± 0.0125	0.26	± 0.001		
10599	11	0.5795	± 0.0005	0.296	± 0.002	OZQ-194	1482 - 1710
10700	12	0.615	-	0.291	-		
10701	12	0.553	± 0.02	0.3035	± 0.0075		
10702	13	0.6055	± 0.0015	0.3405	± 0.0035		
10703	13	0.549	± 0.001	0.5315	± 0.2485		

Table 6.3 - Results of the AAR analysis of *T. granosa* sampled form the Idayu midden material. Each sample was run in duplicate and averaged. UWGA lab code issued by the Amino Acid Racemisation Laboratory at the University of Wollongong. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years applied on marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

Marcia hiantina							
Lab code (UWGA)	**Spit**	**D/L Asx**	**Sample variance**	**D/L Glx**	**Sample variance**	**Radiocarbon lab code**	**Radiocarbon age (cal. BP)**
10552	1	0.492	± 0.003	0.253	± 0.007		
10553	1	0.306	± 0.014	0.708	± 0.004		
10554	2	0.495	-	0.287	-		
10555	2	0.5365	± 0.0005	0.2865	± 0.0075		
10556	3	0.51	-	0.253	-		
10557	3	0.4985	± 0.0005	0.277	± 0		
10558	4	0.527	0	0.229	± 0.003		
10559	4	0.5245	± 0.0005	0.2735	± 0.0015	Wk-42635	1295 - 1490
10560	5	0.497	-	0.271	-		
10561	5	0.525	0	0.3	± 0.007		
10562	6	0.508	-	0.259	-		
10563	6	0.5025	± 0.0015	0.273	± 0		
10564	7	0.526	-	0.262	-		
10565	7	0.523	± 0.001	0.29	± 0.005		
10566	8	0.5245	± 0.0005	0.303	± 0.003		
10567	8	0.5575	± 0.0005	0.3	± 0		
10568	9	0.5215	± 0.0015	0.2915	± 0.0005		
10569	9	0.512	0	0.261	± 0.001		
10570	10	0.539	-	0.292	-		
10571	10	0.516	-	0.287	-		
10572	11	0.4955	± 0.0005	0.2825	± 0.0025		
10573	11	0.685	± 0.002	0.4775	± 0.0015		
10574	12	0.502	-	0.257	-		
10575	12	0.5415	± 0.0035	0.2925	± 0.0025		
10576	13	0.528	0	0.2865	± 0.0005		
10577	13	0.526	± 0.005	0.3065	± 0.015		

Table 6.4 - Results of the AAR analysis of *M. hiantina* sampled form the Idayu midden material. Each sample was run in duplicate and averaged. UWGA lab code issued by the Amino Acid Racemisation Laboratory at the University of Wollongong. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years applied on marine shell (Alan Hogg, pers. comm. 2014), and presented at 2δ confidence.

analysed as part of the archaeological specimens presented results within acceptable margins of error. Only the results of aspartic acid (Asx) and glutamic acid (Glx) are presented here[1]. Asx was selected because of its rapid rates of racemisation which facilitates a good balance between a high resolution of results and time-depth of relative ages to be assessed. In contrast, despite presenting a relatively slow rate of racemisation, Glx exhibits a strong covariance in D/L values in samples free from taphonomic influence when compared with Asx. Both Asx and Glx, when used in association, allow for taphonomically affected samples to be identified that do not necessarily present visual signs of modification or alteration (Kaufman 2006).

Beginning with the results of *T. granosa*, a strong pattern of clustering is observed with three specimens lying outside of the primary cluster as shown in Figure 6.4. Samples UWGA10703 and UWGA10590 (circled and labelled 'A' in Figure 6.4), lie outside of the primary cluster, principally due to a Glx D/L value in excess of its expected covariance with Asx. It has been suggested that a preferential racemisation of Glx can be induced by exposure high temperatures for a period of time (Brooks *et al.* 1991). Indeed, similar patterns of D/L values in excess of the usually faster racemising Asx in archaeological molluscan shell has been interpreted to be the result of exposure to anthropic heating; potentially a fire or hearth (Demarchi *et al.* 2011: 120, Crisp 2013: 181-182). The third sample removed from the primary cluster, UWGA10589 (labelled 'B' in Figure 6.4) accords with the expected covariance between Asx and Glx, and considering the advanced extent of racemisation demonstrated by a higher D/L value, an older relative age is interpreted for this sample. The remaining 22 samples exhibit similar D/L values, cluster, which in this instance is interpreted as demonstrating largely similar relative ages across the majority of the *T. granosa* specimens sampled in this study.

[1] The use of the abbreviation Asx throughout this thesis refers to the combination of native aspartic acid within a sample, as well as the aspartic acid that is generated as a result of the deamidation of asparagine in the preparation process. This is also the case for Glx, glutamic acid and glutamine (Hill 1965).

The *M. hiantina* dataset, seen in Figure 6.5, shows similar patterns of D/L values as those observed in the results of *T. granosa*. Sample UWGA10553 (labelled 'A' in Figure 6.5) shows a D/L value of Glx much higher compared to the same sample's Asx value, as before, implying the influence of some degree of anthropic heating. Another sample, UWGA10573 (labelled 'B' in Figure 6.5), exhibits an advanced extent of racemisation for both Asx and Glx consistent with a relatively older sample andnot an artificially racemised specimen - one influenced by fire for example.

The remaining 24 specimens of *M. hiantina* cluster across a much smaller range than is observed in the *T. granosa* results of Figure 6.4. The range Asx values from, least to most racemised, across the cluster of *M. hiantina* specimens is 0.0655, whereas the range of Asx D/L values spanned by the cluster of *T. granosa* being 0.1505. Assuming that D/L values correlate directly with the progress of time, this represents an almost uniform extent of racemisation and therefore almost identically aged shells.

It should be noted that even though the clusters defined in Figures 6.2 and 6.3 broadly occupy the same position on the scatterplot with regards to D/L values of each amino acid, the results of each species cannot be directly compared. Variation in the racemisation kinetics of each amino acid varies between species (Kaufman 2006). In an independent analysis, the patterns of racemisation of both Asx and Glx across both species of shell utilised in this study were assayed by placing powdered specimens of each species of shell in an oven at 110˚ C for variable periods of time to artificially induce racemisation. The results of these analyses are presented in Figure 6.6 and 6.7. The results show that Asx and Glx in *T. granosa* do appear to racemise at a slightly faster rate when compared to Asx and Glx derived from *M. hiantina*. So, even though both the D/L values from each species exhibit similar ratios of D to L amino acids in Figures 6.2 and 6.5, the *T. granosa* samples took less time to reach an equivalent extent of racemisation as *M. hiantina*, further reinforcing the interpretation of a younger relative age of the *T. granosa* samples when compared to equivalently racemised *M. hiantina* specimens.

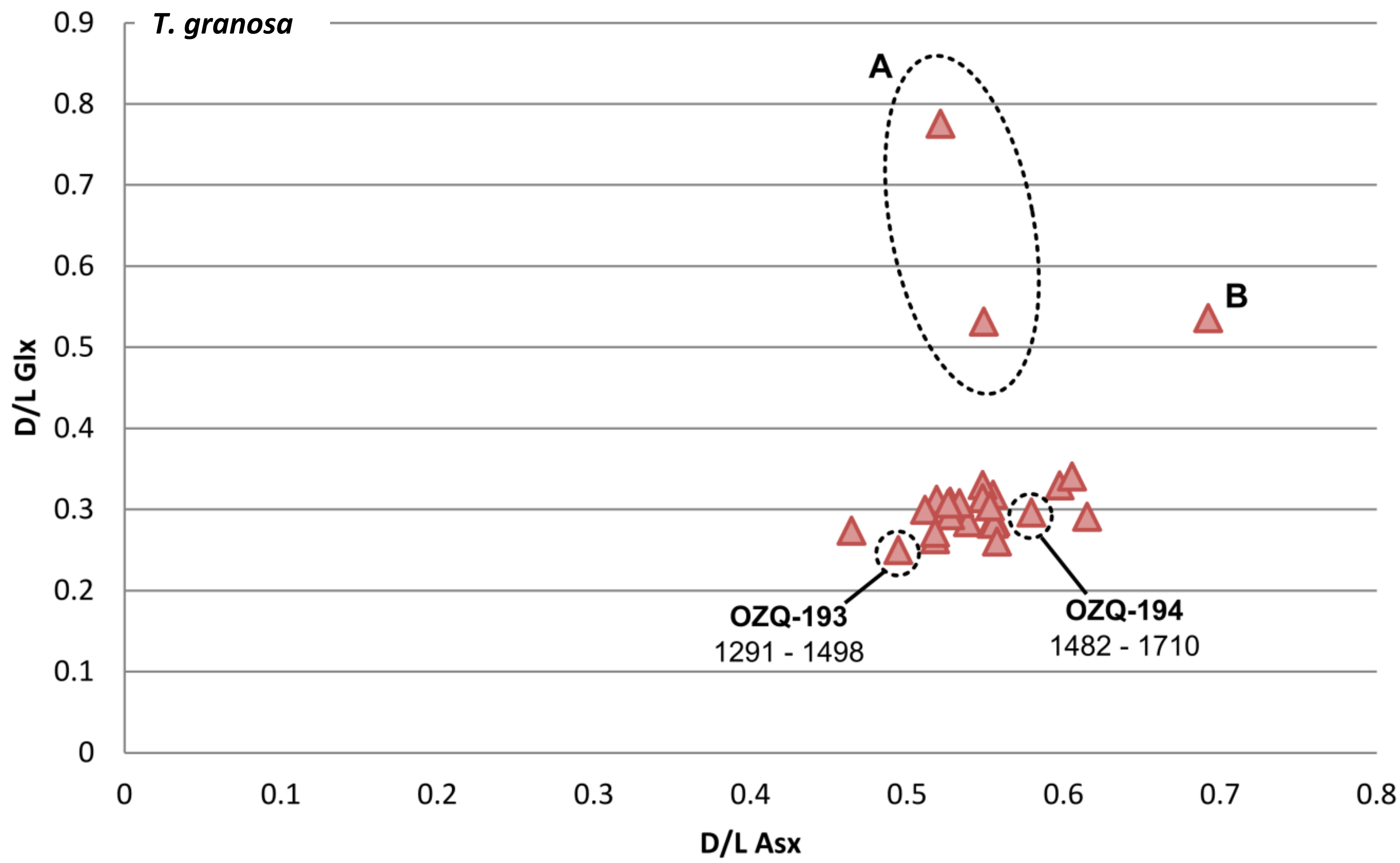


Figure 6.4 - Bivariate plot combining D/L ratios of both aspartic (x-axis) and glutamic acid (y-axis) for each sample of *T. granosa* analysed in this study. Each marker represents one shell specimen.

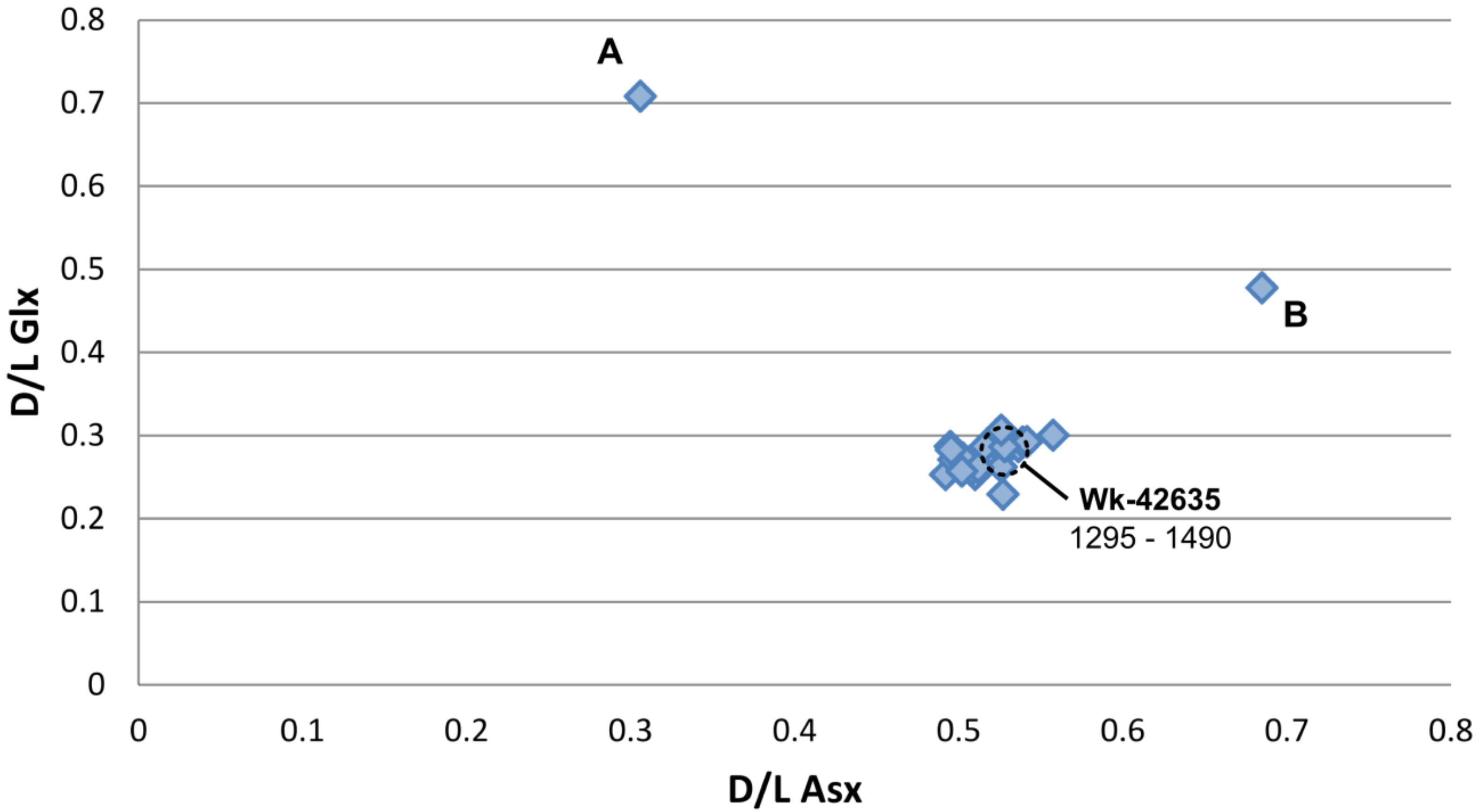


Figure 6.5 - Bivariate plot combining D/L ratios of both aspartic (x-axis) and glutamic acid (y-axis) for each sample of *M. hiantina* analysed in this study. Each marker represents one shell specimen.

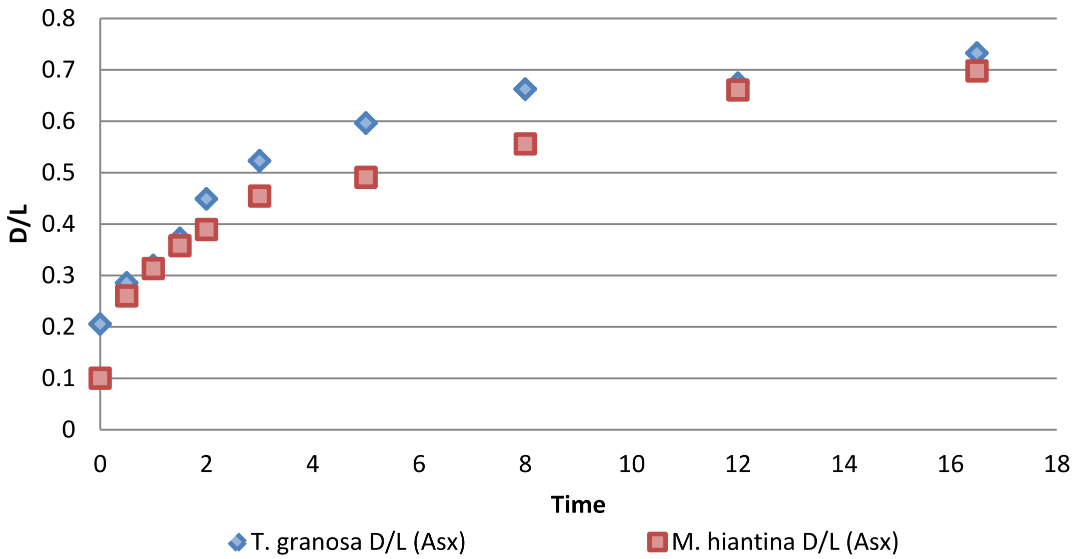


Figure 6.6 - Results of the heating experiments isolating the racemisation kinetics of Aspartic acid (Asx) derived from *T. granosa* and *M. hiantina*. Note that the D/L values of *T. granosa* are consistently higher than *M. hiantina* implying faster rates of racemisation.

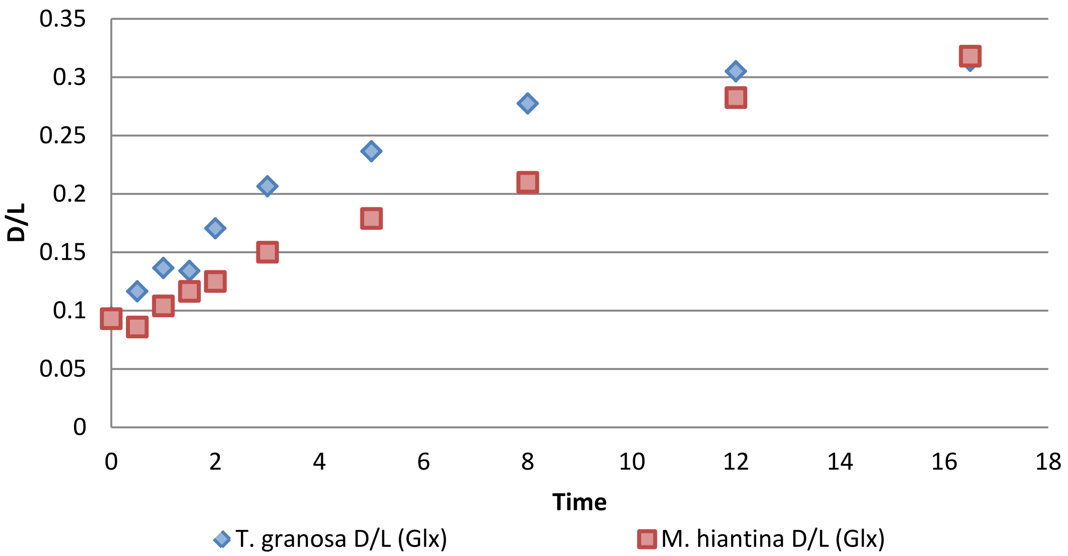


Figure 6.7 - Results of the heating experiments isolating the racemisation kinetics of Glutamic acid (Glx) derived from *T. granosa* and *M. hiantina*. Note that the D/L values of *T. granosa* are consistently higher than *M. hiantina* implying faster rates of racemisation.

Discussion

In building interpretations centred on the formation processes of the Idayu midden, both the AAR and radiocarbon analyses suggest the rapid accumulation of midden shell with two distinct episodes of deposition. The results of the aminostratigraphy of the Idayu midden deposit show strong patterns of clustering for both *T. granosa* and *M. hiantina*, seen in Figures 3 and 4. The comparable extent of racemisation across specimens from each species implies a similar relative age, which is reinforced by the radiocarbon analysis presented in Table 6.1 – the ranges in calibrated ages overlap for all the dated specimens.

An issue that now becomes apparent is whether the clusters of *T. granosa* and *M. hiantina* identified in Figures 2 and 3 represent individual depositional events in their own right. If the Idayu shell mound was formed by two distinct and discrete depositional episodes – firstly *M. hiantina* and followed by *T. granosa* – the transition from one species' dominance with regards to abundance is deceptive. Post-depositional movement and infiltration of the younger *T. granosa* shell into the relatively older *M. hiantina* creates a time-averaged lens between the two units resulting in the illusion of a transition between species as opposed to a distinct and immediate switch from one species' dominance to the other.

Conclusively resolving these two distinct depositional episodes at Idayu using the AAR data, however, is problematic. As described previously, despite the results of each species' analysis exhibiting very comparable extents of racemisation, intraspecies variation in rates of racemisation are an acknowledged occurrence (Kaufman 2006), so both datasets are not directly comparable. Furthering this, the potential exists that AAR on its own lacks the resolution to differentiate between temporally distinct depositional episodes, especially in analysing samples from the relatively recent past of the late Holocene. Temperature is a critical variable in the racemisation reaction, with warmer environments resulting in increased rates of racemisation, with the opposite occurring in cooler temperatures (Schroeder and Bada 1976). Previous studies focussed on the study of shell midden aminostratigraphy along the Admiralty Gulf were successful in isolating distinct depositional episodes in middens dating to the late Holocene (Koppel *et al.* 2016 and 2017). This implies that the temperature of the northern Kimberley is warm enough to facilitate a relatively high degree of resolution in D/L determinations, and therefore a higher degree of precision.

In considering the results of the radiocarbon dating program (Table 6.2), the overlapping age ranges of shell sampled form throughout the entire extent of the midden deposit, a similar issue of resolution in dating results is encountered as with AAR: that even AMS radiocarbon dating lacks the resolution to differentiate distinct depositional episodes of the Idayu midden. Despite this, the results of both radiocarbon dating and AAR point to the interpretation that the deposition of both *T. granosa* and *M. hiantina* occurred over a short period of time.

The transition from one species dominance to another is well noted for certain taxa in Holocene midden deposits; the transition from mangrove associated *Terebralia* sp. and *Telescopium* sp. to bivalves as a result of mangrove ecosystems decreasing in prominence through the mid Holocene for example (e.g. Schrire 1982, Kendrick and Morse, 1982, Woodroffe *et al*. 1985, O'Connor 1999, Przywolnik 2005, see also Cribb 1986). *M. hiantina* to *T. granosa* dominance shifts in the late Holocene however, is less well acknowledged. The typical late Holocene shell midden from tropical northern Australia is dominated by a single species of softshore bivalve – either *T. granosa* or *M. hiantina* (e.g. Bailey 1977, Veitch 1999, Bourke 2012, Faulkner 2013, Cochrane 2014, Koppel *et al.* 2016, 2017 among others). With a present day focus on the surface surveying of midden deposits with only a relatively few deposits being systematically excavated (e.g. Cochrane 2014: 51), the possibility exists that transitions similar to that observed at Idayu may be present in other similar sites, but remain unrecognised. In northern eastern Queensland, a complex of middens dominated by *M. hiantina* in a region characterised by large middens principally composed of *T. granosa* (Cochrane 2014). Cochrane raises the point that "future hypotheses must be able to accommodate the fact that, at least at some times and places, a different species was the focus of foraging activity" (Cochrane 2014: 51).

The idea of changing foraging patterns is an interesting point. In his interpretations of the transition at Idayu, Veitch rules out the possibility of a change in foraging strategies by the people inhabiting Idayu (Veitch 1999a: 149), going on to state that both *T. granosa* and *M. hiantina* inhabit similar ecosystems – the marine intertidal. This is perhaps a generalisation by Veitch, as while both bivalve species do inhabit the marine intertidal, both thrive in completely different environments. *T. granosa* favours fine muds that commonly, but not exclusively, accumulate on the seaward margin of mangrove stands whereas *M. hiantina* favours coarser sandier sediments with little to no apparent overlap between the two ecologies (Broom 1982 and 1983, Meehan 1982: 83, Narasimhim 1985, Davenport and Wong 1986, Tiensongrusmee and Pontjoprawiro 1988). Despite recognising the different ecological conditions both species present at Idayu inhabit, as well as mentioning changing sediment mechanics of a nearby river (Veitch 1999a: 150), Veitch does not progress the discussion of changing local shoreline environments any further.

While an ecological change altering the littoral environment could result in a species turnover, how could this be detected using the midden shell? Large scale environmental changes such as climate change, shifts in precipitation regimes and varying degrees of freshwater input from fluvial contexts would result in a change in the geochemical signature of the marine environment. Geochemical analysis of shell, particularly stable oxygen isotope analysis, is increasing in popularity in Australian archaeological research (e.g. Brockwell *et al.* 2013, Twaddle *et al*. 2016), and has been used to detect changes in ecological characteristics through time. However, within the context of the Admiralty Gulf, this approach would not necessarily work. As both *T. granosa* and *M. hiantina* colonise different habitats, isotopic signatures will reflect those environments. Hence, *T. granosa* will present an estuarine, potentially brackish isotopic signature, purely because this is the type of environment in which *T. granosa* is able to populate. The same applies for *M. hiantina.* In short, different isotopic signatures for the two species could either represent foraging in different habitats or a species turnover in the same locale. Long term changes in environmental conditions (e.g. Brockwell *et al*. 2013) cannot be identified as this extent of time depth of the multi-millennial scale required for such an analysis is not represented within the Idayu midden deposit due to the small range in ages detected in the midden material.

If a changing environment at Idayu cannot be categorically determined as a cause for the switch in species dominance at Idayu, human agency should be rethought. While Veitch quickly discards this possibility (Veitch 1999a: 149), an argument can be made for shellfish gathering within multiple locations in different shoreline environments by the people occupying Idayu, who routinely returned to a single site to process their catch. Similar behaviours in indigenous groups favouring the use of home bases in their hunter-gatherer foraging strategies has been described in the Inuit of north-central Alaska (Binford 1980), and Kiribati (Bird 1997, Thomas 2002) . The use of home bases or dinnertime camps has been described by Meehan researching the subsistence strategies and behaviours of the An-Barra people of the central coast of the Northern Territory (Meehan 1982). The An-Barra people who still routinely practiced shellfish gathering were noted to congregate at a specific location near the shell beds they harvested to process and cook the shellfish they collected. This supposition, however, suggests that middens of each *M. hiantina* and *T. granosa* would be spatially separated and adjacent to each species' preferred shoreline type. Once again, the presence of shellfish derived from two quite different environments in the one site requires explanation. Perhaps environments favoured by each shellfish species were rather close to each other. Extant mangrove associated mudflats and shorelines with coarser sediments are common across the Admiralty Gulf, and probably would have been present in the immediate area during midden formation at Idayu feasibly harbouring *M. hiantina* and *T. granosa* near to one another.

A final approach to resolving the source of each species is trace element analysis. This method has been demonstrated to source molluscan shell to specific geographic locations as elemental signatures become imprinted into shell chemistry (e.g. Peacock *et al.* 2007). Once again, this method is not applicable at Idayu, as the different features that contribute to individual elemental signatures, such as local geology, are of too large a scale to differentiate between different beach environments on a stretch of the Admiralty Gulf.

Conclusion

The formation processes of the Brremangurey and Idayu shell middens are largely comparable. Both sites underwent intensive, but episodic deposition of shell in the late Holocene, comprising of principally soft-shore bivalves. The species transition from *M. hiantina* to *T. granosa* sets Idayu apart from the other middens of the Admiralty Gulf. While species shifts in middens have been identified and attributed to large scale causes such as rising sea levels and climatic changes, the transition between these two species in a midden deposit currently lacks an explanation. Geochemical analyses are unsuitable in the specific context of Idayu due to the relatively small range of ages represented by the shell in the deposit and the homogenous geology of the surrounding area. A logistical explanation is a possibility. The targeting of different shoreline environments, but with a common congregation point in the form of a dinnertime or processing camp, warrants consideration - especially considering the precedence for similar behaviours in ethnographic accounts (Binford 1980, Meehan 1982, Bird 1997, Thomas 2002).

Chapter 7 – Temporal Packaging and Australian shell middens: A synthesis of findings and their implications

Introduction

If the discussions of Chapters 1 and 2 have proven anything, it is that shell middens are hard. Compositionally, middens are often porous and poorly consolidated (Stein 1992), and a range of processes, both natural (e.g. Dwyer *et al* 1985, Robins and Robins 2011, Specht 1985, Szabó 2012) and cultural (e.g. Schiffer 1996), freely displace and redistribute midden material throughout a deposit. Coupled with an often complex formation history (e.g. Stein *et al*. 2003), isolating temporal phases in middens at a relatively fine resolution is difficult. The obstacles mean that middens have often been viewed as an irreconcilable mass of depositional episodes (Claassen 1991: 254), and this frequently sees archaeologists turn to excavating shell middens in spits of arbitrary thickness, side-lining the natural stratigraphy that may or may not be detectable during excavation (see also Estevez *et al*. 2013:109, Harris 2014:15). Spit digging is particularly entrenched in Australian excavation practices (Ward *et al*. 2016: 267). This approach to the excavation of a shell midden can homogenise previously temporally distinct depositional units, further exacerbating the palimpsest nature of the archaeological record (Bailey 2007, see also Chapter 1).

Bailey (2007) acknowledges palimpsests as an unavoidable aspect of working with the archaeological record, and discusses two contrasting perspectives as a way of working with palimpsests in archaeological investigation; the microscopic and macroscopic tendencies (Bailey 2007: 216-217). The microscopic tendency uses techniques and methods at the disposal of the archaeologist to help reduce a palimpsest into its constituent parts; in a sense disentangling temporally distinct units that were previously mixed (Bailey 2007: 216). The macroscopic tendency sees the investigator treating a palimpsest as a single unit, being representative of a larger span of time, and allowing processes operating at an overarching temporal span to be detected and engaged with.

Regarding the microscopic tendency, methods are being developed that are capable of isolating depositional events at exceptionally fine resolution, for example, micromorphology of midden deposits (e.g. Villagran *et al*. 2011a, 2011b, Godino *et al*. 2011). Whether or not this method can be applied to all midden deposits, due to the confluence of conditions necessary for the preservation of depositional features at both the deposit and site scale, is debatable. Midden archaeologists outside of these special locations are generally left with the macroscopic perspective alone in interpreting midden data, as are as 'down-the-line' specialists analysing midden material post-excavation.

This thesis has attempted to test and demonstrate the applicability of low cost, high resolution dating using amino acid racemisation (AAR) and Temporal Packaging to resolve these issues refining chronological frameworks of midden deposits. Through a review of findings and a discussion of outcomes and implications, I will assess the viability of Temporal Packaging using AAR as an approach to addressing key issues in midden analysis post-excavation.

Review of findings

Chapter 1 concluded with a series of questions that the research contained in this thesis attempted to answer. These questions addressed the complex nature of shell midden formation and transformation through time, and applied them to the specific cases of the Brremangurey and Idayu middens (Chapter 3). The analyses and results presented in Chapters 4, 5 and 6 have demonstrated that Temporal Packaging, mobilised through an efficient and effective amino acid racemisation (AAR) dating program, is capable of tackling these issues.

1) *Can a shell midden be deconstructed using Temporal Packaging to isolate the formation processes and behavioural patterning of a site?*

Temporal Packaging aimed to present a new way in which the potentially complex formation processes of shell middens could be isolated and described to allow the appropriate temporal scale of investigation and questioning to be defined. As discussed above, a range of processes complicate the analysis of midden deposits, as fine-grained patterns of deposition are lost through the influences of post-depositional processes, and the techniques and methods archaeologists employ in excavating and analysing shell midden deposits. Chapters 4, 5 and 6 all demonstrated that AAR and Temporal Packaging has the capability to isolate these patterns.

Amino acid racemisation and Temporal Packaging, as presented in Chapters 4 and 5, revealed the complex depositional history of the Brremangurey midden deposit and how these depositional patterns changed through time. A phase of relatively low intensity and ephemeral deposition of *T. granosa* initiated midden formation within the rockshelter in the early Holocene. The late Holocene portion of the deposits revealed a very different pattern, as the gathering and deposition of *T. granosa* as well as *M. hiantina* transitioned into a phase of extremely intensive but punctuated depositional phases. This same analytical approach was then applied to shell material previously excavated from the nearby Idayu midden (Chapter 6). The AAR analysis and Temporal Packaging revealed two distinct depositional 'pulses' – each pulse seemingly dominated by a single species and both being deposited between approximately 1,300 and 1,750 years BP (see Table 6.2). The depositional patterning of the Idayu midden contrasted with that of the Brremangurey deposit, with the latter exhibiting a more variable and complex formation history.

The results of this approach provided a more detailed understanding of the depositional patterning of the midden deposits at both Brremangurey and Idayu. These results also provided an opportunity to scale our level of questioning more appropriately to better accord with the evidence now generated.

2) *Can a time-averaged unit be untangled into its constituent parts to facilitate a finer temporal scale of investigation?*

Radiocarbon dates on shell sampled from the lower spits of the Brremangurey midden revealed the presence of a substantially time-averaged layer. A valve of *T. granosa* was dated to 8,152 – 8,334 cal.

BP (Wk-37137), while a valve of *M. hiantina* and a fragment of charcoal from the same spit dated to 2,375 – 2,682 (OZQ-190) and 1,733 – 1,876 (OZQ-187) respectively (see Table 3.4), with all of these dates acting as a prelude to later large-scale depositional episodes. Chapter 5 demonstrated that Temporal Packaging is able to disentangle this time-averaged portion of the midden into at least some of its constituent parts, thus providing additional detail in describing the formation history of the midden deposit. In the case of Brremangurey, this time-averaged layer proved critical, as it represented the transition between starkly contrasting patterns of midden depositional intensities.

3) *Can vertically displaced shell from within a deposit be identified as such, and if so, can temporally comparable material be identified within the rest of the midden assemblage?*

Chapter 4 sought to identify whether the fragments of *M. hiantina* found in sediments underlying the principle midden deposit at Brremangurey were *in situ*, or were rather downwardly displaced through post-depositional movement. These fragments were found in association with sediments dating to the late Pleistocene, and had they been identified as *in situ*, would have carried with them significant cultural and palaeoenvironmental implications. The relative dating program using AAR conclusively determined that they were indeed vertically displaced, and using the Temporal Packages defined using this approach, it was possible to isolate synchronous 'pulses' of shell in the upper portions of the midden.

The results of the AAR dating program, and the application of Temporal Packaging to midden deposits presented in this thesis achieved two overarching aims; 1) the results refined our understanding of the chronology and formation patterns of the Brremangurey and Idayu middens, and 2) generated Temporal Packages which allow the level of further questioning of each deposit to be scaled accordingly with the newly established resolution of depositional patterning. With the results of this new approach, a novel perspective can now be taken on long standing issues in Australian archaeological investigation.

Shellfish gathering in Holocene northern Australia and environmental change

Shellfish gathering through the Holocene in northern Western Australia has largely been characterised into two phases; subsistence gathering focussed on mangrove taxa in the early to mid-Holocene, transitioning to a focus on soft-shore bivalves through the late Holocene (e.g. Beaton 1985, Veitch 1999b, Faulkner 2013 among others). The earliest examples of mangrove-associated taxa being gathered come from Noala Cave, Barrow Island, where a specimen of the mangrove whelk *Terebralia palustris* dating to 10,822 – 12,400 cal. BP was recovered (Manne and Veth 2015: 4). Further excavations in other rockshelter sites on Barrow Island isolated specimens of *T. palustris* and *Telescopium telescopium* dating from the terminal Pleistocene to approximately 8,500 cal. BP (Manne and Veth 2015: 4). Midden deposits dominated by *T. palustris* and *T. telescopium* then proliferated through the early Holocene across the northwestern Australian coast until the mid-Holocene (e.g. Lorblanchet 1977, Vinnicombe 1987, Bradshaw 1995, O'Connor 1999b, see Harrison 2009).

A transition away from mangrove taxa and to soft-shore bivalves then occurred at approximately 4,000 years ago (Clune and Harrison 2009). Prior to the research presented in this thesis, the earliest archaeological evidence for the gathering of *T. granosa* dated to 4,290 ± 70 uncal. BP from Skew Valley on the Burrup Peninsula (Lorblanchet 1977). Similar ages of approximately 3,500 to 4,000 uncalibrated radiocarbon years are reported for other sites in regions south of the Kimberley including the Abydos Plain (Veth and O'Brien 1986, Veitch and Warren 1992), and other sites of the Burrup Peninsula (Bradhsaw 1995, O'Connor 1999b, see also Harrison 2009: 94-96). In the northern Kimberley, the broad geographic region in which Brremangurey is situated, an age of 2,726 – 2,991 cal. BP on an archaeological *T. granosa* was returned at Wundadjingangnari (Veitch 1999a), which, at the time, represented the earliest example of the gathering of *T. granosa* in the northern Kimberley.

Communities of mangrove forests were clearly more widespread in the early Holocene compared to more recent times, and an hypothesis explaining this decline of mangrove abundances, and subsequent decline in mangrove-associated molluscan species being gathered by people, has centred on large scale environmental process. O'Connor (1999b) proposes that a weakening and subsequent northward migration of the tropical monsoon climate cycle resulted in a decrease in size and abundance during the mid-Holocene (O'Connor 1999b: 48). Following the retraction of mangrove communities, gathering of molluscan fauna shifted in focus to *T. granosa* that colonised a vacant ecological niche, or existing populations became accessible (e.g. Allen 1996: 198). O'Connor (1999b) then proposes a northward cline of ages representing the initiation *T. granosa* gathering in north Western Australia in the mid-Holocene.

O'Connor's model does seem to accord with findings presented with an earth sciences perspective. The rise and fall of mangrove forests in the early to mid-Holocene has been documented in river systems in Arnhem Land, Northern Territory (e.g. Woodroffe *et al*. 1985 and 1988, Woodroffe 1995), and there is also evidence for increased forest abundance across the coastline of northern Western Australia (e.g. Jennings 1975). A recent review of Holocene climatic change (Aplin *et al*. 2016: 106-107) summarised paleoclimate research describing a relatively stronger monsoonal regime in northern Australia in the early Holocene (Prentice and Hope 2006, Reeves *et al.* 2013a, 2013b, Shulmeister and Lees 1995) followed by cooler conditions in the mid-Holocene (Gagan *et al*. 2004). At approximately 6,000 cal. BP, with the flooding of the Sahul shelf, water-flow between the Pacific and Indian oceans was re-established coinciding with the mid-Holocene high sea stand. This resulted in a contracting of the Indo-Pacific Warm Pool as sea surface temperatures increased (Aplin *et al*. 2016: 106). As a result of this "the [Inter-Tropical Convergence Zone] appears to have narrowed and moved equatorward, both probably resulting in a weakening of the monsoonal system" (Aplin *et al*. 2016: 106).

Recently, a specimen of *Anadara* (=*Tegillarca*?) sp. has been recovered from within a midden deposit in Hayne's Cave on Barrow Island, with associated midden shell dating to between 9,173 and 8,248 cal. BP (Manne and Veth 2015: 6). This specimen, coupled with the *T. granosa* dated to 8,152 – 8,334 cal. BP from Brremangurey, forces a re-evaluation of O'Connor's (1999b) model. The presence of these specimens in archaeological contexts suggests two main points: 1) populations of *T. granosa* were present in the northernmost parts of the Kimberley at 8,000 years before present, and 2) people were collecting *T. granosa* at this time.

Prelude to 'Intensification'?

Until relatively recently, all of the evidence pointed towards *T. granosa* gathering and shell mound formation being restricted to the late Holocene in northern Australia – largely within the last 3,000 years (e.g. Bailey 1977, Veitch 1999a, Bourke 2004, Barker 2004, Faulkner and Clarke 2004). Beaton (1985: 18), in speaking of the gathering and deposition of *T. granosa* and formation of midden deposits in northern Australia, stated "the late Holocene sites on our coast are not just some tail end of our coastal history, they are *it*". The evidence of early Holocene dated specimens of archaeological *T. granosa* found at Brremangurey (Chapter 3) and Hayne's Cave on Barrow Island (Manne and Veth 2015), suggests that a more complex story.

A distinct shift in subsistence economies in the late Holocene amongst Aboriginal Australian cultures resulted in a sharp increase in importance of soft-shore bivalve gathering, as evidenced by the mass proliferation of shell midden deposits being formed across northern Australia within the last 3,000 years (Barker 2004: 12). It has been argued that growing pressures on Aboriginal groups, such as increasing climatic variability (e.g. Bailey 1993, Veitch 1999b) or population growth (Beaton 1985), forced a reorganisation of the subsistence base of Indigenous Australians towards fast replenishing, highly fecund 'r-selected' species, such as soft-shore bivalves; in particular *T. granosa* and *M. hiantina*. A similar transition in subsistence strategies is also observed in interior Aboriginal cultures with the increasing adoption of seed-grinding technology (e.g. Smith 1986, 1988, 1989, Veth 1989) and the appearance of bifacial point manufacture (Veitch 1996, 1999b: 57) at approximately the same time. This reorganisation of the subsistence resource base towards a focus on resources from lower trophic levels forms part of the 'Intensification' argument; a broad-reaching economic reorganisation hypothesized to have occurred across the Australian continent in the late Holocene (Lourandos 1983, 1985, see also Bourke 2012: 6).

The *T. granosa* and *Anadara* sp. midden shells found at Brremangurey and Barrow Island respectively, both dating to the early Holocene, expand on this story. These findings suggest that soft-shore estuarine bivalves, specifically *T. granosa*, were not unknown to Aboriginal peoples of the northern Kimberley of the early Holocene. *T. granosa* is instead a resource with an antiquity of use spanning over 8,000 years. However, the results from Brremangurey offer further insights. The use of AAR in Chapter 5 isolated the time-averaged layer at the base of the Brremangurey midden, and the application of Temporal Packaging allowed patterns of gathering intensities to be interpreted and contextualised within the discussion of 'Intensification'. The results revealed two distinct Temporal Packages of *T. granosa* that preceded the main depositional episodes of dating to the late Holocene (see Figure 5.1). These earlier Temporal Packages depict a trend of increasing gathering and depositional intensity through time at Brremangurey. With this information, the late Holocene subsistence resource reorganisation, with specific reference to molluscan bivalves, appears less abrupt and can instead be interpreted as increasing intensity of gathering rather than a brand new resource appearing on the landscape.

Of course this interpretation is formed using evidence from one specific site. Whether or not this pattern is reflected at other locations will require the investigation of other sites and the analysis of other midden deposits. The possibility exists that other specimens of archaeological of *T. granosa* gathered and deposited in the early Holocene have formed some component of midden deposits in northern Australia, but if similar stratigraphic patterns of time-averaging to those seen at Brremangurey are also present, identifying these specimens is the issue. Depositional intensities of *T. granosa* is observed to be low at Brremangurey, and if the patterns revealed there are reflected within deposits elsewhere, such palimpsests are unlikely to be isolated using traditional radiocarbon approaches alone. The AAR dating program presented in Chapters 4, 5 and 6 of this thesis presents a new technique that increases to possibility of isolating such deposits, and Temporal Packaging allows a novel way of isolating and interpreting these data.

Types and typologies of shell middens in north Australia

During initial survey and excavations, being able to discern between the two varying modes of midden formation was impossible, as the earlier, low intensity deposition of *T*. *granosa* had become conflated with the younger, denser midden material above. It was only the result of a fortuitous radiocarbon age determination that this time-averaged deposit was detected, and then confirmed and constrained by the AAR dating program presented in this thesis. How do these distinct early and late Holocene types of midden deposits at Brremangurey fit within the scope of Holocene midden deposits in northern Western Australia?

There are very few examples of early, low-intensity marine shell middens in the early Holocene record of northern Western Australia, and all are in rockshelters: Koolan Shelter 2, Haynes Cave and Noala. Koolan Shelter 2 is a rockshelter on an island on the southwest Kimberley coastline. Excavations revealed a sparse shell midden deposit dating to the terminal Pleistocene (O'Connor 1999a: 29-30). Compositionally, the early Holocene component of this midden assemblage is characterised by mangrove and rock platform species including the chiton species *Acanthopleura spinosa*, and the rocky-shore gastropods *Turbo cinereus* and *Nerita undata* (O'Connor 1999a: 39). Midden shell is rather diffuse, with no spit containing more than 260 grams of subsistence shellfish throughout this early portion of the deposit (O'Connor 1999a: 41). Hayne's Cave and Noala are rockshelters located on Barrow Island, an island that forms part of the Montebello island group off the Pilbara coast, south of the Kimberley biogeographic region. Both sites contain midden deposits incorporating molluscan faunal remains that date to approximately 8,500 cal. BP for Hayne's Cave, and from approximately 14,500 cal. BP for the earliest material at Noala (Manne and Veth 2015: 4).

The midden deposit within Hayne's Cave is dominated by mangrove-associated species, such as *Terebralia* sp., *Telescopium* sp., *Anadara* sp., and *T. palustris* which alone represents 77% of the molluscan fauna by MNI (Manne and Veth 2015: 6-7). The midden deposit in Noala is less diverse than Hayne's Cave, but shares a similar suite of mangrove-associated taxa (Manne and Veth 2015:7). Midden density, like Koolan Shelter 2, is low with inferred gathering and deposition rates to be likewise low. Low density 'scatters' of predominantly *T. palustris* and other mangrove-dwelling gastropods have also been dated to the early Holocene at sites along the northern Western Australian coastline (e.g. Lorblanchet 1977, Vinnicombe 1987, Bradshaw 1995, O'Connor 1999b, see also Harrison 2009: 94-95), thereby demonstrating that shell midden deposition was not solely confined to rockshelters.

Clear parallels can be drawn between the well-reported late Pleistocene/early Holocene midden deposits at the above-mentioned rockshelter sites, and the oldest midden material at Brremangurey. Apart from chronological similarities, the densities of midden shell at each site are largely similar as well; a diffuse lens of shell as opposed to an extremely dense masses of shell such as the younger, overlying layers of the Brremangurey midden deposit for example. Species composition presents a slightly more complex comparison. The midden material at Brremangurey conclusively identified to be early Holocene in age is solely *T. granosa*. *Anadara* sp. of this antiquity was found at Hayne's Cave (Manne and Veth 2015: 7), but *Tegillarca/Anadara* was lacking at both Noala and Koolan Shelter 2. Mangrove gastropods, predominantly *T. palustris,* were found at Hayne's Cave, Noala (Manne and Veth 2015: 7) and Koolan Shelter 2 (O'Connor 1999a: 39), however similar taxa of this antiquity has not yet been identified at Brremangurey. Figures 24f and 24g presented in Chapter 3 presents the NISP counts of *T. palustris* and *T. telescopium* respectively, found within the Brremangurey assemblage. Abundances of these two taxa peak at the lower levels of the midden deposit, at the same stratigraphic depth as the 8,200 year old *T. granosa* valve. The AAR analysis has already concluded that midden material at this depth has undergone some degree of time-averaging (Chapter 5), so whether or not the *T. palustris* and *T. telescopium* found at these levels group with the younger, late Holocene midden material or with the older, early Holocene tradition of shellfish gathering and deposition requires further investigation. However, the potential exists that these specimens of mangrove-associated gastropods are indeed contemporary with the ancient *T. granosa* valve and are also representative of a much older shell-gathering tradition at Brremangurey, coinciding with similar patterns of gathering and chronology demonstrated at Hayne's Cave, Noala (Manne and Veth 2015) and Koolan Shelter 2 (O'Connor 1999a).

Where Brremangurey stands alone from these other sites is what occurred in the late Holocene. To date, Brremangurey is the only site so far recorded in northern Western Australia that contains a large, extremely dense shell midden *within a rockshelter* comparable in chronology and composition to the open midden-mound deposits that are so ubiquitous across the rest of the continent's tropical north (e.g. Bailey 1977, Morrison 2003, Bourke 2012, Faulkner 2013). The early phases of the Brremangurey midden can be likened and compared to the previously discussed sites of Barrow and Koolan islands. However, occupation at both Hayne's Cave and Noala is entirely restricted to the early Holocene (Manne and Veth 2015: 4), and while mid- to late Holocene molluscan midden material has been identified at Koolan Shelter 2, the later deposits maintain a similar species representation and density to the older, early Holocene portions (O'Connor 1999a: 39).

In Chapter 2, a discussion of the lack of an effective and systematic typological approach to categorising shell middens in Australia was presented. Terms such as 'scatter', 'midden' and 'mound' are frequently used in describing shell midden deposits in Australia (e.g. Cochrane 2014:48, Bowdler 1983:135, Sullivan 1989:49, Bourke 2000:60), and are at least implicitly wielded in exactly the same manner as a typology (*sensu* Gorodzov 1933: 102, Gifford 1960:341, Trigger 1989:21-22, Read 2007:204). Chapter 2 went on to argue that without thought being given to the formation processes of shell midden deposits, and with few explicit attempts to link observable and unobservable variation in midden deposits to the behavioural causes of these variations, typological terms offer little analytical or interpretive benefit. Put another way, the behavioural differences which generated 'scatters', 'middens' and 'mounds' have never been clearly articulated and the relationship between the three types is likewise unclear in the literature.

Focussing on Brremangurey, and using the standardised approach to classifying midden deposits in Australia (e.g. Cochrane 2014:48, Bowdler 1983:135, Sullivan 1989:49, Bourke 2000:60), two distinct midden types can be discerned; a 'shell scatter' dating to the early Holocene, and a 'shell mound' in the upper, late Holocene portion of the midden. How does the 'shell mound' at Brremangurey then compare with the nearby Idayu 'shell mound' with specific regards to the gathering and depositional behaviours that created each deposit? At the deposit scale, both are compositionally and morphologically comparable, and while the Brremangurey deposit does exhibit a more complex formation history, using the AAR analysis it can be concluded that both sites formed through a similar process; punctuated pulses of intensive shellfish deposition. However, the situational differences between each deposit needs to be incorporated into this discussion. The fact that the Brremangurey midden lies within a rockshelter, whereas Idayu is an open site is potentially critical in contextualising how and why each site was utilised by ancient people. Similarly, the extended occupation and use of Brremangurey through the Holocene compared with the relatively short history of Idayu is a further situational difference between two comparable 'shell mounds' that potentially has significant ramifications in describing ancient human behaviours.

An interesting point that can be made about the Brremangurey midden assemblage is the potential evidence for ritualised middening practices to be identified (e.g. McNiven and Feldman 2003, Milner 2005, McNiven and Wright 2008, McNiven 2004, 2010, Thompson and Pluckhahn 2012, Thompson and Moore 2015). The dense layer of the pearl oyster *Pinctada* c.f. *albina* (see Chapter 3) that was observed to extend across multiple excavation squares clearly outgroups from the rather archetypal subsistence midden material in the layers above and below. This particular species is not associated with subsistence practices of prehistoric north Australian cultures (but see Ulm 2011: 448), and its stratigraphic position in such a discrete layer over a broad area potentially complicates an origin that is exclusively economic. With this in mind it is possible that such a feature of the Brremangurey midden may reflect extra-economic behaviours of the occupants of the rockshelter, however further examination into this is beyond the scope of this thesis, and will be the focus of future research.

The application of AAR and Temporal Packaging at Brremangurey and Idayu has demonstrated that outwardly-similar shell middens can be quite different, and that one 'shell mound' is not necessarily comparable to another 'shell mound'. Current typological structures do not allow us to make this distinction. A strong understanding of the formation processes of shell middens is critical to describing shell midden variation and classifying different forms of midden deposits. While proposing an alternative typology to the scatter/midden/mound approach currently used in Australian archaeological investigation is beyond the scope of this thesis, it has instead demonstrated the potential for AAR and Temporal Packaging to inform on discussions of midden variation and underlying behavioural patterning.

Scalar interpretation and Temporal Packaging

A key aspect of time perspectivism, as discussed by Bailey (1981:103), is "the belief that differing time-scales bring into focus different features of behaviour, requiring different sorts of explanatory principles". Put another way, processes are best investigated and discussed within the appropriate temporal perspective (see also Lucas 2005: 29, Bailey 2007). However, issues arise when we as archaeologists lack the tools and methods to properly isolate and engage with the appropriate temporal scale of the processes we wish to investigate. This is particularly true for shell midden archaeology, where a general reliance on a small number of radiocarbon age determinations to inform on site chronology is the norm (Stein *et al*. 2003). When combined with potentially complex formation processes (e.g. Claassen 1991: 254, Stein 1992, Stein *et al*. 2003) and the suite of complex and variable post-depositional transformation processes that can influence a deposit (e.g. Dwyer *et* *al* 1985, Specht 1985, Schiffer 1996, Rick 2002, Robins and Robins 2011, Szabó 2012), isolating the appropriate temporal scale of investigation with shell middens is problematic.

Recent micromorphological approaches to shell midden excavations and analyses match Bailey's (2007: 216) 'microscopic' approach. Such methods can isolate exceptionally high resolution depositional episodes in midden deposits, to the scale of an individual discard event (e.g. Villagran *et al*. 2011a, 2011b, Godino *et al*. 2011). Micromorphological techniques, however, are reliant on specific environmental conditions to preserve depositional features at this resolution. As well as this, pristine, unexcavated deposits are necessary for the success of this method and it also needs to be factored into initial research designs. In an Australian context, micromorphology has not been widely used. While there is some potential for its application in the future, such a leap in general approaches to excavation in Australia are unlikely to happen in the immediate future. It is also yet to be demonstrated how amenable northern Australian shell middens may be to micromorphological techniques.

As pointed out by Ward *et al.* (2016: 270-271), the Australian inclination to spit-digging means that the onus is on the post-excavation analyst to interpret, and indeed reconstruct, stratigraphic patterning. However, without a method to identify the potentially complex patterns of midden deposition, as per Bailey (2007: 216) questions must be framed at a larger scale to accommodate what are likely conflated deposits. We are therefore left to treat an aggregated deposit as a single mass, rather than its constituent parts which remain inaccessible using standard approaches (see, e.g., Szabó 2009: 187 for an example of how this affects the quantification of molluscan remains, and Ward *et al.* 2016 for the impact on artefact sequences).

Bailey (2007: 216) suggests that, in the case of an unresolved palimpsest, questions and explanations are best targeted at a macroscopic level. This would seem to fit the situation as it is in Australia. However, fine-grained ethnographic, ethnohistorical, and anthropological observations have had a privileged position in archaeological interpretations of shell middens locally. There is a clear scalar lack of fit between the nature of datasets and the explanatory frameworks being applied. Some key examples of explanatory frameworks within northern Australian shell midden archaeology are summarized here.

Meehan's (1982) influential ethnoarchaeological study on the An-Barra people of the Blyth River, central Northern Territory, *Shell Bed to Shell Midden* resulted in an unprecedented description of the subsistence behaviours of the Indigenous people of the area. Over the course of a year, Meehan recorded how and where shellfish were gathered, how shellfish were processed prior to consumption, as well as the relative contribution of shellfish to the overall diet of the An-Barra (Meehan 1982). She also recorded and described, with exceptional detail, how shell remains were discarded at 'dinnertime camps' (e.g. Meehan 1982: 26). Since this ethnoarchaeological study, Meehan's accounts have been routinely incorporated into interpretations of shell midden deposits both in Australia (e.g. McDonald 1992, Nicholson and Cane 1994, Brockwell 2006) as well as in international archaeological midden contexts (e.g. Reitz 1988, Thomas 2002, Mannino and Thomas 2002, Erlandson *et al*. 2009, Marquardt 2010).

As discussed in Chapter 2, the use of ethnographic analogy in interpreting archaeological deposits is not without its complications. As material passes from the ethnographic record to the archaeological record (*sensu* Schiffer 1996), the temporal distinction between individual depositional events are conflated into palimpsests (Bailey 2007: 205). The problems associated with the application of ethnographic analogy as a method of interpreting archaeological data have been widely discussed in the global literature (e.g. Gould and Watson 1982, Wylie 1982, 1985a, 1985b, 1988, 1989, Jochim 1991, Lane 2005).

Another distinct strand of socially-focussed evidence can be found in ethnohistories, and Morrison (2003) incorporates the ethnohistorical observations of Roth (1901) as the catalyst for his interpretation of the formation processes of shell mounds at Weipa, northeast Queensland. Amongst other things, Roth (1901) describes the intermittent ceremonial gathering of Aboriginal

Australians. Morrison (2003) proposes that these sporadic gatherings can be connected to pulses of *T. granosa* abundance in the immediate local environment. He argues that these ceremonial gatherings were deliberately timed to coincide with these explosions in *T. granosa* populations providing the necessary boost to the subsistence resource base to support this periodic increase in occupational intensity (Morrison 2003: 5).

As with the scalar problems in applying ethnographic data to archaeological interpretation through analogy, Morrison's (2003) conclusions are largely untestable. His interpretations centre on the relatively short term cycles of ecologically driven explosions in *T. granosa* abundances, but it is unlikely that events of such a fine temporal resolution would be preserved within shell midden deposits.

A study conducted by Brockwell *et al*. (2013) sought to investigate the intersection between environmental and cultural change across coastal Northern Territory. A total of 28 archaeological valves of *T. granosa* (n=10) and *Dosinia* c.f. *laminata* (n=18) were sampled from excavated midden material at three sites: Hope Inlet, Blyth River and Blue Mud Bay. These valves were assayed using stable oxygen isotope analysis (Brockwell *et al*. 2013: 25). Only four of these valves were directly dated using AMS radiocarbon techniques, while the remaining, undated valves had inferred ages assigned to them using a depth/age model (Brockwell *et al*. 2013: 25-26). These 28 specimens represented an age range of 2,300 – 600 cal. BP. Using the results of the stable oxygen isotope analysis, the authors interpret "a declining summer monsoon rainfall and increasing aridity" from 2,000 to 500 cal. BP at two of the sites (Brockwell *et al.* 2013: 29). The results from the third site were inconclusive as hypothesised fractionation differences between *T. granosa* and *D.* c.f. *laminata* obfuscates a clear environmental interpretation (Brockwell *et al*. 2013: 29).

Although a novel application of isotopic techniques within an Australian context, this study highlights the complications that arise when the scale of interpretation does not accord with the scale of evidence being generated. The authors state that "we currently lack reliable data for distinguishing seasonal fluctuations from millennial scale climate change" (Brockwell *et al*. 2013: 30); these scales are indeed starkly differentiated. The high resolution, yet temporally constrained isotopic data was contextualised within a coarse chronological framework constructed from a minimal number of radiocarbon age determinations and supplemented with a depth/age curve to provide an inferred age for the undated shell specimens in this study. As a result, the higher resolution isotopic records cannot be neatly placed within the overarching interpretation of long-term, large-scale environmental change for which the authors argue using the coarse and somewhat speculative chronology they have established. This case exemplifies Bailey's (2007: 202) point that "different sorts of phenomena are best studied at different time scales". The approach of Brockwell *et al*. (2013) contrasts with that of O'Connor (1999b), whose expansive interpretations of large-scale ecological changes are grounded within an equally broad and coarsely-resolved chronological framework.

It should be stated that all of the methods and approaches described in the previous four case studies, including ethnoarchaeological, ethnohistorical and isotopic data, do have interpretive value, but only when grounded in the appropriate temporal scale of investigation. Herein lies the issue: without a confident handle on the temporal patterning contained within an archaeological deposit, we cannot know if the temporal resolution of analysis appropriately matches the temporal resolution the deposit can sustain. Presently, there is a missing fulcrum in analysing shell midden deposits, as confidently establishing the chronological framework of a deposit is hamstrung by the typical approaches to dating shell middens, heavily relying on a limited number of radiocarbon dates.

Amino acid racemisation and Temporal Packaging can contribute to addressing this issue. This approach offers a step towards establishing the temporal resolution offered by a deposit that is efficient, and effective. With this, investigations can be appropriately scaled, enhancing the meaningfulness of the results as interpretations are grounded in demonstrable chronologies of a known resolution through Temporal Packaging.

Chapter 8 – Rates of accumulation, Temporal Packaging and interpreting the archaeological record

Introduction

Globally, there are relatively few middens studies that have seriously addressed the issue of time-averaging, and as a general rule, they have considered the issue with reference to 'rates of accumulation'. While there are many commonalities with Temporal Packaging as conceptualised in this thesis, there can also be stark differences in assumptions and mobilisation. Before a broader consideration of the similarities and differences between 'rates of accumulation' and Temporal Packaging, I look at two contrasting examples from northern Australia: Koolan Shelter 2 in the Kimberley, northern Western Australia (O'Connor 1999a), and the Kwamter mound in far north Queensland (Bailey 1977).

A discussion on 'rates of accumulation'

Koolan Shelter 2, as introduced in Chapter 7, is a rockshelter on Koolan Island off the west coast of the Kimberley mainland, Western Australia. Within this rockshelter are both Pleistocene and Holocene archaeological deposits (O'Connor 1999a: 29). Two horizons were described (See Figure 8.1), each containing distinctive molluscan faunal remains. The shell within the 'Pleistocene Horizon' "was not only sparse, but consisted of only two species, pearlshell (*Pinctada* sp.) and mangrove clam *Geloina* [=*Polymesoda*] *coaxans"* (O'Connor 1999a: 27). The presence of these shell taxa were interpreted to not be the result of subsistence practices but rather "for use as tools or as value items" (O'Connor 1999a: 27). Overlying this, the Holocene dated 'Shell Horizon' presented higher species diversity, predominantly *Saccostrea* sp., *Acanthopleura spinosa*, *Nerita undata* and *Turbo*

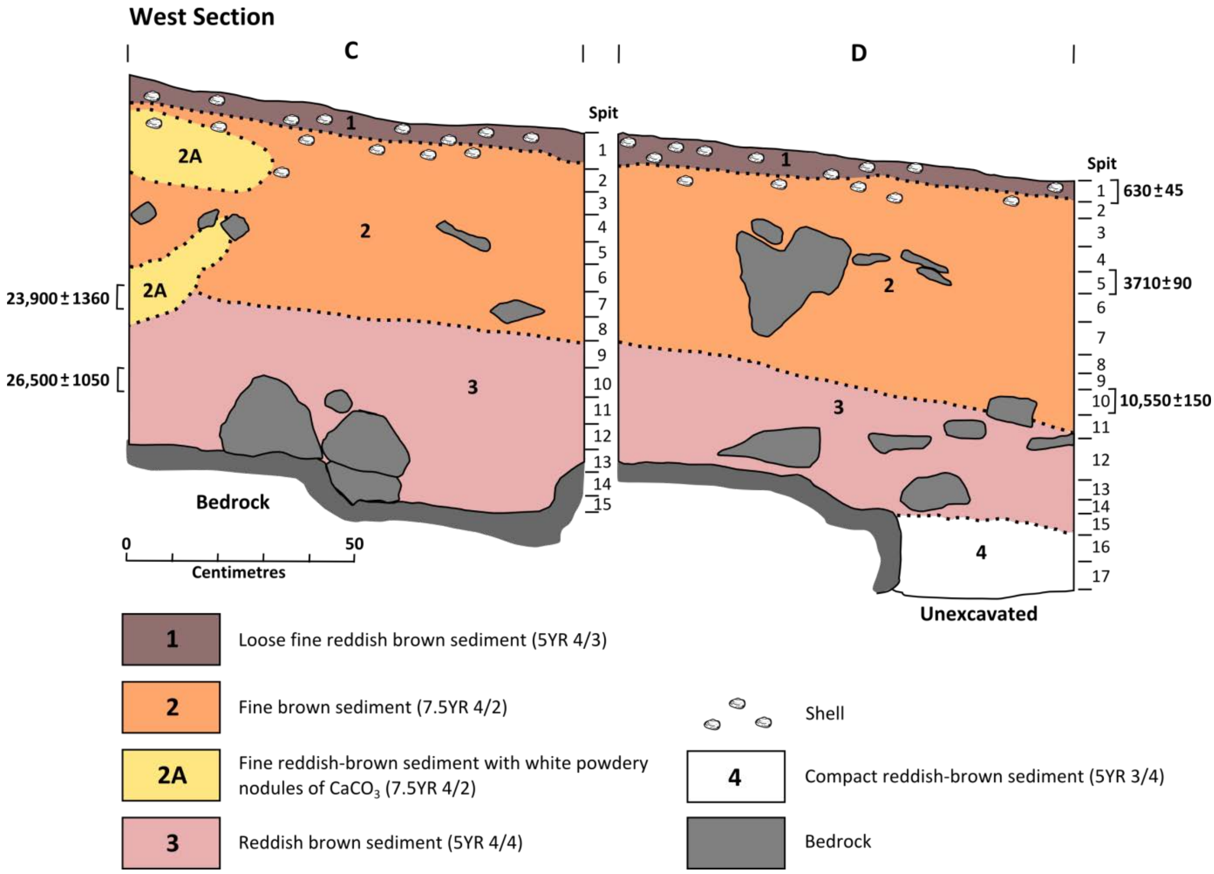


Figure 8.1 - Stratigraphic section of the Koolan Shelter 2 excavations. Figure redrawn after O'Connor (1999a: 27)

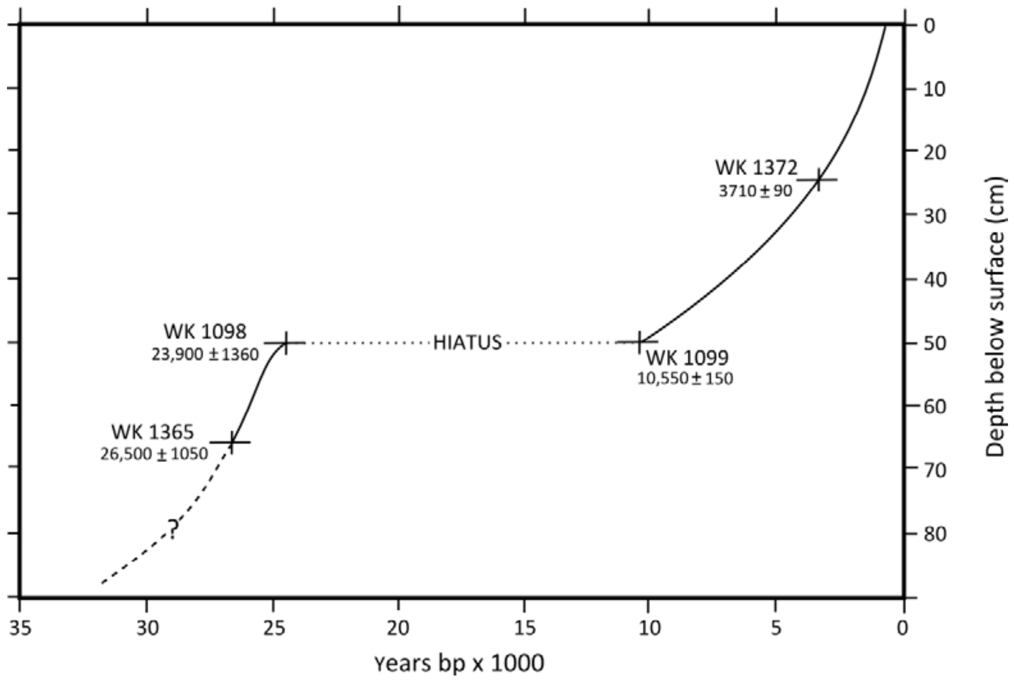


Figure 8.2 – Depth/age curve for Koolan Shelter 2 as calculated by O'Connor (1999a). Figure redrawn from O'Connor (1999a: 32).

cinereus (O'Connor 2009: 39). Small amounts of mangrove-associated taxa, principally *Terebralia palustris,* were identified in the lower portions of this 'Shell Horizon' (O'Connor 1999a: 40).

Focussing on the Holocene dated 'Shell Horizon', parallels can be drawn with the Brremangurey midden deposit. Two ages were generated from this horizon; the first from Spit 10, approximately 48-53 cm below surface, and dating to 10,500 ± 150 years BP, and the second from Spit 5, approximately 22-27 cm below surface, returning an age of 3,710 ± 90 years BP. Both radiocarbon dates were from the same excavation square. Using a simple 'rates of accumulation' model (see Figure 8.2), whereby O'Connor simply connected the two points/dates on depth-time axes, she then argued for the presence of an early Holocene mangrove phase in the lower portions of the Shell Horizon (O'Connor 1999a: 122). Given that the extrapolated chronology for the Shell Horizon at Koolan 2 relied on two radiocarbon dates, there were questions as to whether these accurately represented the surrounding, spatially associated midden material. In other words, does the early Holocene date from the base of the Shell Horizon accurately date spatially-associated shell? Additionally, the presentation of the Koolan Shelter 2 data in the form of a depth/age curve (Figure 8.2) gives the impression of a continuous and regular process of deposition between each known age. It is this appearance of continuity that allows O'Connor (1999a: 122) to speak at some length of early/mid-Holocene mangrove formations existing through until circa 7000 bp, with the assumption deposits dating to this time period are present in her midden with no radiocarbon evidence for such. Further dating, either absolute or relative, would be required to refine this chronology, allowing more reliable assessments of both the relative contributions of temporally distinct midden material and the time periods actually represented.

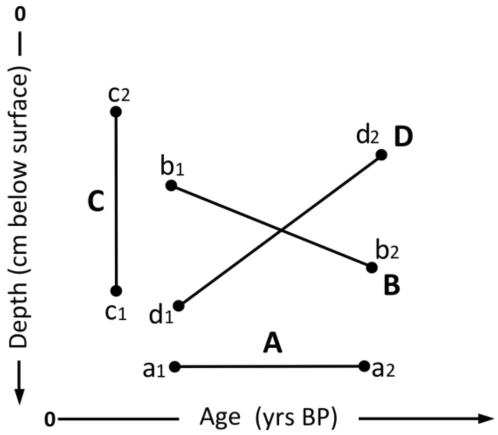
Another north Australian example of the application of rates of accumulation in shell midden archaeology is Bailey's (1977) analysis of a shell mound at Kwamter, south of Weipa, in Cape York, northern Queensland. First excavated by Wright (1963 and 1971), Bailey's re-excavation and analysis pointed towards a more complex midden formation history than preliminary observations had suggested. The mound showed no clear signs of stratigraphy, however taphonomic indicators in the form of a lightening of colour and increased brittleness in the lowest 5-10 cm of the deposit, interpreted “as a function of age” (Bailey 1977: 134), suggested two phases of mound formation. Three charcoal samples were submitted for radiocarbon dating, and were supplemented by Wright’s original radiocarbon determinations from the same deposit. Bailey notes that when interpreted separately, Wright’s and his own ages both returned a rate of accumulation of “about 55 cm per 100 years when plotted against a depth scale. Taken together, however, the five dates suggest marked irregularities in the rate of accumulation of the shell deposit” (Bailey 1977: 134).

Bailey then goes on to contemplate various possibilities to account for this variability in the rates of accumulation described for the Kwamter mound. He considers factors such as the error margins associated with radiocarbon dating, as well as how the small number of dates complicates interpretations (Bailey 1977: 134-135). He concludes that rates of accumulation that formed the Kwamter mound were variable through time, and goes on to “consider how such a pattern, if real, would affect interpretation” (Bailey 1977: 135). Following this, Bailey hypothesises a range of formation processes that could feasibly result in the inferred depositional patterning of this mound.

What both studies require, and Bailey (1977: 134) explicitly calls for, is further refinement to the scientific chronology applied to shell midden sites to move interpretations forward. In recognition of said problems, and a need for further certainty in the chronology of deposits, Stein *et al*. (2003) developed a sophisticated approach to assessing rates of accumulation and tested this at a series of shell midden deposits on the San Juan Islands, Washington.

In their study, Stein *et al*. (2003) aimed to isolate the formation patterns of shell middens to make apparent “otherwise invisible aspects of human behaviour” (Stein *et al*. 2003: 297) using a high resolution approach to the radiocarbon dating of shell middens. A total of 82 radiocarbon ages on charcoal fragments sourced from six different shell midden sites (Stein *et al*. 2003: 298) revealed complex and variable patterns of deposition, with discrete layers within deposits revealing vastly different rates of accumulation when compared to the deposit as a whole (Stein *et al*. 2003: 313). Statistically applying a line-of-best-fit to the age/depth data, Stein *et al*. (2003) were able to isolate instances of hiatuses and time-averaged layers in their fine-grained comparison between rates of accumulation across layers and deposits (Stein *et al*. 2003: 313).

The aims proposed by Stein *et al*. (2003) broadly accord with the aims of Temporal Packaging. The formation processes, specifically the depositional patterning, of an archaeological deposit is intrinsically linked to the behavioural processes of the people behind the deposition of material, and gaining a stronger understanding of the former allows a more reliable interrogation of the latter. However, considering the nature of the methods used by Stein *et al*. (2003), and more fundamentally how the data are being wielded to build behavioural interpretations requires further thought.



$$A: \frac{\text{depth a2 - depth a1}}{\text{age a2 - age a1}} = 0 \text{ cm/yr}$$

$$B: \frac{\text{depth b2 - depth b1}}{\text{age b2 - age b1}} = X \text{ cm/yr}$$

$$C: \frac{\text{depth c2 - depth c1}}{\text{age c2 - age c1}} = \infty$$

$$D: \frac{\text{depth d2 - depth d1}}{\text{age d2 - age d1}} = -X \text{ cm/yr}$$

Figure 8.3 – Stein *et al*.'s (2003) conceptual model of different forms of rates of accumulations typically encountered in the archaeological record. "Hypothetical accumulation rates: radiometric age as a function of sample depth. Line A models zero accumulation, Line B models a positive accumulation rate, Line C models an infinite accumulation rate, and Line D models a negative accumulation rate" (Stein *et al*. 2003: 300).

Rates of accumulation of shell midden deposits, as used by Stein *et al*. (2003), is an exercise in chronological refinement, and its focus is on understanding the (potentially) punctuated nature of deposits and isolating zones of disturbance. However, by reducing the chronological data points to a line of best fit, Stein *et al*. (2003) average out and homogenise the behavioural evidence they state they seek to understand (Stein *et al*. 2003: 297). This is in contrast to the manner in which the relative ages of AAR have been interpreted, where the data points themselves organically form groupings and clusters that are *not* then further averaged, which then becomes the focus for analysis and interpretation.

If we were to apply rates of accumulation (specifically *sensu* Stein *et al.* 2003) to the radiocarbon dating program undertaken using material from Brremangurey, this point is demonstrated. Figure 8.3 shows the idealised model of types of patterns of accumulation as conceptualised by Stein *et al.* (2003) that one might expect archaeologically. Applying rates of accumulation to Brremangurey, as defined by Stein *et al.* (2003), we would be able to identify a zone of disturbance at the base of the midden deposit as a back-and-forth of B and D line types suggesting that dated specimens are not in stratigraphic order. The rates of accumulation for the upper portions of the midden would return a pattern closer to line type C (Stein *et al*. 2003: 300), which suggests a large amount of shell being deposited in a rapid, almost single phase dump.

Relying solely on radiocarbon dates, both methods were able to identify the time-averaged layer at the base of the Brremangurey midden deposit. However, the numbers of radiocarbon ages were insufficient to establish the extent of time-averaging of this layer. It was only with the addition of the AAR samples at Brremangurey that it became clear that the bulk of stratigraphically-associated shell in fact dated to the late Holocene. With AAR, it is possible to more effectively disentangle the unit into its constituent parts allowing behavioural interpretations of changing depositional intensities to be drawn.

Concluding remarks

This thesis began with the recognition of the palimpsest nature of the archaeological record as discussed by Bailey (2007: 203-214). Palimpsests can be representative of a variable temporal span, and it is this potential breadth of time that opens up the archaeological record to the investigation of a range of spatial and temporal scales (Bailey 2007:201). Throughout his manifesto, Bailey stresses that palimpsests need to be appropriately temporally defined so the investigator understands the resolution afforded to them, and what scale of processes can/cannot be accessed. Bailey outlines two contrasting approaches in working with palimpsests: the 'microscopic tendency' (Bailey 2007: 209), where a palimpsest is deconstructed towards its constituent parts, and the 'macroscopic tendency' which sees "a widening perspective of large scale comparison" (Bailey 2007: 210) and the analysis of the palimpsest as a whole.

The micro- and macroscopic tendencies tend towards the investigation of processes on the opposing ends of the temporal spectrum, with short term, small scale processes being favoured by the former and long term, large scale processes for the latter. The deposits engaged by archaeologists generally sit somewhere in between, and this poses a methodological question of how best to engage with this intermediate scale of temporal investigation. Techniques that aim to refine the archaeological record in chronostratigraphic terms towards this intermediate scale of investigation have previously been developed; 'rates of accumulation' is one such technique. However, 'rates of accumulation' focus on exactly that: *accumulation*. Temporal Packaging, on the other hand, seeks to *define analytical units*, which can then be further interrogated at an appropriately-judged resolution; a purpose far better suited to defining and engaging with the palimpsest nature of the archaeological record (*sensu* Bailey 2007).

Archaeology is the one discipline of the human sciences that cannot directly observe its subject matter (i.e. people) (Chippendale 1989: 70). To engage with socio-cultural processes, historically, archaeology has borrowed, sequestered or commandeered from other theory-driven disciplines

(Bailey 2007: 214-215). However, disciplines such as social anthropology, sociology and history (Bailey 2007: 215) investigate behavioural process on a far shorter temporal scale, and the palimpsest nature of the archaeological record is ill-suited to sustaining evidence of behaviours on the scale of individual, day-to-day events (*sensu* Bailey 2007: 214-215). Rather than seeing the lack of resolution of the archaeological record as a deficiency, archaeology is uniquely placed to engage with a range of processes intrinsically linked to human behaviour operating at temporal scales beyond the capabilities of these other disciplines (e.g. see Binford 1981: 197, Bailey 2007: 203).

The common extra-disciplinary perception that it is the role of archaeology to rebuild ancient ethnographies (see Binford 1981: 197) "only tends to reinforce the opinion of social anthropologists, sociologists, historians and perhaps also philosophers, that archaeology is a derivative discipline that attempts to study with inherently imperfect data the past tense of phenomena that are better studied in the present. Archaeologists who go down this route of enquiry also inevitably end up chastising themselves and their colleagues for always being one step behind the chosen authority discipline" (Bailey 2007: 215). Archaeology should not be the neglected cousin of the theoretical hegemony of the day (*sensu* Bailey 2007: 215), but rather carve a niche better suited to the temporal and spatial scales represented by the material record with which we investigate; assuming we have the appropriate tools to do so. Temporal Packaging is one of those tools.

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Appendices

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Untangling time-averaging in shell middens: Defining temporal units using amino acid racemisation

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ABSTRACT

Time-averaging is a process that affects almost every form of archaeological deposit. The conflation of two or more units from different time periods masks the true temporal span of units which is hidden by post-depositional processes. The implications of this are obvious as archaeological material found in close stratigraphic association may differ in age by hundreds or thousands of years. Some sites have a greater tendency towards the effects of time-averaging, with shell middens being one of the more susceptible. Conventional approaches to midden excavation or analysis, however, do little to tackle the issue of time-averaging. Using amino acid racemisation (AAR), an intensive relative dating programme was undertaken on shell midden excavated from a potentially time-averaged midden deposit. This approach revealed temporally distinct units that had been conflated into one deposit resulting in shell specimens temporally separated by up to 6000 years being found in close stratigraphic association. The application of AAR allowed us to define the temporal parameters of the various comingled deposits, and in doing so isolate temporal units which showed very different depositional patterns. These contrasting units imply different depositional behaviours and in turn changes in site use through time. This new application of AAR offers a way to approach shell midden archaeology to expose instances and repercussions of time-averaging that were previously hidden.

1. Introduction

Archaeological sites are not frozen in time. Rather, environmental and cultural processes act on deposits to add, remove and redistribute archaeological material (Ascher, 1961, 1968; Schiffer, 1972, 1996). One particular product of these transformations is the creation of a palimpsest: an agglomeration of previously separated material into one homogenised unit (Bailey, 2007). This mixing of originally spatially separated material creates the illusion of contemporaneity during excavation with obvious implications regarding initial interpretations and subsequent analyses utilising the time-averaged material. It is therefore critical that a time-averaged deposit be identified as such. Establishing that a unit is time-averaged allows restructuring of the scale of questions being asked of the deposit to account for the expanded bracket of time represented. By establishing the time range represented within an assemblage, relevant information can still be gathered from material representing a much greater timespan, however the possibility to tackle themes on a smaller temporal scale is lost (Bailey, 1981, 1983; Lucas, 2005: 45, 49; Stern, 2008: 134; Sullivan, 2008).

Compositionally, shell midden deposits are usually dominated by large amounts of molluscan shell with smaller proportions of sediments such as sand, silt and ash. Middens tend to be extremely permeable due to the relatively large size of the abundant shells that facilitates the free movement of water, which can subsequently influence materials within the midden itself (Stein, 1992). Lighter elements such as sand, ash, small fish bones and charcoal, can be blown away by wind, leading to deflation of the deposit, or washed away either through the matrix or away from the deposit (Rick, 2002, see also Wandsnider, 1988). Animals also act as agents of transformation within midden deposits. Among others, bowerbirds (Dwyer et al., 1985), ants and termites (Robins and Robins, 2011), crabs (Specht, 1985; Szabó, 2012) and earthworms (Stein, 1983) have all been identified as adding, removing, and redistributing midden material in archaeological sites. Finally, human activity can greatly contribute to the movement of midden shell through processes such as trampling, pit digging and other activities associated with various cultural behaviours (Schiffer, 1996).

Recognising a significantly time-averaged unit in a shell midden during excavation is troublesome due to the coarse nature of the shell dominated matrix and frequent compositional homogeneity. Increasing the number of chronometric age determinations obtained can increase temporal resolution and potentially bracket the age of a deposit (Kowalewski et al., 1998: 291), although this can be a costly exercise.

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Cost means that the dating of shell middens often only involves a handful of age determinations for the entire sequence, and rarely more than one per stratigraphic unit (Stein et al., 2003). The implication of this is that the acknowledged temporal range of a time-averaged unit will be severely underrepresented, or indeed not be identified at all.

The problem of time-averaging in shell dominated deposits is not confined to archaeology and has been addressed in the geomorphological and palaeontological literature (*e.g.* Fürsich and Aberhan, 1990; Kowalewski et al., 1998; Flessa and Kowalewski, 1994; Fujiwara et al., 2004 and Kidwell et al., 2005). Indeed, within some of these disciplines, time-averaged deposits are considered the norm (Krause et al., 2010: 428). While the same limitations regarding the costs involved for radiometric dating techniques carry over into geological and palaeontological research, these latter disciplines have utilised alternative dating methodologies to tackle the issue of time-averaged, carbonate-dominated deposits in a cost effective way; most notably in the application of amino acid racemisation (AAR) (*e.g.* Wehmiller et al., 1995; Goodfriend and Stanley, 1996; Carroll et al., 2003 and Krause et al., 2010). The cost-effectiveness of AAR allows a large number of samples to be analysed, with multiple samples from the same stratigraphic unit being tested to establish a range of ages for time-averaged deposits (Kowalewski et al., 1998). While the processes that result in time-averaging in the earth sciences often differ from those that are occur in the archaeological record (*e.g.* Hughes and Lampert, 1977; Schiffer, 1996: 47), the principles and implications of time-averaging remain the same.

Amino acid racemisation (AAR) is a dating method that has had a long history of use in archaeological investigation (*e.g.* Masters and Bada, 1977; Parfitt et al., 2005; Johnson and Miller, 1997; Bateman et al., 2008; Ortiz et al., 2009; Demarchi et al., 2011). While the method his principally been used to replace or supplement ^{14}C dating as a chronological device to understand broad site chronology (*e.g.* Bada and Protsch, 1973; Parfitt et al., 2005; Kosnik et al., 2008), AAR has been utilised for other ends: for example acting as a range finder for shell midden units (Demarchi et al., 2011: 123), potentially identifying anthropogenic heating (Demarchi et al., 2011: 120) and using amino acids to taxonomically identify shell fragments (*e.g.* Andrews et al., 1985) and artefacts (Demarchi et al., 2014). The potential exists for AAR to address issues of post-depositional transformation in archaeological deposits utilising the concept of 'aminostratigraphy' developed within the earth sciences (*e.g.* Miller et al., 1979; Kennedy et al., 1982; Hearty et al., 1986) which at present remains unexplored (but see Demarchi et al., 2011: 123). We do not intend that increasing the resolution of our understanding of how middens are deposited and over what range of time using AAR is a way to deconstruct middens to mealtimes. Rather, our approach intends to identify conflated deposits, provide a guide as to the temporal ranges encapsulated within and 'unravel the palimpsest into its constituent parts' (Bailey, 2007: 216). The principal aim is to refine a time-averaged deposit into smaller scale of episodes appropriate and relevant for the scale of investigations, such as changes in environment and gathering behaviours, we ask of archaeological sites (Sullivan, 2008: 33).

To test the applicability of an aminostratigraphic approach to isolating time averaging in middens, we have undertaken an intensive dating programme on midden material excavated from Brremangurey rockshelter in the northwest Kimberley, Western Australia (Fig. 1). Our aim was to identify zones of time-averaged midden and identify and quantify the extent of time-averaging that had occurred through the deposit's history. We further elaborate on the implications of the results, which substantially change our understanding of the accretion of midden at Brremangurey.

2. Background to site and sample

The site called Brremangurey, named after who local clan group that are custodians of the surrounding area, is a rockshelter found approximately 70 m inland from the present day coast of the Admiralty Gulf, in the far north of the Kimberley region, Western Australia. The site formed from the internal collapse of a flat-lying quartzite outcrop which resulted in a ridge-like feature rising approximately 3 m from the ground at the southern main entrance. The eastern and western extents of the shelter are composed of quartzite bedrock (Moore, 2011), whilst the northern entrance and western most portion of the main entrance remain accessible despite abundant quartzite boulders (Ross

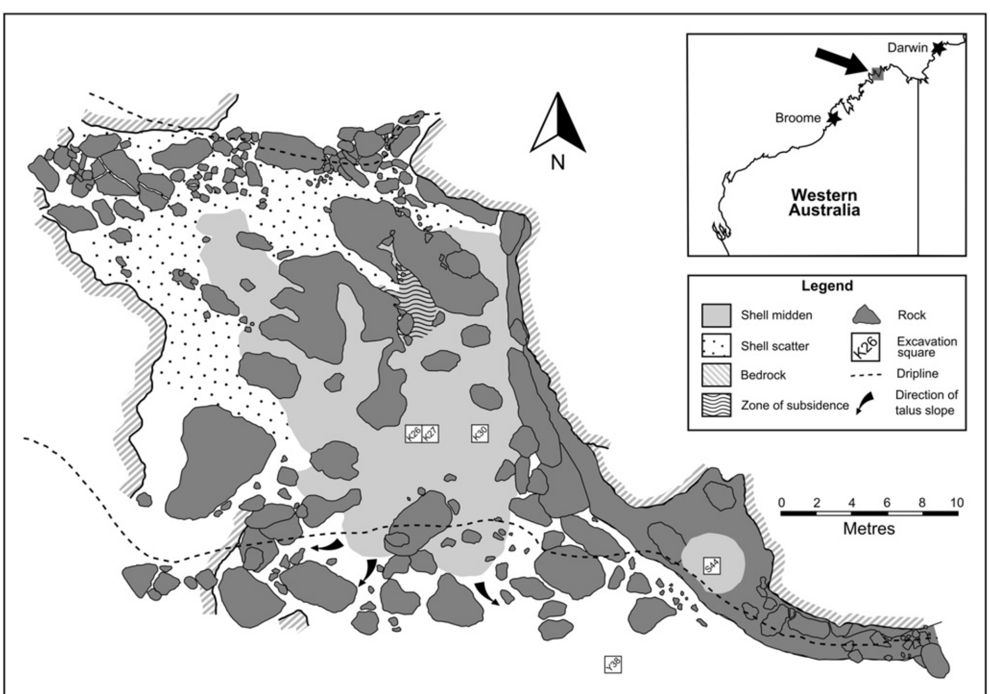

Fig. 1. Plan view of the Brremangurey rockshelter showing extent of midden deposit and location of squares excavated. Location of site shown on inset map. Site plan redrawn from original figure by Kim Newman.

et al., 2011). The southern entrance is *ca.* 23 m in length and the rockshelter extends *ca.* 31 m through the collapsed bedrock. Overall the entire surface area of the shelter is approximately 1200 m^2 (Moore, 2011; Ross et al., 2011). Except for a few quartzite boulders, the floor surface inside the rockshelter is loose shell midden (see Fig. 1). A talus slope of midden material is present outside the southern entrance to the shelter, extending past the dripline. A zone of subsidence is apparent towards the centre of the shelter, and is potentially the result of water flowing into the rear of the shelter during periods of abundant rainfall, such as during the summer monsoons (Robert Vaughn, personal communication, 2011). Rock art extends across much of the roof and wall surfaces and is discussed elsewhere (Huntley, 2014; Travers, 2015).

2.1. The excavation

Three 1×1 m^2 were selected from within the main shelter for excavation, and labelled using an alphanumeric grid: K26, K27 and K30. They were strategically placed under particular rock art motifs painted on the shelter roof. The excavation was conducted in arbitrary 5 cm spits because of the visual homogeny of the midden as viewed from the surface of the deposit. An underlying sand deposit was encountered from spit 24 (121.4 cm below surface) to bedrock, and spit depths were reduced to 2.5 cm.

Excavation of square K26 revealed two broad horizons defined primarily by the sediments that formed the overall matrix of the deposit; 'Horizon 1' which is predominantly shell supported ash and silt, and 'Horizon 2' in the lower portions of the site from approximately 83 cm below surface where sediments coarsen to a sand deposit (Moore, 2011) seen in Fig. 2. The total depth of the excavation was 183 cm at its deepest point when bedrock was reached. The shell midden characterises 'Horizon 1', and is only partially present in the upper extent of 'Horizon 2'. Hearth features with burnt shell and charcoal are common, interbedded among abundant layers of unburnt shell, and are also present, albeit without shell, in the underlying sandsheet. The pH of the deposit remained high throughout, with values of 8–9 in all units. This resulted in excellent preservation of organic material including shell, bone and both charred and uncharred plant material. Material culture, stone and otherwise, is largely absent from 'Horizon 1' with only minor occurrences of flaked quartz, quartzite, and ochre fragments being found. However ochre crayons, bone points and stone tools increase in abundance throughout 'Horizon 2' and were identified to bedrock (Moore, 2011).

2.2. Chronology

The initial charcoal radiocarbon ages obtained post-excavation at Brremangurey (seen in Table 1) reveal intensive midden deposition throughout the later stages of the Holocene from approximately 2500 cal. years BP, with the cessation of deposition occurring at approximately 500 cal. years BP. Other key north Australian shell midden deposits such as Weipa (Bailey, 1977, but see Morrison, 2014), Blue Mud Bay (Faulkner, 2013), Darwin (Bourke, 2012) and the Admiralty Gulf (Veitch, 1999), show a parallel chronological spread that would seem to accord with the ages for Brremangurey.

A second series of ages yielded an early Holocene age of 8152–8334 cal. BP on a valve of *Anadara granosa* (Wk-37137) from the lower extent of the midden, and this prompted a chronological rethink. Sourced from spit 18A (91–95.9 cm below surface), this shell was taken from the same spit as an adjacent fragment of charcoal that returned an age of 1,733–1876 cal. years BP (OZQ-187); a difference in age of over 6000 cal. years BP. Obviously, questions have to be asked regarding stratigraphic integrity. This result has significant repercussions for interpretations of both the material culture found in association with the shells, as well as having clear implications regarding the formation history of the shell midden. If these results mean that a conflated deposit has been identified in the Brremangurey assemblage, what proportion of shell specimens are similarly temporally obscured? Conventional dating methods such as radiocarbon could resolve this issue, however the number of individual age determinations required to adequately bracket the extent of time-averaging within the conflated deposit renders this approach unfeasible. This conundrum provided a good

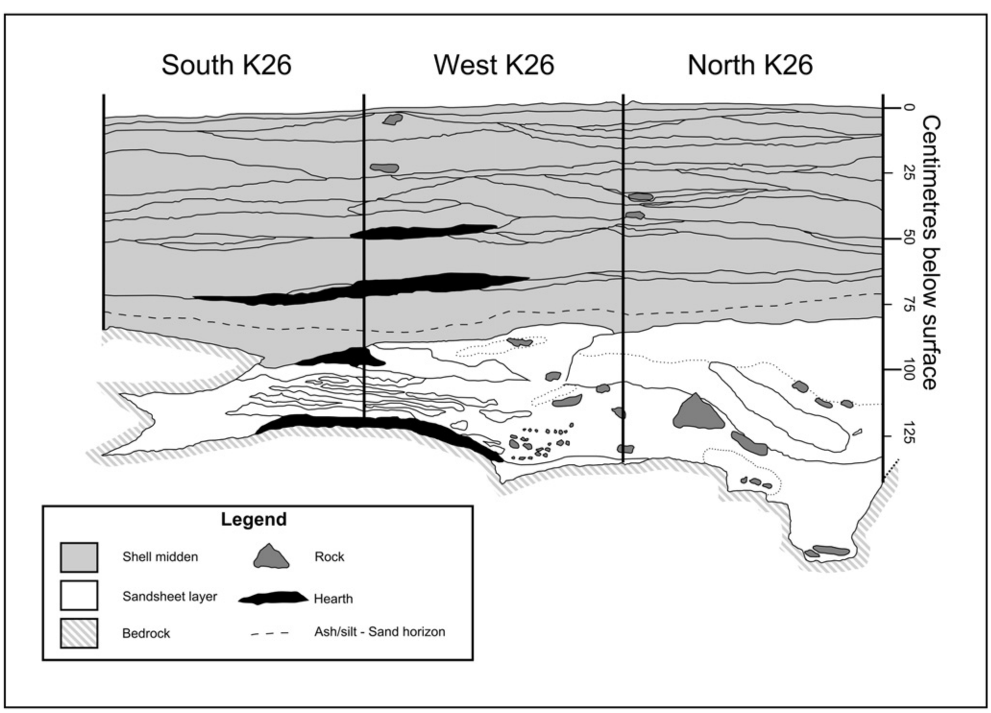

Fig. 2. Stratigraphic section of 3 of the walls of the square K26, the material is utilised in this study. Figure redrawn from original stratigraphic section diagram by Kim Newman.

Table 1
Ages of the initial AMS radiocarbon dates of charcoal sourced from the wall of the excavation and shell from excavated material during preliminary midden analysis. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm., 2014), and presented at 2δ confidence.

Sample code	Sampling location	Material	Depth (cm. below surface)	Age (uncalibrated)	Calibrated age
Wk-32405	Trench wall	Charcoal	8.6	493 ± 33	498–552 (99.4%) 614–617 (0.6%)
OZQ-181	Excavated material	*Anadara granosa*	24.1–28.1 (spit 6)	1415 ± 25	785–988
OZQ-185	Excavated material	Charcoal	24.1–28.1 (spit 6)	930 ± 25	791–918
Wk-32407	Trench wall	Charcoal	57.6	1896 ± 33	1733–1899 (98.9%) 1913–1920 (1.1%)
OZQ-182	Excavated material	*Anadara granosa*	75.9–80.3 (spit 15)	2615 ± 30	2115–2326
Wk-37137	Excavated material	*Anadara granosa*	91.0–95.9 (spit 18A)	7828 ± 25	8152–8334
OZQ-187	Excavated material	Charcoal	91.0–95.9 (spit 18A)	1875 ± 25	1733–1876
Wk-32409	Trench wall	Charcoal	91.0	3394 ± 25	3579–3694
Wk-32410	Trench wall	Charcoal	108.3	10,867 ± 39	12,694–12,801
Wk-32411	Trench wall	Charcoal	125.5	12,303 ± 44	14,059–14,564

opportunity to test an application of an alternative chronological method — amino acid racemisation.

3. Approach to investigation

Amino acid racemisation (AAR) is a dating technique that centres on the two chiral forms of amino acids. During life, amino acids are almost solely maintained in the laevorotatory (L) form. After death, these L-amino acids convert to their dextrorotary (D) forms; a process called racemisation. Over time, the proportion of D-amino acids relative to L-amino acids increases until equilibrium is reached. By establishing the ratio of D- to L-amino acids allows the time since the organism's death can be identified. In summary, the higher the D/L value, the more time passed since the death of the organism. The primary variable that affects the rate of racemisation is temperature, however a number of different environmental factors can influence the rate of racemisation, such as pH, presence of metal ions and microbial alteration to name a few (Penkman, 2005: 33–38). Recent research has identified a small proportion of proteins that are encapsulated within individual calcium carbonate crystals that form molluscan shell (Sykes et al., 1995; Penkman et al., 2008). These intracrystalline proteins have been proven to act as a closed system, insulated from external taphonomic processes that have the potential to obscure or skew results. Isolating the products of intracrystalline protein diagenesis (IcPD) for use in AAR has subsequently provided more precise and reliable results. The IcPD approach to AAR dating has been utilised here.

Geomorphological studies have routinely used AAR as a means of assessing the depositional history of a deposit by establishing the relative ages of carbonate sediments, including molluscs and foraminifera, with comparable D/L values; a concept termed aminostratigraphy (*e.g.* Miller et al., 1979; Murray-Wallace et al., 1991; Bates, 1993; Hearty and Kaufman, 2000; Wehmiller and Miller, 2000; Penkman et al., 2007, 2013; Meijer and Cleveringa, 2009). By establishing clusters of specimens exhibiting similar D/L ratios, called aminozones, then comparing extent of racemisation with spatial positioning allows interpretations to be made regarding both site formation as well as post-depositional transformation. Substantially time-averaged deposits are immediately identified as spatially associated specimens return D/L values belonging to different aminozones (*e.g.* Kowalewski et al., 2000; Kidwell et al., 2005; Kosnik et al., 2007). While the agents and processes that drive deposition and transformation in geomorphological settings frequently differ to those of archaeological contexts, the principles of recognising the temporality of deposition and transformation processes remain the same, and this approach is especially applicable to shell middens. As applied to the Brremangurey shell midden we aimed 1) to isolate any major instances of time-averaging within the midden, and 2) establish a more accurate chronostratigraphic interpretation for such layers.

4. Methods

4.1. Sampling methodology

Shells were sampled from all excavation units (spits) from which shell midden was recovered. This approach allowed the results to portray clustering without the bias associated with preferential sampling of one excavation unit over another. A total of 42 valves of *A. granosa* were sampled from both the dense midden overlying the sandsheet from spits 1 to 21 (surface to 118 cm below surface). Two valves were selected from the excavated and sorted midden material of each spit, except for spits 10 and 12 where only one whole left valve was found. No whole valves of *A. granosa* were found in spit 11 (a full list of samples, their codes, and relevant excavation data is presented in Table 2). To remove the possibility of dating the same animal twice, only the left valves were selected for analysis. Specimens that had no visible signs of burning or other taphonomic influence such as acid dissolution were selected. Where possible, the same shells that were sampled for AMS radiocarbon dating were incorporated into the AAR programme to provide a direct link between D/L values and radiocarbon age (samples OZQ-181 and OZQ-182).

4.2. Sample preparation

Preliminary sample preparation followed the process described by Lachlan (2011). Shell specimens were cleaned of adhering sediment using a soft-bristled brush. Following this, using a dental drill, the surfaces of the interior and exterior regions near the umbo were abraded. A small subsample of the shell was removed from near the umbo. Already fragmented shells were not subsampled further, but were simply cleaned and abraded. All specimens were then sonicated in purified (Millipore) water for 5 min. This sonication step was repeated at least three times until the water post-sonication was clear, replacing the water after each cycle. Specimens were then air dried in sterile covered plastic dishes.

The shell fragments were accurately weighed and subjected to a 2 M HCl etch at 0.0033 mL of acid per milligram of shell. Fragments were then rinsed thoroughly in purified water. The fragments were once again air dried and then crushed to a fine powder using an agate mortar and pestle. Following methods outlined by Sykes et al. (1995) and Lachlan (2011), the powdered shell was then exposed to a bath of 12.5% sodium hypochlorite (NaOCl) for 24 h and agitated regularly. The NaOCl solution was then poured off and the powdered shell was rinsed using purified water at least four times. A rinse of methanol was also used to ensure the neutralisation of the NaOCl, and was then followed by a final Millipore rinse.

Following the method outlined by Kaufman and Manley (1998), preparation for hydrolysis began with dissolving the powdered shell

Table 2
Results of the AAR analysis. Each sample was run in duplicate and averaged. UWGA lab code issued by the Amino Acid Racemisation Laboratory at the University of Wollongong. AMS radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for marine shell (Alan Hogg, pers. comm., 2014), and presented at 2δ confidence.

Lab code (UWGA)	Spit	D/L Asx	Sample variance	D/L Glx	Sample variance	Radiocarbon lab code	Radiocarbon age (cal. BP)
10470	1	0.201	±0.001	0.1115	±0.0005	Wk-40856	326–496
10471	1	0.3395	±0.0015	0.12	±0		
10472	2	0.543	±0.006	0.6195	±0.005		
10473	2	0.3485	±0.0005	0.141	0	Wk-40857	387–525
10474	3	0.35	±0.001	0.148	0		
10475	3	0.346	±0.008	0.1345	±0.0015		
10476	4	0.356	±0.003	0.1335	±0.0005		
10477	4	0.4025	±0.0065	0.159	0		
10478	5	0.35	±0.010	0.1275	±0.0015		
10479	5	0.394	±0.001	0.1485	±0.0005		
10480	6	0.3755	±0.0005	0.150	0		
10481	6	0.4185	±0.0065	0.1535	±0.0005		
10494	6	0.413	±0.017	0.155	±0.001	OZQ-181	785–988
10482	7	0.428	±0.0105	0.1665	±0.0035		
10483	7	0.4365	±0.0105	0.185	±0.001		
10484	8	0.496	±0.002	0.214	0		
10485	8	0.405	±0.011	0.156	±0.004		
10486	9	0.463	0	0.1975	±0.0005		
10487	9	0.393	±0.010	0.1505	±0.0025		
10488	10	0.5165	±0.0115	0.2255	±0.0005		
10489	12	0.5765	±0.0075	0.2655	±0.0005		
10490	13	0.5605	±0.0185	0.2505	±0.0015		
10491	13	0.309	±0.001	0.127	0		
10492	14	0.514	±0.016	0.2115	±0.0015		
10493	14	0.5095	±0.0095	0.2265	±0.0005		
10495	15	–	–	–	–	OZQ-182	2115–2326
10394	15	0.514	–	0.263	–	Wk-40858	2139–2330
10395	15	0.5095	±0.0065	0.2705	±0.0015		
10396	16	0.541	±0.010	0.303	±0.001		
10397	16	0.5245	±0.0045	0.273	±0.003		
10398	17	0.806	±0.005	0.5425	±0.0005	Wk-40859	2844–3080
10399	17	0.5695	±0.0045	0.2875	±0.0005		
10400	18A	0.410	±0.005	0.1815	±0.0005		
10401	18A	0.9715	±0.0205	0.856	±0.013	Wk-37137	8208–8365
10402	18B	0.5585	±0.0005	0.3145	±0.0005		
10403	18B	0.5395	±0.0105	0.618	±0.004		
10404	19	0.6525	±0.0045	0.4625	±0.0015		
10405	19	0.597	±0.001	0.4145	±0.0045		
10406	20	0.441	±0.002	0.2245	±0.0015		
10407	20	0.5105	±0.0075	0.5355	±0.0035		
10408	21	0.566	±0.001	0.565	±0.002		
10409	21	0.4785	±0.0005	0.776	±0.003		

in a sterile vial using 8 M HCl at 0.02 mL of acid per milligram of shell. This destroys the crystalline component of the shell releasing the proteinaceous material contained within. The vials were then filled with nitrogen (N_2) gas and sealed. The vials were placed into an oven at 110 °C for 22 h to induce hydrolysis of the peptide bonds. Following this process, samples were dried in a vacuum desiccator and then rehydrated using a solution 0.01 mM L-HomoArginine + 0.01 M HCl + 0.77 mM sodium azide and L-HomoArginine acting as a an internal lab standard. Sample analysis was conducted using an Agilent 1100 reverse phase high pressure liquid chromatograph (RP-HPLC). Two analyses per shell sample were run to quantify instrumental uncertainty in measurements of amino acids and the results averaged.

5. Results

Of the 42 shells that were analysed for this study, one sample (UWGA10495) was lost when the vial was not sufficiently sealed prior to the 110 °C oven stage of sample preparation. All other specimens provided useable results. Only the results of aspartic (Asx) and glutamic (Glx) acids are presented here. Of all of the amino acids that can be analysed, aspartic acid was selected because of its abundance in molluscan shell, but also because of the balance it offered between temporal resolution and time-depth it provided. Glutamic acid was also selected due to the high degree of covariance with aspartic acid, which allows taphonomically affected samples to be identified through the deviation from this covariance (Kaufman, 2006).

An initial observation of the results of this study is a clustering of specimens circled in Fig. 3. The D/L values of these specimens (UWGA10472, UWGA10403, UWGA10407, UWGA10408 and UWGA10409) match patterns that are thought to result from burning, or exposure to fire. As mentioned previously, aspartic acid undergoes racemisation at a faster rate than glutamic acid, and subsequently equivalent D/L values between each amino acid should not be identified until equilibrium. Similar patterns are observed and described by Crisp (2013: 181–182), Demarchi et al. (2011: 120), and Brooks et al. (1991) who were able to demonstrate that exposure to high temperatures for a short period of time preferentially affected aspartic acid D/L values over other, slower racemising amino acids, such as glutamic acid. While none of the shells selected exhibited any visual signs of burning, the thermal influence of campfires has to be expected in a site like Brremangurey, especially considering the abundance of charcoal, hearth features and other evidence of anthropogenic fire within the archaeological material. As these specimens have been taphonomically altered, these samples have not been incorporated in further analyses and interpretations of this study.

Looking to the rest of the dataset, the pattern observed in the bivariate analysis of aspartic acid *versus* glutamic acid (Fig. 3) reveals a steady increase in the extent of racemisation in the shells analysed which,

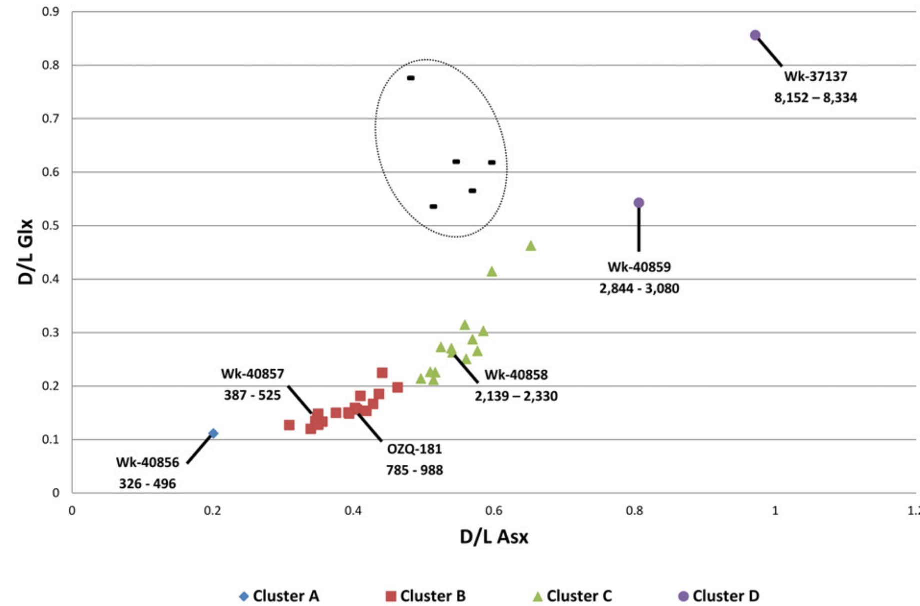

Fig. 3. Bivariate plot combining D/L ratios of both Asx (x-axis) and Glx (y-axis) for each sample analysed in this study. The results of the k-means cluster analysis are also incorporated. Specimens that have been circled have been interpreted to have been affected by burning or exposure to high heat. Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm., 2014), and presented at 2δ confidence.

when the previously determined radiocarbon ages are included, correspond well with increasing age. Generally, there is little clustering between samples seen in Fig. 3 with a very regular increase in D/L values being observed. k-Means cluster analysis statistically isolated 4 distinct clusters, shown in Fig. 3. Cluster A is a single specimen (UWGA10470) exhibiting a much lower D/L value when compared with the rest of the sequence. Cluster B is a dense grouping of shells, comparable to cluster C, although cluster C exhibits a more advanced extent of racemisation. In contrast, cluster D exhibits the greatest extent of racemisation by a substantial margin (for example centroid of cluster D of Glx D/L value is 0.699 compared to 0.284 for the centroid of cluster C, seen in Table 3).

When comparing D/L values of each specimen with their spatial positioning during excavation (Fig. 4), clusters A and B are almost entirely comprised of shells sourced from spits 1 through to 7 (surface to 40.5 cm below surface). Such a pattern is not seen in the lower portion of the midden as little correlation between stratigraphic level and relative D/L values are observed. This is further depicted in Fig. 4, which plots stratigraphic depth of each sample and Asx D/L values. While a positive correlation between depth and D/L value is seen in the upper and younger portion of the midden, the lower and older extent of the midden, particularly from spit 13 onwards, does not continue this trend. Instead, a much more variable pattern is apparent with very different ages being associated with the same spit, and regularly younger shell specimens being stratigraphically below older ones (for example shell specimens from spit 19 compared with spits 17 and 18A in Fig. 4 and Fig. 5).

Table 3
Results gathered from k-means cluster analysis utilising the Brremangurey AAR samples. Centroids refer to the average D/L values of Asx and Glx for each cluster.

	Amino acid	Centroid mean (D/L)	Cluster range (D/L)	Standard deviation
Cluster A	Asx	0.201	–	–
	Glx	0.1115	–	–
Cluster B	Asx	0.387	0.309–0.463	0.042
	Glx	0.1558	0.120–0.2245	0.027
Cluster C	Asx	0.5529	0.496–0.6525	0.042
	Glx	0.2844	0.2115–0.4625	0.073
Cluster D	Asx	0.8888	0.806–0.9715	0.117
	Glx	0.6993	0.5425–0.856	0.222

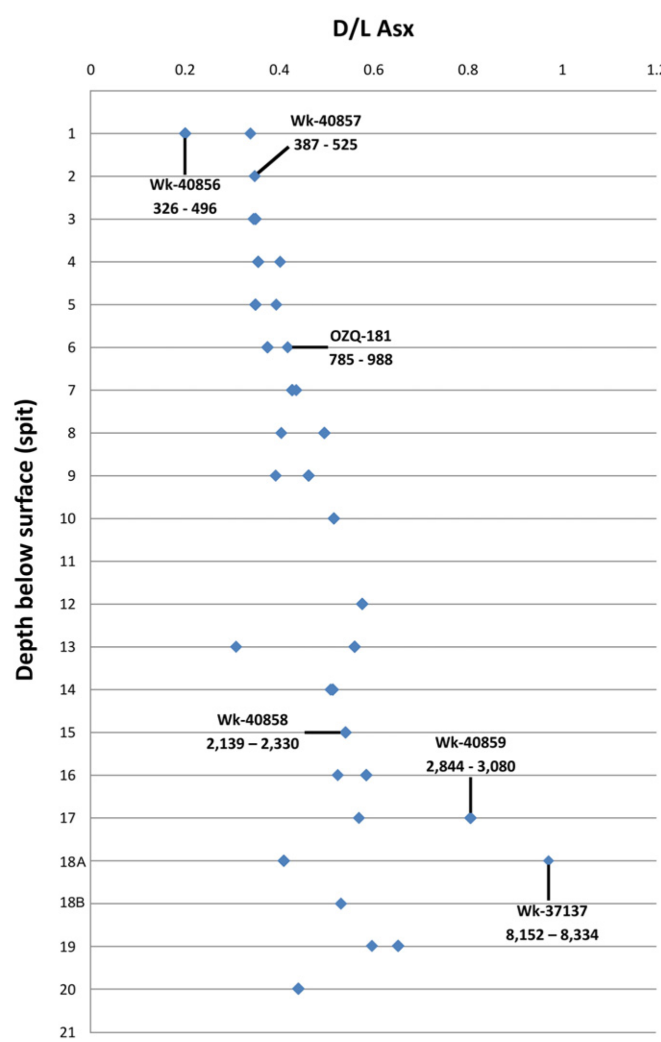

Fig. 4. D/L values (x-axis) compared with excavation units that shells were sampled from. Note increasing D/L value to the right of the figure indicates older age.

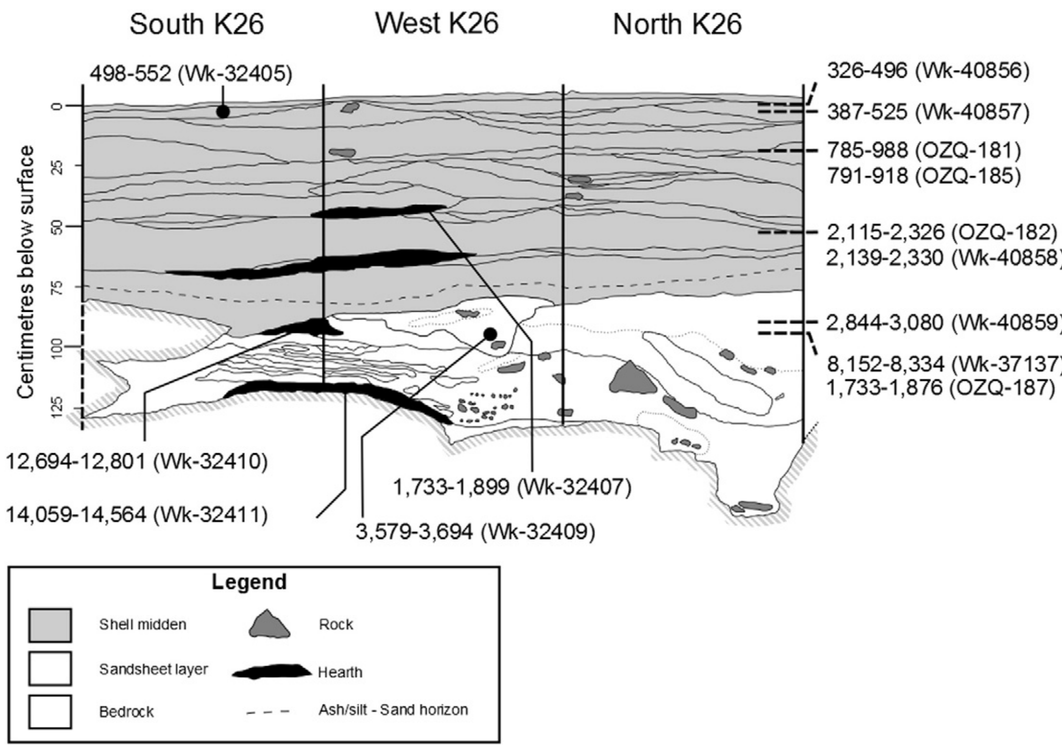

Fig. 5. All radiocarbon ages presented in this study placed in in stratigraphic order from where the material was sampled from. Specimens for radiocarbon dating marked with a solid line were sampled directly from the wall of the trench during excavation. Specimens that were selected post-excavation from analysed midden material are indicated by a dashed-line at the approximate depth from which they were excavated.

These patterns present a strong indication that time-averaging has occurred in the lower extent of the Brremangurey midden.

A further four shells were selected for radiocarbon dating based on their relative positioning derived from the results of the AAR analysis to properly bracket the age range of the deposit, as well as identify when punctuations in deposition occurred (Table 4). When these ages are marked on the bivariate plot, the numerical ages derived from the radiocarbon analysis coincide very neatly with the D/L values and relative ages of this study, seen in Fig. 3.

6. Discussion

While the initial radiocarbon dating program suggested the presence of a time-averaged deposit, the AAR analysis presented here was able to expand on the story of deposition and disturbance within the Brremangurey midden. A population of shells exhibiting a substantially more advanced extent of racemisation (cluster D in Fig. 3) than the majority of shell specimens that form the main bulk of the shell midden has become apparent. The close agreement of the extent of racemisation established using AAR on the shell specimen also AMS radiocarbon dated to over 8000 cal. years BP (Wk-37137), as well as its position relative to the other D/L values generated in this study, further reinforces the position that this shell is genuinely older than those surrounding it, and not a product of some process that skews age determinations such as the marine reservoir effect in radiocarbon dating. The implication of this result is that an older deposit of shell has become conflated into the younger shell deposit, as highlighted in Fig. 4 and Fig. 5.

Comparing the younger shell deposit to the older and far less abundant deposit, the extent of time bracketed by each grouping of shell is an obvious distinction. The primary grouping of shell (clusters B and C seen in Fig. 3) represent the bulk of the shell material present in the Brremangurey midden deposit, and covers a time range of approximately 2300 to 350 cal. years BP. The much more scattered grouping of shell specimens (cluster D in Fig. 3) covers a considerably larger time range from approximately 8300 cal. years BP. With the oldest and youngest material dated, the effective range of shell midden accumulation observed in the Brremangurey midden assemblage extends throughout the Holocene, from approximately 8300 to 350 cal. years BP.

While this conclusion in itself reveals a critical part of the history of the Brremangurey deposit, the refining of the chronology of the Brremangurey assemblage presents new opportunities for investigation. The results of the AAR analysis reveal a considerable difference in the proportional abundance of shell specimens between the various groupings of shell identified. The vast majority of midden shell specimens are restricted to the younger grouping (clusters B and C in Fig. 3), and by comparison the oldest grouping of shell (cluster D in Fig. 3), represents a much smaller population of shell specimens. Two interpretations can be offered; 1) the proportional abundances between the groupings are reflective of the relative depositional patterns that

Table 4
Results of additional AMS radiocarbon analyses on shell specimens selected as a result of the AAR analysis (see Fig. 3). Radiocarbon dates have been calibrated using Calib 7.02 software with a delta-R value of 60 ± 31 years used for Kimberley marine shell (Alan Hogg, pers. comm., 2014), and presented at 2δ confidence.

Sample code	UWGA sample code	Method	Material	Depth (cm. below surface)	Age (uncalibrated)	Calibrated age
Wk-40856	10470	AMS radiocarbon	*Anadara granosa*	0–3.1 (spit 1)	851 ± 20	326–496
Wk-40857	10473	AMS radiocarbon	*Anadara granosa*	3.1–5.4 (spit 2)	882 ± 20	387–525
Wk-40858	10394	AMS radiocarbon	*Anadara granosa*	75.9–80.3 (spit 15)	2631 ± 20	2139–2330
Wk-40859	10398	AMS radiocarbon	*Anadara granosa*	83.7–90.1 (spit 17)	3232 ± 20	2844–3080

created them and thus the original level of deposition of *A. granosa* was low; or 2) the quantified abundances of *A. granosa* do not reflect the original scale of deposition and the earlier deposits have undergone a significant degree of loss of midden material over time. The first assumption closely aligns the Brremangurey midden with Bailey's (2007): 207) description of a 'cumulative palimpsest', where no (or little) material evidence is lost between two units when both are conflated — they are simply mixed. The second is closer to a 'true palimpsest' (Bailey, 2007: 205) that involves some or total loss of material evidence through time.

Depending on which form of palimpsest is present in the Brremangurey midden assemblage, the overall interpretations of behavioural practices at Brremangurey change. Assuming that the abundance of shell present in the excavated assemblage is a reasonable reflection of the nature of *A. granosa* deposition in the past, we observe a substantial shift in gathering practices through time. The deposition of shell midden was initially rather sporadic and ephemeral with relatively small quantities of shell brought back to the rockshelter through most of the Holocene from approximately 8300 to 2500 cal. years BP. Patterns in midden deposition then changed, as gathering strategies focussing on shellfish increased in intensity with much larger quantities of shell being deposited in the rockshelter. This interpretation has further implications for the intensity and frequency of site use through time.

The alternative scenario is that a substantial amount of midden material has been lost through some process, mechanical or chemical, resulting in an underrepresentation of the true abundance of shell brought into the shelter in earlier phases of midden accumulation. Chemical dissolution has the potential to destroy carbonates in a deposit through slightly acidic water percolating through the site, however this process leaves traces in the form of reprecipitated minerals (*e.g.* Beck, 2007; Villagran et al., 2011); something that was not observed during excavation or analysis of the midden material. Similarly, none of the shells selected for AAR analysis exhibited signs of low-level acid dissolution signalled by of rounded margins and muted sculpture and a chalky texture (Claassen, 1998: 59–60). Mechanical removal of midden is a definite possibility, however once again evidence associated with this process was not found during excavation or analysis (*e.g.* Glover, 1979: 306–7 on remnant midden-bearing breccias on cave walls). It is possible that evidence exists of the mass movement of shell within the talus slopes at the entrance of the rockshelter (see Fig. 1) that could provide further insights into mechanical processes of shell removal at Brremangurey.

Without any lines of evidence from the analysed material that suggest a chemical or mechanical explanation of the removal of midden shell at Brremangurey, the most parsimonious explanation is that the shell excavated from the rockshelter is an adequate reflection of the depositional behaviours practised over time and that the proportion of shell present in the midden is indicative of the amount of shell midden deposited in the early-mid Holocene. Thus, the change in proportional abundances of shell between the primary clusters of shell specimens and the oldest grouping of shell (cluster D in Fig. 3) has been interpreted to be the result of a behavioural shift in shellfish gathering practices. Initially, shellfish collection and shell deposition followed a low intensity, ephemeral and very episodic pattern from approximately 8,300 cal. years BP. Rather suddenly, shellfish gathering behaviours became more focussed and intensive and this ultimately underpinned the formation of the very dense shell midden that accumulated from approximately 2,300 cal. years BP to 350 cal. years BP.

7. Conclusion

The key aims of this study were to refine the chronology of the Brremangurey midden assemblage and to isolate any potential time-averaged deposits, which have been achieved. Initial radiocarbon ages gathered using material excavated from Brremangurey were fortunate in likely identifying a time-averaged deposit, however the number of AMS radiocarbon ages presented in this study is unusual when compared to the typical approaches to midden chronology. Despite this, the true extent of time-averaging remained hidden. Similarly, shifts in shellfish gathering intensity through time would have remained masked. It was only with the intensive use of AAR presented here that the extent of time-averaging and changing gathering intensities could be further expanded. By isolating appropriate temporal units, the scale of questions we can now appropriately ask of the Brremangurey assemblage can be refined, allowing investigation of changes in the depositional behaviours practised by Brremangurey's ancient occupants on a resolution that would have been previously impossible.

Shell middens are always going to be beset with issues associated with time-averaging across a range of temporal, spatial and quantitative scales, largely due to their large constituent parts and complex and often fine-grained formation processes. While methodological advancements in standard chronometric techniques continue to allow for ever-finer resolution of ages, reducing a shell midden down to the individual mealtimes will remain impossible and arguably unnecessary considering the questions we as archaeologists ask of an assemblage. Refining the chronology enough to isolate temporal disjuncture and conflation in time-averaged deposits is necessary to establish the actual temporal envelope that brackets the archaeological material, and rationally reframe our scale of enquiry to engage with the processes behind the material which will provide a much more accurate and complete story of the deposit as a whole through time.

This study has shown that not only can temporal ranges be elucidated, but that changing patterns of deposition can be brought into sharper focus. It is also not unreasonable to assume that the hidden issues in the Brremangurey deposit are not also present in other midden deposits around the world. This study has, using the novel adaptation of a well-established dating method, presented a new approach to how we analyse midden material.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2015.08.040.

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Isolating downward displacement: The solutions and challenges of amino acid racemisation in shell midden archaeology

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ABSTRACT

Shell middens are particularly susceptible to post-depositional processes that can rework and redistribute material through a deposit. As archaeological material is moved from its original primary context, the assumption that a temporal connection exists with spatially associated material becomes tenuous. It therefore becomes critical to identify displaced archaeological material within a deposit to ensure correct chronologies are being built. Radiometric dating techniques can identify individual displaced materials, but are sometimes prohibitively costly to utilise on a large scale. This study presents a new application of amino acid racemisation (AAR) dating that identifies stratigraphically displaced midden shell from within a deposit from the northwest Kimberley, Western Australia. Low-cost AAR analysis of 72 samples identified a sample of downwardly-displaced midden shell. Upon close inspection, comparison of AAR and AMS radiocarbon determinations identified fine-grained inconsistencies. Possible processes generating these discrepancies are considered with future avenues for research presented. While an enormous amount of potential is contained within AAR, more work is required to bring the method to the same level of precision as other commonly utilised dating techniques in archaeological research.

1. Introduction

Archaeological deposits are constantly being influenced by environmental and cultural processes that can add, remove or redistribute material (Schiffer, 1996). These processes can result in the distortion or complete disassociation of the original spatio-temporal connections that artefacts and sediments (Bailey, 2007). This is a major complication, especially considering that researchers constantly rely on assumptions of spatial and temporal relationships between materials in archaeological deposits to build interpretations regarding the ancient behaviours and palaeoenvironments represented within the deposit (e.g. Burleigh, 1974: 79, Taylor and Bar-Yosef 2014). Recognising that the potential exists for material within an archaeological deposit to be displaced is therefore critical for any interpretations or subsequent analyses to carry any form of accuracy or relevance. Resolving these ambiguities, however, can present methodological problems.

Radiocarbon dating is by far the most widely used absolute chronological tool in archaeological in archaeological investigation, however issues regarding site integrity and patterns of disturbance still have the potential to greatly skew results and interpretations (Burleigh, 1974). The development of AMS techniques facilitated the direct dating of archaeological material (e.g. Rick et al. 2005; Wild et al. 2005; O'Connor et al. 2010). The key advantage of this practice is that the assumption that spatial association represents temporal association is circumvented by attributing an age to the artefact or ecofact itself rather than relying on the chronology of the surrounding material. Despite its prolific use in archaeological research, the radiocarbon method as we know it today is most effective on a small scale of chronological inquiry; dating one specific event or artefact (see Lucas, 2005: 45, 49; Sullivan, 2008). In answering larger site-scale questions, such as assessing the spatial and temporal relationships between populations of artefacts and material, one single age determination is insufficient. While two radiocarbon ages can at times be enough to identify a disturbed deposit (see O'Connor et al. 2010: 37–38), such minimal data can rarely pinpoint the degree or nature of disturbance. Many individual samples are required to reliably identify disturbed deposits and go beyond the mere label of 'disturbed'. Only then can

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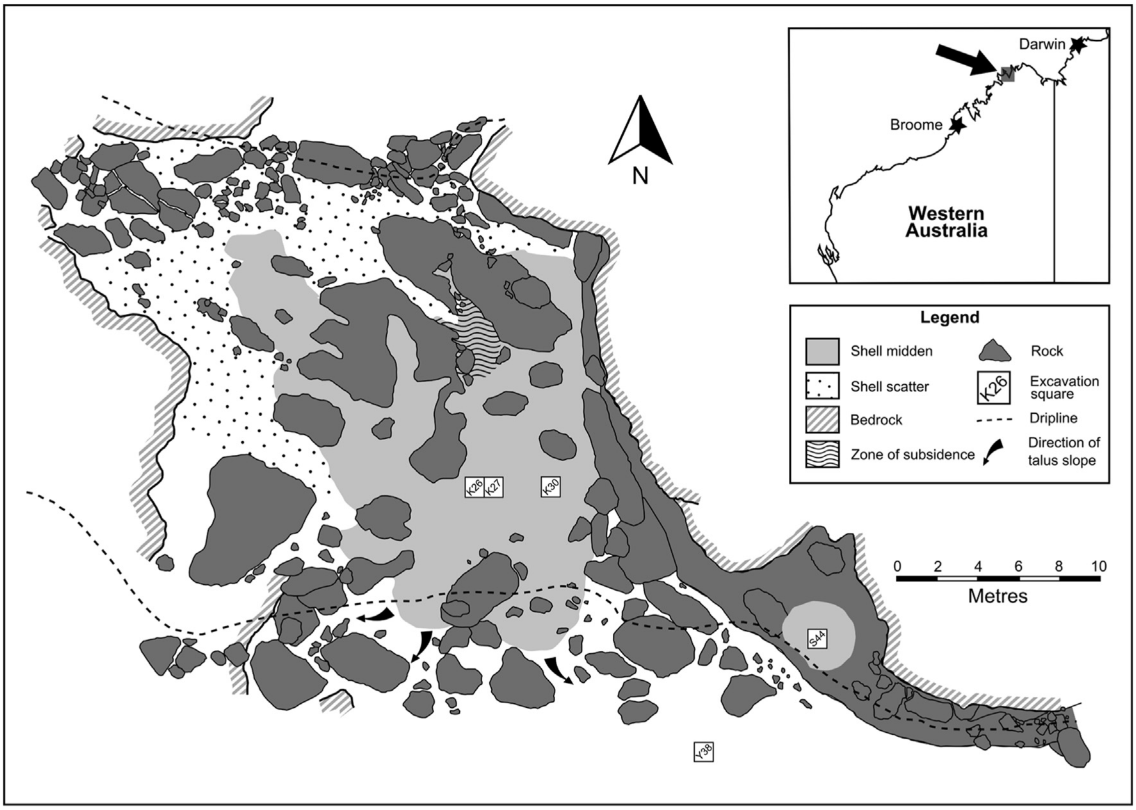

Fig. 1. Site plan and inset map of Admiralty Gulf.

researchers actually assess the relative contributions of units of temporally distinct sediments, ecofacts and artefacts in a time-averaged deposit and build reliable interpretations of site transformation.

Shell middens are ubiquitous archaeological features across the globe, and are particularly susceptible to post-depositional transformation (Stein, 1992). This is largely due to their generally coarse and porous composition that allows material held within to be freely displaced, removed or altered by environmental and cultural processes (e.g. Dwyer et al. 1985; Specht, 1985; Wandsnider, 1988; Rick, 2002; Robins and Robins, 2011; Szabó, 2012). Considering the significant potential that shell middens have in contributing to important issues in archaeological research (e.g. Bailey, 1977; Cannon, 2000; Lombardo et al. 2013), it is critical that the identification of displaced material within a shell midden is identified. Unfortunately, few methodologies are currently utilised that can unambiguously identify and isolate displaced shell in middens, especially on a larger scale (but see Villagran et al. 2009, Villagran et al. 2011a, 2011b for a microscale perspective). While an intensive dating program using the radiocarbon method and multiple samples would identify temporally disconnected, but spatially associated shells, the financial costs associated with so many radiocarbon age determinations generally make this approach unrealistic.

Amino acid racemisation (AAR) is a relative dating method that has had a long history of use in archaeological investigation (e.g. Masters and Bada, 1977; Wehmiller, 1977; Parfitt et al. 2005; Bateman et al. 2008; Ortiz et al. 2009; Demarchi et al. 2011). Rather than providing numerical values, AAR results tell us which samples are more or less racemised and thus, broadly, older or younger. While AAR experienced some negative perception in the discipline of archaeology in the late 20th century as a result of anomalous ages being generated (Bada et al. 1974, see also Johnson and Miller, 1997: 276), refinements in the method have yielded consistently reliable results (e.g. Kaufman and Manley, 1998; Penkman et al. 2008; Demarchi et al. 2013a, 2013b). The technique carries with it major advantages compared with more conventional dating methodologies such as radiocarbon and OSL. Firstly, AAR allows for a substantial number of samples to be analysed for the same cost as a single radiocarbon age determination. This cost effectiveness creates the opportunity for a much more intensive dating program incorporating many more samples than relying on radiocarbon dating alone. A second key advantage is that the archaeological material is being directly targeted and not

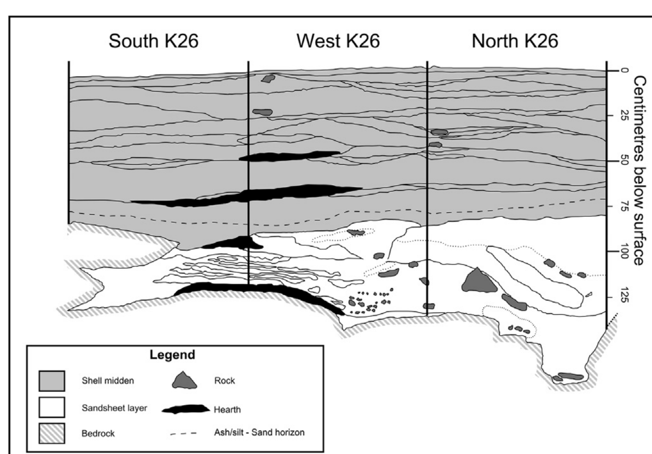

Fig. 2. Stratigraphic section of Brremangurey.

sediments argued to be in association, as with OSL dating. This removes a layer of inference which would otherwise have the potential to skew results due to post-depositional movement of sediments and archaeological material. The relatively low cost coupled with the ubiquity of dateable material in shell midden archaeology, results in AAR being perfectly suited for intensive dating programs to ascertain a much broader understanding of the ages of materials present within a deposit.

2. Background to site and sample

2.1. The excavation

The site of Brremangurey on the coastline of the Admiralty Gulf, northern Western Australia, is a quartzite rockshelter containing the remnants of human occupation extending through the late Pleistocene into the late Holocene (Ross et al. 2011; Koppel et al. 2015) (Fig. 1). Rock art covers a substantial portion of the walls and roof of the shelter, and is discussed elsewhere (Huntley, 2014; Travers, 2015). A shell midden covers the entire floor surface of the interior of the shelter, and extends out past the dripline of the southern entrance forming a talus slope that drops approximately three metres. The floor surface of the rockshelter is predominantly ash-supported silts with abundant shell and charcoal present. The bivalves *Marcia hiantina* (Lamarck 1818) (Bivalvia: Veneridae) and *Tegillarca granosa* (=*Anadara*) (Linnaeus 1758) (Bivalvia: Arcidae) are by a large margin the most abundant shell species observed on the surface of the midden, with *M. hiantina* occurring in much higher numbers than *T. granosa.*

Excavations were conducted within the rockshelter in 2011. Three 1 × 1 metre squares were excavated into the midden deposit, with the location of each square being determined by their position relative to individual art motifs on the roof above (Moore, 2011). The excavation was conducted in arbitrary 5 cm spits, with a spit being concluded once a new stratum or distinguishable feature became apparent (Moore, 2011). From Spit 24 (121.4 cm below surface) to bedrock, spit depths were reduced to 2.5 cm as excavation reached sediments dominated by sands, allowing finer and more controlled excavation of units. Excavated material was sieved through 5 mm and 3 mm screens, with 50% of shell material by volume of both fractions retained for analysis.

Bedrock was reached at a depth of 183 cm. Two major distinct stratigraphic units were identified (Fig. 2). The matrix of Unit 1 is ash and silt, while in Unit 2 the sediments coarsen to a sand deposit (Ross et al. 2011). The contact between the two Units occurred at a maximum of 100 cm below surface. Extremely dense shell midden deposit characterise all of Unit 1, and there is only limited shell midden material in the uppermost extent of Unit 2 (Koppel et al. 2015). Material culture is largely absent from Unit 1 with only minor occurrences of flaked quartz and quartzite, and ochre fragments being found. However, ochre crayons, bone points and stone tools increase in abundance throughout Unit 2 and were identified to bedrock (Moore, 2011).

2.2. Radiocarbon chronology

The chronology of ancient *M. hiantina* collection and deposition at Brremangurey largely parallels late Holocene high intensity shell collection across tropical northern Australia as observed in other sites such as Blue Mud Bay (Faulkner, 2013), the western Admiralty Gulf (Veitch, 1999), Darwin (Bourke, 2012) and Weipa (Bailey, 1977, but see; Morrison, 2014). Initial AMS radiocarbon ages derived from whole valves at the lowest excavation unit from which shell was recovered suggests that the large-scale gathering of *M. hiantina* commenced at 2375–2682 cal. BP (OZQ190) (Table 1). A fragment of charcoal (Wk-32405) sampled from the wall of square K26 post-excavation from a depth of 8.6 cm below surface returned an age of 498–552 (99.4%) cal. BP which provides an indication of the time of cessation of midden building at Brremangurey. An AMS radiocarbon date from a pit feature identified at approximately 91 cm below surface (Wk-32409) was also obtained, and returned an age of 3579–3694 cal. BP.

Table 1
Initial radiocarbon ages.

Sample code	Sampling location	Material	Depth (cm. below surface)	Radiocarbon age (uncalibrated)	Calibrated age
Wk-32405	Trench wall	Charcoal	8.6	493 ± 33	498 – 552 (99.4%) 614 – 617 (0.6%)
OZQ-188	Excavated material	*Marcia hiantina*	24.1–28.1 (Spit 6)	1305 ± 25	695 – 892
OZQ-185	Excavated material	Charcoal	24.1–28.1 (Spit 6)	930 ± 25	791 – 918
Wk-32407	Trench wall	Charcoal	57.6	1896 ± 33	1733–1899 (98.9%) 1913–1920 (1.1%)
OZQ-189	Excavated material	*Marcia hiantina*	75.9–80.3 (Spit 15)	2495 ± 30	1942–2215
OZQ-186	Excavated material	Charcoal	75.9–80.3 (Spit 15)	2210 ± 30	2148–2319
OZQ-190	Excavated material	*Marcia hiantina*	91.0–95.9 (Spit 18A)	2850 ± 30	2375–2682
OZQ-187	Excavated material	Charcoal	91.0–95.9 (Spit 18A)	1875 ± 25	1733–1876
Wk-32409	Trench wall	Charcoal	91.0	3394 ± 25	3579–3694
Wk-32410	Trench wall	Charcoal	108.3	10,867 ± 39	12,694–12,801
Wk-32411	Trench wall	Charcoal	125.5	12,303 ± 44	14,059–14,564

Table 2
D/L values of all shell in this study.

Lab code (UWGA)	Spit	D/L Asx	Sample variance	D/L Glx	Sample variance	Radiocarbon lab code	Radiocarbon age (cal. BP)
10325	1	0.2405	±0.001	0.12	±0.002		
10326	1	0.307	±0.002	0.132	0	Wk-40860	295 – 462
10327	1	0.208	–	0.101	–		
10328	2	0.301	0	0.137	0		
10329	2	0.2775	±0.001	0.1405	±0.001		
10330	2	0.261	±0.004	0.1155	±0.001		
10331	3	0.2415	±0.003	0.108	0		
10332	3	0.2035	±0.001	0.1265	±0.001		

(continued on next page)

Table 2 (*continued*)

Lab code (UWGA)	Spit	D/L Asx	Sample variance	D/L Glx	Sample variance	Radiocarbon lab code	Radiocarbon age (cal. BP)
10333	3	0.3305	±0.003	0.259	0		
10334	4	0.2305	0	0.1155	±0.001		
10335	4	0.196	±0.004	0.1125	±0.001	Wk-40861	639 − 774
10336	4	0.234	0	0.106	0		
10337	5	0.257	–	0.084	–		
10338	5	0.2325	±0.007	0.0185	±0.003		
10339	5	0.221	–	0.026	–		
10340	6	–	–	–	–		
10341	6	0.270	0	0.0595	±0.115		
10342	6	0.240	0	0.103	0		
10496	6	0.362	±0.002	0.1485	±0.001	OZQ-188	695 − 892
10343	7	0.2235	±0.003	0.1065	±0.001		
10344	7	0.2385	±0.001	0.1185	±0.001		
10345	7	0.212	0	0.1105	±0.001		
10346	8	0.3265	±0.001	0.1735	±0.005		
10347	8	0.3265	±0.001	0.176	0		
10348	8	0.3545	±0.001	0.164	0		
10349	9	0.4435	±0.003	0.2195	±0.001		
10350	9	0.342	0	0.1375	±0.001		
10351	9	0.419	0	0.2055	0		
10352	10	0.425	±0.002	0.2155	±0.001		
10353	10	0.480	0	0.2375	±0.003		
10354	10	0.387	0	0.1785	±0.003		
10355	11	0.4235	±0.001	0.1795	±0.001		
10356	11	0.389	–	0.179	–		
10357	11	0.4075	±0.001	0.206	±0.002		
10358	12	0.6195	±0.003	0.2935	±0.001		
10359	12	0.4325	±0.002	0.232	0		
10360	12	0.573	0	0.269	±0.008		
10361	13	0.466	±0.002	0.2035	±0.001		
10362	13	0.4285	±0.003	0.195	0		
10363	13	0.399	–	0.191	–		
10364	14	0.3735	±0.005	0.198	0		
10365	14	0.4445	±0.001	0.1965	±0.001		
10366	14	0.4215	±0.007	0.1945	±0.003		
10367	15	0.4265	±0.001	0.2235	±0.001		
10368	15	0.364	±0.002	0.202	±0.004		
10369	15	0.4025	±0.001	0.1985	±0.003		
10497	15	0.4335	±0.021	0.214	±0.004	OZQ-189	1942–2215
10370	16	0.4225	±0.001	0.2235	±0.001		
10371	16	0.4095	±0.001	0.1925	±0.003		
10372	16	0.3965	±0.003	0.190	0		
10373	17	0.3875	±0.001	0.191	0		
10374	17	0.3825	±0.001	0.211	0		
10375	17	0.3625	±0.003	0.145	±0.002		
10376	18A	0.774	±0.006	0.6845	±0.003	Wk-40863	1983–2247
10377	18A	0.407	±0.002	0.153	±0.002		
10378	18A	0.423	0	0.2135	±0.001		
10498	18A	0.4265	±0.019	0.1905	±0.003	OZQ-190	2375–2682
10379	18B	0.543	0	0.3655	±0.001	Wk-40862	2756–2962
10380	18B	0.411	±0.002	0.189	±0.002		
10381	18B	0.412	0	0.2315	0		
10410	21	0.4195	±0.001	0.2445	±0.001		
10411	21	0.485	0	0.2385	±0.005		
10412	21	0.422	±0.002	0.2185	±0.003		
10413	23	0.3405	±0.001	0.1595	±0.011		
10414	23	0.415	±0.010	0.2305	±0.003		
10415	23	0.3855	±0.003	0.2085	±0.013		
10416	25	0.386	0	0.189	0		
10417	25	0.4485	±0.001	0.214	±0.002		
10418	25	0.4375	±0.001	0.236	±0.006		
10419	30	0.3635	±0.001	0.1545	±0.003		
10420	30	0.6845	±0.001	0.5375	±0.009		
10421	30	0.4065	±0.003	0.203	±0.002		

Table 3
Results of k-means cluster analysis, centroids etc.

	Amino acid	Centroid mean	Cluster range	Standard deviation
Cluster A	Asx	0.2421	0.196–0.307	0.03
	Glx	0.1022	0.0185–0.1405	0.033
Cluster B	Asx	0.4031	0.326–0.485	0.038
	Glx	0.2	0.1375–0.259	0.028
Cluster C	Asx	0.6388	0.543–0.774	0.093
	Glx	0.43	0.269–0.6845	0.177

In summary, the chronological patterning of Brremangurey can largely be separated into two distinct depositional phases; firstly a sand dominated deposit dating to the terminal Pleistocene, and secondly, intensive episodes of shellfish gathering and deposition through the late Holocene that resulted in the formation of the shell midden series seen in the upper extent of the deposit.

2.3. Midden analysis

Molluscan shell dominated the deposit at Brremangurey to a far greater extent than the initial observations of the midden's surface suggested. Of the total 1.79 m^3 that was excavated from square K26, 1.53 m^3 contained culturally deposited shell. The 50% sample of this total volume retained for analysis yielded 207 kg of culturally deposited shell material, with 205 kg coming from the uppermost 0.455 m^3 of the square.

Preliminary results of the midden analysis square of K26 are presented in Koppel et al. (2015). In summary, the midden deposit is dominated by marine bivalves. The soft-shore venerid *Marcia* (=*Tapes* = *Katelysia*) *hiantina* was the most abundant species present in the assemblage, comprising 70% of MNI (n = 27,906) and 81% of NISP (n = 259,556) counts in square K26. Much smaller quantities of the pearl oysters *Pinctada* cf. *albina* and *Isognomon ephippium* were identified, representing 2.2% (n = 878) and 1.4% (n = 570) of total MNI counts respectively. Belying surface observations, *T. granosa* comprised only a small proportion of the overall assemblage, at less than 1% (n = 316) of total MNI and NISP counts across all analysed material (Koppel et al. 2015). This small proportion of the mudflat inhabiting *T. granosa* is in contrast to the typical archaeological shell mound deposits reported across Australia's tropical north (e.g. Bailey, 1977; Veitch, 1999; Faulkner, 2013; Bourke, 2012; but see; Cochrane, 2014) where it is by far the most dominant species. MNI and NISP counts of all species drop dramatically at approximately 96 cm below surface which marks the lower limits of the midden unit. Below this level relatively small quantities of shell, particularly fragmented *M. hiantina* (n = 1010), were found between a depth of 96 and 156 cm below surface.

These fragments were in remarkably good condition considering the difference in age between the late-Holocene midden above and the terminal Pleistocene sandsheet below, raising questions about the stratigraphic integrity of the lowermost shell fragments. Do these 1010 fragments of *M. hiantina* found within terminal Pleistocene sands represent of late Pleistocene shell gathering, or are they Holocene fragments that are *ex situ*? Early Holocene shellfish gathering has been demonstrated in this site (Koppel et al. 2015) but at present this is confined to the species *T. granosa*. Do these stratigraphically-deeper fragments of *M. hiantina* represent an even older shell-gathering tradition at the site? The alternative explanation is that these shell fragments infiltrated into the older sandsheet from the younger midden deposit in Unit 1. Visually, texturally and taphonomically, there was nothing distinguishing *M. hiantina* fragments found within the Holocene midden deposit from the fragments found in the terminal Pleistocene sandsheet underneath. A zone of subsidence is noted towards the centre of the rockshelter and is potentially the result of water flowing into the rear of the shelter during periods of abundant rainfall, such as during the annual summer monsoons (Robert Vaughan personal communication 2011). Therefore the scenario of water flowing into the site, interacting with the midden shell and redistributing fragments into the lower and older portions of the site is a possibility. Nevertheless, if this occurred it must have been low energy to not leave visually distinctive taphonomic traces on shell surfaces.

Radiocarbon dating of fragments found within the terminal Pleistocene sands would conclusively define their temporality, especially when these dates are then compared with those already determined from material sourced from the Holocene midden deposit above. Due to the costs of individual age determinations, dating these potentially displaced fragments using the radiocarbon method is unfeasible. Constraining the dating program to only a few age determinations in order to reduce the costs narrows the scope and scale of questions that can be asked of the deposit (see Sullivan, 2008: 33), and may not adequately determine the whole range of dates. A greater number of age determinations will allow a greater understanding of the range of ages represented within the sandsheet-sourced shell fragments which will subsequently increase the chance of identifying temporally separate groups of shell.

To determine whether the shell fragments of *M. hiantina* found in the Pleistocene sands have been displaced downwards from the Holocene midden deposit above, an intensive dating program centred on the AAR technique was undertaken that assessed the D/L values of shell sourced from the two stratigraphic locations to establish relative ages. If the fragments from the sandsheet were *in situ*, their D/L values would be distinctively separated from the D/L values of shell from the midden deposit above. Conversely, should a displaced population of shell be identified, their D/L values would be equivalent to shells sourced from the midden deposit. Below, the results of the AAR analysis on *M. hiantina* are discussed, with the implications of these, as well as a comparison with a complementary radiocarbon dating program. The approach presented in this study is then critiqued, with the current challenges facing this method and its potential contributions to the discipline of archaeology considered.

3. Approach to investigation

As a dating method, AAR measures the proportional abundances of amino acids in their two forms. During life, amino acids are maintained in the laevorotary (L) form. Post mortem, the L-form amino acid molecules are rearranged into their dextrorotary (D) form with increasing proportional abundance through time: a process termed racemisation (Johnson and Miller, 1997; Wehmiller and Miller, 2000). Racemisation occurs until the ratio of D and L form amino acids reaches equilibrium and both forms occur in equal abundance, after which equilibrium is maintained through time. In short, the higher the D/L value the greater time since the organism's death. In an ideal, closed system, racemisation is primarily influenced by temperature. A number of other factors, however, can influence the rate of racemisation of amino acids such as pH, the presence of metal ions and microbial alteration to name a few (e.g. Bada, 1972; Bada and Schroeder, 1975; Child, 1995, summarised in Penkman, 2005: 33–38). Recent research has identified a small proportion of proteins that are encapsulated within individual calcium carbonate crystals that form molluscan shell (Sykes et al. 1995; Penkman et al. 2008). Once isolated, these intracrystalline proteins have proven to act as a closed system, and unlike the intercrystalline protein component of the shell matrix, are not influenced by contamination and exchange of non-indigenous proteins as well as the other aforementioned environmental factors. Targeting the products of intracrystalline protein diagenesis (IcPD) for use in AAR has subsequently provided more precise and reliable results (Penkman et al. 2008), and these techniques are applied in this study.

AAR has had a long history of application in shell midden archaeology (e.g. Masters and Bada, 1977; Bateman et al. 2008; Ortiz et al. 2009), however the method has largely been applied in a supplementary fashion to other techniques such as radiocarbon dating (but see Wehmiller, 1977; Demarchi et al. 2011). In contrast, geological and geomorphological research routinely uses AAR, and specifically aminostratigraphy, as a method for understanding patterns of deposition and post-depositional transformation (e.g. Miller et al. 1979; Kennedy et al. 1982; Hearty et al. 1986). Aminostratigraphy centres on the comparison of 'aminozones', which are groupings of similarly aged specimens. It is important to note that aminozones are established by temporality alone irrespective of spatial positioning of each sample. Following the identification of aminozones, a comparison between temporal patterning and spatial positioning allows interpretations regarding site formation and transformation processes to be made (Miller and Hare, 1980). A high resolution and broad AAR aminostratigraphic analysis will result in similarly aged fragments of shell clustering together in a scatterplot, whereas temporally distinctive populations of samples will separate from each other. Comparing these clusters with the relative spatial positioning of each sample stratigraphically will provide insights into how populations of similarly aged materials have moved through a site subsequent to initial deposition.

By comparing the aminozones identified using samples of *M. hiantina* sourced from the younger shell midden deposits and the older terminal Pleistocene sands of Brremangurey, the relative temporality of shells from both sampling locations should become clear. The IcPD method of AAR also accounts for the various taphonomic factors so prevalent in archaeological deposits. Based on the results, additional radiocarbon samples from shell fragments already dated using AAR provide a numerical age through which to anchor and further interpret results.

4. Methods

4.1. Sampling

To properly establish the aminostratigraphy of the midden deposit, shell specimens for AAR analysis were evenly sampled from all spits. In total, 72 specimens of *M. hiantina* were assayed. Fifty-seven specimens were sampled from the surface down to a depth of approximately 104 cm. This represents the first 19 spits of the excavation, as well as the entire extent of the dense Holocene midden in the Brremangurey rockshelter. Three shell specimens from each spit were selected for analysis. Only specimens that had no visible signs of burning or other taphonomic alterations were selected. A further 3 shell fragments were sampled from spit 21 (112–118 cm below surface), spit 23 (121–124 cm below surface), spit 25 (125–128 cm below surface) and spit 30 (150–154 cm below surface). Where possible, a complete right valve was selected to avoid the potential for sampling opposing valves of the same animal. While whole vales of *M. hiantina* were abundant within midden layer, the shell within the sandsheet was fragmented and sampling both left and right valves as well as fragments was unavoidable. Furthermore, the specimens of *M. hiantina* that were selected for the initial radiocarbon determinations were also incorporated into this study. This provided a paired radiocarbon age to the D/L value generated.

4.2. Sample preparation

Sample preparation was conducted as per Lachlan (2011) and described in detail in Koppel et al. (2015). In summary, shell fragments were thoroughly cleaned of adhering dirt and sediments through a series of rinses and sonication episodes in ultrapure Millipore water and mild abrasion using a rotary drill. Following this, whole shells were subsampled and the exterior and interior face abraded. A soak in 2M hydrochloric acid (HCl) was undertaken to remove the outermost surface of the shell which is the area of shell most likely to contain contaminants. Following Sykes et al. (1995), the shell fragments were then powdered and exposed to a 12.5% sodium hypochlorite bleach solution (NaOCl) to oxidise and destroy the intercrystalline protein component of the mollusc shell structure. The intracrystalline proteins are then isolated by dissolving the mineral calcium carbonate in 8M HCl. The vials are then filled with nitrogen gas and sealed, and then placed into an oven at 110° Celsius for 22 h to induce hydrolysis of the peptide bonds. The solution was then completely desiccated and rehydrated using a solution of 0.01 mM L-Homoarginine + 0.01M HCl + 0.77 mM sodium azide – with L-Homoarginine acting as an internal laboratory standard. Sample analysis was conducted using a reverse phase high pressure liquid chromatograph (RP-HPLC). Instrument procedures follow the method of Kaufman and Manley (1998) and refined by Kaufman (2000), summarised in Lachlan (2011: 345–347). Samples were run in duplicate and averages given.

5. Results

Out of the 72 samples analysed during this study, all but one provided useable results. Sample number UWGA10340 underwent an incomplete injection in the RP-HPLC and did not provide assessable results. Only the results of aspartic and glutamic acids are presented here. While 8 amino acids are isolated and quantified in the RP-HPLC, only the results of aspartic (Asx) and glutamic acid (Glx) are presented here. Throughout this manuscript, the use of the abbreviation Asx refers to the combination of native aspartic acid within a sample, as well as the aspartic acid that is generated as a result of the deamidation of asparagine in the preparation process. This is also the case for Glx, glutamic acid and glutamine (Hill, 1965). Aspartic acid was selected because of its abundance in molluscan shell, but also because of the balance it offers between temporal resolution and time-depth. Glutamic acid was also selected due to the high degree of covariance with Asx, which allows taphonomically affected samples to be identified through the deviation from this covariance (Kaufman, 2006).

The initial bivariate scatter plot showing the D/L values of Asx and Glx (Fig. 3) of all specimens analysed in this study reveal three main groupings of specimens, further defined by k-means cluster analysis. The two densest clusters, labelled clusters A and B in Fig. 3, contain the majority of the shell specimens used in this study.

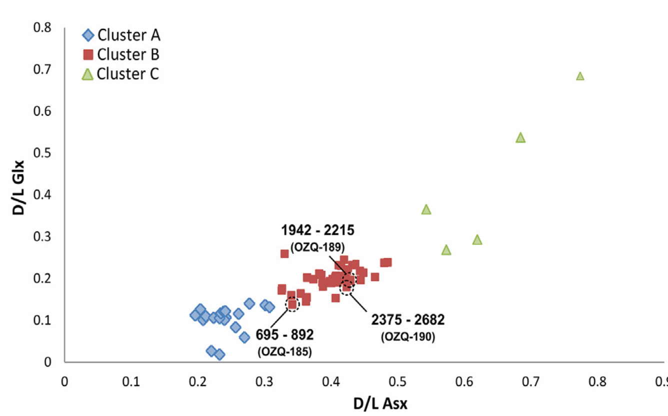

Fig. 3. Bivariate scatter plot with cluster analysis and radiocarbon ages.

Fig. 4. Scatter plot showing displaced specimens.

Cluster C contains the remaining 5 samples, and these exhibit the greatest extent of racemisation. Cluster C is also considerably more scattered when compared to clusters A and B with results covering a much greater range of D/L values.

Highlighting the shell fragments sampled from the Pleistocene sands underneath the Holocene shell midden, seen in Fig. 4, the temporality of these specimens become clear. All but one of these shell fragments exhibit D/L values consistent with specimens contained within Cluster B which dates to the early Holocene. The implication of this grouping as a result of the AAR analysis utilising spatially separated specimens becomes clear – the shell fragments are of identical age to those found in Cluster B and have therefore been spatially displaced through some process over time. The identification of the driving process or processes behind the displacement of these specimens is ongoing.

The similarity in D/L values exhibited between specimens from the lower extent of the midden layer and the displaced specimens sampled from the Pleistocene sand layer is further demonstrated in Fig. 5 which compares D/L of Asx with location of sampling. Specimens from spits 8 to the lowest level of sampling at spit 30 exhibit a restricted and consistent range of D/L values through the sequence. Contrasting to this are the specimens sampled from the upper portion of the midden unit between spits 1 and 7, which show an equally lesser extent of racemisation, yet a similar restricted and consistent range of values. Applying the results of the k-means cluster analysis, presented in Fig. 3, the specimens in Cluster A were all sourced from the upper most extent of the midden layer between spits 1 and 7. Similarly, clusters B and C are spread through the lower excavation units, from spits 8 to 30.

In drawing together the results of the relative dating program using AAR, along with the spatial positioning of each of the specimens utilised in this study, interpretations regarding episodes of deposition of shell at Brremangurey can be formed. The close concordance of relative age exhibited within Cluster A of Fig. 3 with the samples' restriction to the 7 uppermost spits of the midden, seen in Fig. 5, suggests a distinct episode of shellfish deposition at the site. The same interpretation can be made of the samples of Cluster B. This is in stark contrast to Cluster C, which contains only 5 specimens, yet covers a much greater range of D/L values than clusters A and B. Relying solely on the results of the AAR analysis in interpreting the very different pattern observed in Cluster C compared to the other clusters, an argument of a far less intensive period of shellfish deposition over a much longer period of time can be made. Whereas clusters A and B imply rapid deposition of a large amount of shell at the site, Cluster C suggests a more ephemeral and punctuated depositional behaviour of the occupants of Brremangurey.

To test whether the specimens observed in Cluster C of Fig. 3 are representative of an older tradition of shell gathering, as well as establishing a more complete chronological framework to anchor the results of the AAR analysis, a further program of AMS radiocarbon dating was undertaken. Using the range of relative ages established using AAR, 4 additional specimens of *M. hiantina* were selected for dating, and the results are presented in Table 4. Plotting all of the radiocarbon ages used in this study with the paired D/L values generated in this study, seen in Fig. 6, major, fine-grained complications arise. In some instances, multiple age reversals are identified where AMS radiocarbon ages do not conform to the samples' relative D/L values – meaning "younger" specimens according to the AAR analysis were determined to be older according to the radiocarbon dating program, and vice versa. For example, specimen Wk-40862 presented an extent of racemisation roughly half of Wk-40863, and yet recorded a radiocarbon age approximately 800 calibrated years older. A similar reversal is observed for samples Wk-40861 and Wk-40860, while samples OZQ-190 and OZQ-189 present nearly identical D/L values yet are separated by approximately 500 calibrated radiocarbon years.

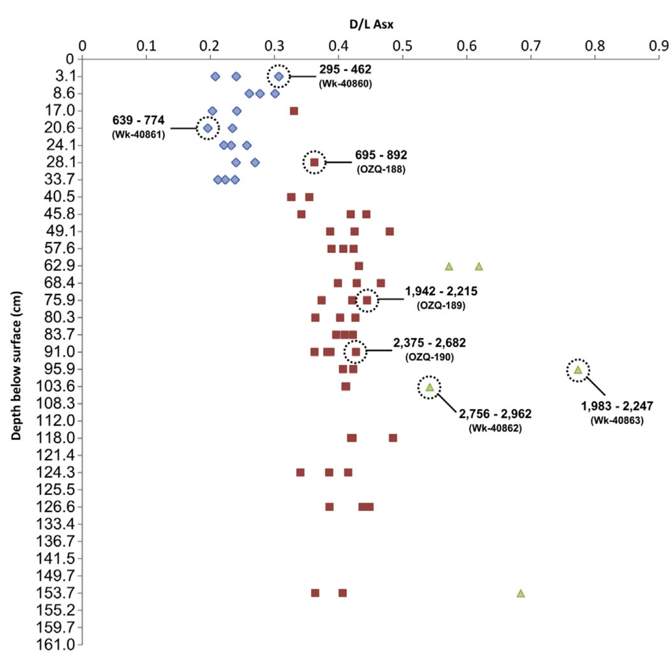

Fig. 5. Spit/depth versus D/L.

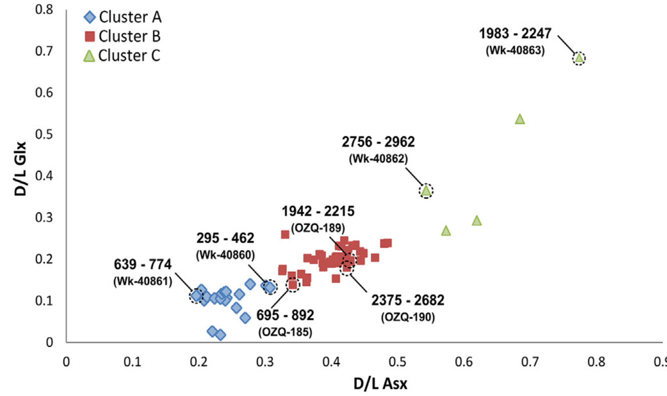

Fig. 6. Bivariate scatter plot with clusters and additional/all radiocarbon ages.

Table 4
Additional radiocarbon dates.

Sample code	UWGA sample code	Material	Depth (cm. below surface)	Radiocarbon age (uncalibrated)	Calibrated age
Wk-40860	10326	*Marcia hiantina*	0–3.1 (Spit 1)	800 ± 20	295 − 462
Wk-40861	10335	*Marcia hiantina*	17.0–20.6 (Spit 4)	1211 ± 20	639 − 774
Wk-40862	10379	*Marcia hiantina*	95.9–103.6 (Spit 18B)	3151 ± 20	2756–2962
Wk-40863	10376	*Marcia hiantina*	91.0–95.9 (Spit 18A)	2512 ± 20	1983–2247

The results of the additional radiocarbon dating program undertaken after the AAR analysis have effectively nullified the hypothesis that Cluster C is a depositional episode temporally distinct from clusters A and B. Despite exhibiting a substantially greater extent of racemisation, the radiocarbon ages do not reveal a similar distinction in numerical age. While AAR was able to reintegrate the shell midden temporally in terms of broad depositional episodes, the finer grained details are problematic. Exactly why this may be the case is considered below.

6. Discussion

Taken on its own, the program of intensive relative dating of midden shell using AAR reported in this study conclusively identified shell material that was spatially separated as being chronologically contemporaneous, and therefore identified vertical displacement in a shell midden. However, on a more fine-grained level, a lack of correlation between paired AAR and radiocarbon dating methodologies was noted. A similar approach to the one presented here, albeit focussing on *Anadara granosa* rather than *M. hiantina*, yielded successful results including a positive correlation between AAR and paired radiocarbon ages (Koppel et al. 2015). Why one study found no issues in the correlation of AAR and radiocarbon ages while the other encountered problems raises immediate questions regarding this new application of the long-standing AAR method.

AAR has traditionally been utilised alongside or as a substitute for radiometric methods such as radiocarbon and OSL dating. While sometimes this is out of necessity due to a lack of dateable material or samples being beyond the limit of radiocarbon dating (e.g. Parfitt et al. 2005), in other examples it is not (e.g. Bada, 1985; Cann et al. 1991). Despite AAR being a relative dating technique, its use as an alternative for numerical dating methods has driven developments to "calibrate" the racemisation reaction to allocate projected numerical ages (Johnson and Miller, 1997: 269). Through a combination of independent radiometric ages, coupled with modelling the species-specific rate of racemisation, an absolute age can be determined from the D/L value of a sample (e.g. Wehmiller et al. 1995; Clarke and Murray-Wallace, 2006; Kosnik et al. 2008). This contrasts with the calibration of radiocarbon ages, where independent proxies such as tree rings and speleothems, match radiocarbon to calendrical years (Stuiver, 1982). This is an important distinction between the calibration of radiocarbon age determinations and the "calibration" of D/L values as the former is absolute, and the latter is much less strongly anchored and remains susceptible to many other external influences.

It is precisely these external influences which may result in a lack of congruence between radiocarbon and AAR results. The temporal and spatial scale of geological contexts, where AAR is most commonly used, is generally much larger and coarser in resolution than those of archaeological contexts. Because of this, distortions in the results of AAR analyses are muted purely due to the relatively larger scale of the investigations being undertaken and questions asked. Archaeological contexts are of much smaller and fine-grained spatial and temporal scale (Lock and Molyneaux, 2006), and as such the influence of analytical error has a much greater impact on overall interpretations. As well as this, the additional influence of anthropic factors, such as the potential thermal influence of small scale camp-fires, adds an additional layer of complexity to AAR in archaeological contexts. With this in mind, can the traditional assumptions which underpin the "calibration" and use of AAR be directly applied to archaeological contexts without reformulation? The complications identified in this study suggest that a rethink is required.

The racemisation reaction, and more specifically the rate of racemisation, which underpins this particular dating methodology is influenced by many factors (Schroeder and Bada, 1976; Johnson and Miller, 1997). In attempting to identify the reason behind the lack of correlation between what should be complementary dating methods, four different possibilities are hypothesised here: human and machine error, intraspecies variations in racemisation rates due to biological and metabolic processes, and taphonomic influences including variations in thermal histories.

Both human and machine error during the process of analysis was quickly ruled out. The samples that presented a lack of agreement between extent of racemisation and radiocarbon age determinations were reanalysed twice, and in all instances resulted in statistically identical D/L values. The exact samples of shell that were submitted for radiocarbon dating were also returned and subjected to AAR analysis, also resulting in statistically identical D/L values. Intraspecies variations in the rate of racemisation have also been observed. Different areas within the same shell specimen have resulted in varying D/L values (e.g. Hare, 1963; Goodfriend and Weidmen, 2001). Similarly, protein composition and amino acid abundance has been identified to vary between different microstructures in molluscan shell (e.g. Kobayashi and Samata, 2006). Due to the consistency of sampling locations in the shell valves utilised in this study, along with the focus on one particular species, the effects of intraspecies variations in AAR determinations should not be apparent. The infiltration of non-endogenous proteins is also not a possibility as the IcPD approach to AAR utilised in this study completely destroys the non-intracrystalline protein fraction. With these possibilities ruled out, one factor remains as arguably the most parsimonious explanation for the lack of congruence between the results of the AAR and AMS radiocarbon dating programs utilised in this study.

The greatest variable of the rate of the racemisation reaction is temperature. Increasing temperatures increases the rate at which racemisation occurs (Miller and Brigham-Grette, 1989). The Brremangurey rockshelter is located in the tropics (Latitude − 14° 32′ S), thus little seasonal fluctuation in mean average temperature is observed. Similarly, the squares from which the midden material was excavated are permanently protected from the radiant heat of sunlight because of the shade generated by the rockshelter itself. These two features of Brremangurey result in a largely consistent ambient air temperature year round. Should the cause for the age inversions between AAR and radiocarbon be thermal in origin, it would not be on an environmental scale, but rather smaller and more isolated events such as campfires and hearths; features that are abundant throughout the Brremangurey rockshelter and midden deposit sequence (Moore, 2011). It is a distinct possibility that the heat generated by these small scale fires would hasten protein diagenesis, with little impact upon radiocarbon ages generated from the same specimen.

Identifying the influence of heating using AAR has been an area of limited research (Brooks et al. 1991). Heating experiments, in this case exposure to temperatures of 200–230° Celsius for one hour, revealed that the rate of racemisation of Glx was preferentially hastened. This resulted in D/L values of Glx exhibiting an increased extent of racemisation in comparison to the usually faster racemising Asx. While the experiments presented by Brooks et al. (1991) were focussed on ostrich eggshell, similar patterns of relatively advanced racemisation of Glx interpreted to have been the result of anthropic heating have been identified in molluscan shell (Demarchi et al. 2011: 120; Koppel et al. 2015). Preferentially advanced racemisation of Glx was not observed in the results of this study, and as such the identification of anthropic heating as the driver of the anomalous ages presented above remains unresolved. Experimental work to date has only tested the effects of heat; however it is possible that combustion and oxidation, as well as the high and sometimes unstable temperatures associated with fires, may play an equally influential role in the overall effects of fire in the AAR reaction. This requires further experimental work if AAR methods are to be refined and prove useful in fine-grained archaeological interpretations.

7. Conclusion

The results of the AAR analysis presented in this study, when treated independently, neatly and efficiently identified that the majority of *M. hiantina* fragments found within the terminal Pleistocene sands at Brremangurey to have undergone significant vertical displacement and be of a late Holocene age. Without the need for numerical calibration, AAR was able to firmly establish two major phases of *M. hiantina* deposition that formed Brremangurey's Holocene midden, and it is from the older of these two phases that the displaced fragments originated. The results of the subsequent confirmatory radiocarbon dating program, however, produced ages not strictly in accordance with the relative ages generated here using AAR.

The exact cause of these inversions between radiocarbon and D/L values remains unknown. Methods of sample preparation and analyses specifically designed to negate taphonomic influences that distort AAR results were undertaken, and no indication of the influence of anthropic heating was detected. The forces that have resulted in the non-alignment of what should be two complementary dating methodologies remain elusive.

Despite this obstacle, the potential of this new application of the well-established AAR dating technique is clear. AAR is undergoing a renaissance in archaeological research, and like the developments through time in both radiocarbon and OSL dating, the method is becoming more refined and reliable. In saying this, however, issues do need to be resolved; particularly centred on archaeocentric hazards to AAR such as burning. This is but one of a number of anthropic processes not typically encountered by geochronologists, and thus remains underdeveloped methodologically. Further experimentation is therefore required to bring this method up to speed with other dating techniques and into the chronological toolkit of archaeological researchers across the world.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2015.09.052.

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The Brremangurey pearl: a 2000 year old archaeological find from the coastal Kimberley, Western Australia

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A small marine pearl was recovered at the Brremangurey rockshelter, on the Kimberley coast, from layers dating to approximately 2000 years ago. In an area famous for its pearls and history of cultured pearl production, public interest centred on whether the pearl was as old as the layer in which it was contained, or whether it was a recent cultured pearl that had infiltrated down from above. The near-spherical shape of the pearl hinted at a possible cultured origin. Owing to the uniqueness and historic cultural significance of this find, non-invasive analytical techniques were used to investigate whether the Brremangurey pearl was cultured or natural. Midden analysis was further used to assess the likely origin of the pearl within the stratified deposits. Analysis confirmed that the pearl is of natural origin and a dense midden lens of Pinctada albina shells is its likely origin.

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SHORT REPORTS

The Brremangurey pearl: A 2000 year old archaeological find from the coastal Kimberley, Western Australia

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Abstract

A small marine pearl was recovered at the Brremangurey rockshelter, on the Kimberley coast, from layers dating to approximately 2000 years ago. In an area famous for its pearls and history of cultured pearl production, public interest centred on whether the pearl was as old as the layer in which it was contained, or whether it was a recent cultured pearl that had infiltrated down from above. The near-spherical shape of the pearl hinted at a possible cultured origin. Owing to the uniqueness and historic cultural significance of this find, non-invasive analytical techniques were used to investigate whether the Brremangurey pearl was cultured or natural. Midden analysis was further used to assess the likely origin of the pearl within the stratified deposits. Analysis confirmed that the pearl is of natural origin and a dense midden lens of Pinctada albina *shells is its likely origin.*

Introduction

During excavations in 2011 at Brremangurey, a north Kimberley coastal rockshelter, a small nacreous marine pearl was recovered from within the site's shell midden. Although there is no record of pearls being of cultural importance to Australia's Indigenous peoples, the pearl generated much excitement and many questions from Kimberley locals, both around the site and further afield. Given the pearling heritage of the Kimberley, many of these questions related to the age and origin of the pearl. Although recovered from a layer which was radiocarbon dated to 1800–1906 cal. BP, local pearl experts raised the possibility that it could be an intrusive cultured pearl, based on its size, colour and spherical shape. We acknowledge that the pearl is most likely an incidental find in archaeological terms, but the public interest in its history, age and origin compelled us to develop tools to address these questions. As a unique object of historical value to many, a programme of non-invasive analyses was developed; we hope some of the techniques presented here will provide a constructive pathway to others working in these fields.

Background

Brremangurey is a quartzite rockshelter located 70 m inland from the current shoreline on the north Kimberley coast (Figure 1). The site deposits span periods of the late Pleistocene and Holocene, with a dense mid- to late Holocene shell midden dominating the upper portion of the sequence; the pearl was recovered whilst screening these midden deposits. Despite having the appearance of a cultured pearl, it was recovered from a depth of 70–77 cm below datum (Square K26, Spit 14). Marine shell from this level was AMS radiocarbon dated to 1800–1906 cal. BP (Table 1). A detailed excavation report is currently being prepared for publication, as are papers on the shell midden analysis.

Measuring 5.9 mm in maximum diameter and weighing 0.25 g (Figure 2), the Brremangurey pearl is the only pearl to have been recovered from a prehistoric archaeological site in Australia and one of only a small number found in archaeological contexts globally (e.g. Charpentier et al. 2012; Koerper and Desautels-Wiley 2007 from the Arabian Gulf and southern California, respectively). The Kimberley coast is a well-known centre for the production of South Sea pearls, farmed from the large pearl oyster species *Pinctada* *maxima*. The collection of natural pearls from local beds of the smaller species *P. albina* further to the south in Shark Bay was a significant industry in the 1860s before the beds collapsed, after which the industry never entirely recovered (Kunz and Stephenson 1908:200–201; Moore 1994:123; Streeter 2006:144). Subsequently, a new industry utilising then novel Japanese technologies of pearl culturing was introduced to the areas surrounding Broome in the 1950s (Edwards 1994:70; Ward 2002:32). Today, pearl farms are scattered along the northern Australian coast from the Kimberley to Darwin (Dennis 2011; Hills 2013).

Despite the fact that the pearl was recovered from sub-surface deposits in what appeared to be a robustly stratified midden, two Broome pearl experts (James Brown and Penny Arrow) likened the Brremangurey pearl to a cultured Akoya pearl. Akoya pearls are smaller than those generally produced by *P. maxima* and are cultured from the Japanese species *P. imbricata fucata* (=*fucata*) (Bouchet 2014; Landman et al. 2001:30; Ward 2002:25). The slightly golden-rose hue of the

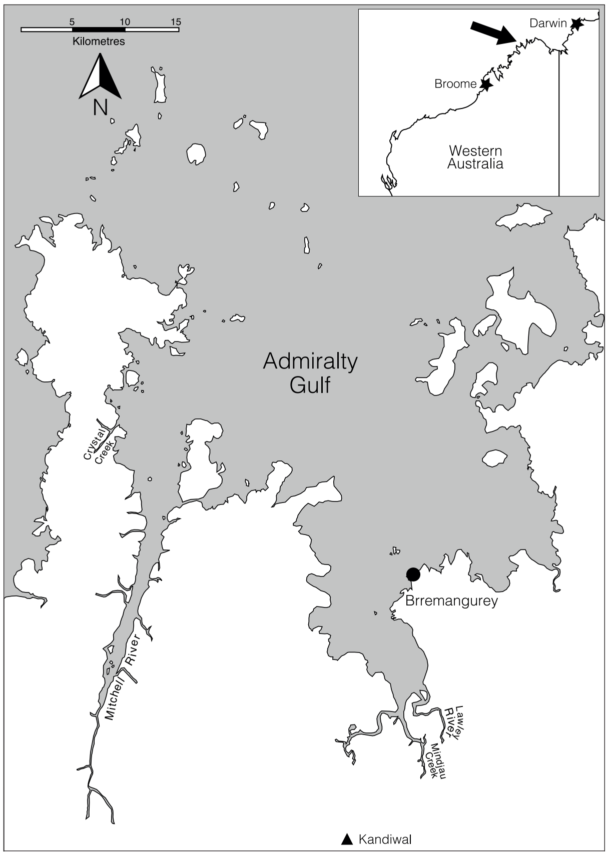

Figure 1 The location of the Brremangurey site on the shore of the Admiralty Gulf, northern Western Australia.

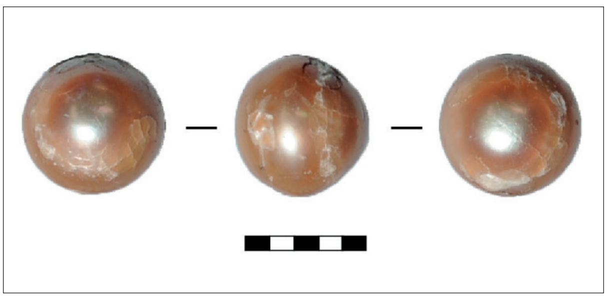

Figure 2 The Brremangurey pearl. Scale bar is in millimetres.

Laboratory Code	Material	Uncalibrated Age	ΔR	Calibrated Age (1 σ)	Calibrated Age (2 σ)
OZQ-192	*Pinctada albina*	2305±25	60±31	1800–1906	1730–1954

Table 1 AMS radiocarbon date stratigraphically associated with the Brremangurey pearl. Calibrated using Calib 7.0.2 with the Marine 13 dataset (Reimer et al. 2013; Stuiver and Reimer 1993). ΔR as recommended by Alan Hogg (23 December 2014).

Brremangurey pearl also aligned with the common colour palette of Akoya pearls. Shell midden deposits are notoriously porous (e.g. Stein 1992; Villagran et al. 2009) and detailed analytical work on the chronostratigraphic integrity of the Brremangurey shell midden using amino acid racemization clearly demonstrated that there has been significant time-averaging of portions of the midden deposits, as well as instances of substantial downward movement of shell within the matrix. The possibility that the pearl could be intrusive was therefore investigated.

Analytical Approaches

Standard analytical techniques, such as radiocarbon dating, stable isotope analysis and elemental analyses (e.g. ICP-MS), all require parts of the sample to be destroyed (Malainey 2011:106–107, 264), and thus were inappropriate for this study[1]. In coordination with Cygnet Bay Pearl Farm, a comparative analysis of known-age beaded and unbeaded ('keshi') pearls, and the Brremangurey pearl was conceived, in which x-ray computed microtomography (µ-CT) analysis would be used to visualise the pearls' interior structures, including banding and bead/nucleus morphology.

µ-CT is a non-destructive imaging methodology with high spatial resolution. Samples are typically rotated through 360°, creating a three-dimensional model comprised of a large series of two-dimensional slices which can be individually assessed. The use of x-ray technology allows differences in density to be clearly defined and mapped through the differential blocking and absorption of x-rays (Karampelas et al. 2010). The abilities and non-destructive nature of µ-CT make it ideal for studying pearls and the structures and layers of which they are composed (Karampelas et al. 2010; Krzemnicki et al. 2010).

A GE Phoenix v|tome|x ultra high resolution CT system with an additional nanofocus x-ray tube was used for the analysis, with a 3D maximum resolution of 2 µm. Three pearls (two seeded in 2010 and harvested in 2012) made available by Cygnet Bay were scanned. The beads used were aragonitic spheres manufactured from the shell of a species of North American freshwater mussel ('Mississippi mussel'). The third example from Cygnet Bay was a keshi pearl that grew without an inserted bead. The Brremangurey pearl was also scanned and, in addition to a scan of the complete pearl, a scan focused on the interior nucleus was also undertaken. Final images were scanned at the most appropriate resolution to capture the whole pearl structure; however,

1 It should be noted that 'non-destructive' in archaeological terms (i.e. no physical modification of the object) is more equivalent to the term 'non-invasive' in the physical sciences, rather than their usage of the term non-destructive (Cassar and Degrigny 2005).

SHORT REPORTS

initial scans at high resolution were checked to ensure that small changes in final resolution did not alter the type and number of banding observed in each pearl.

Results

The scans of the beaded Cygnet Bay pearls, which had a growing duration of two years before harvest, showed clear bands of aragonite laid down over the bead. For each year of growth, a single band of nacre was deposited (Figure 3). In contrast, the scan of the Brremangurey pearl revealed no less than 14 layers of nacre (Figure 4). The layers of nacre are also relatively thinner than those seen in the cultured Cygnet Bay pearls.

The µ-CT scans demonstrated that the Brremangurey pearl had a near-spherical nucleus (Figure 5). It was also apparent that it was composed of calcium carbonate. As with the aragonite beads of the modern cultured pearls, materials of the same mineralogical composition appear with the same colour/density in the µ-CT scans. Despite both the Brremangurey and Cygnet Bay beaded pearls having spherical calcium carbonate centres, there were clear visual differences in their internal structures. The Cygnet Bay examples had a solid, homogeneous aragontic mass at their centre in line with the sculpted bead used in pearl aquaculture (Figure 3). The Brremangurey pearl had a nucleus seemingly comprised of a hollow centre surrounded by radial calcium carbonate struts projecting outwards to a pustulose exterior (Figure 5). This morphology clearly accords with what is expected in a natural pearl generated by damage during growth at the mantle of the mollusc (Hänni 2012). The younger mantle cells, which sit outermost on the mantle, generate the dull outer calcitic prismatic layer of shell, whereas the older cells produce the nacreous lustrous shell interior (Hänni 2012). Thus, when damage occurs at the edge of the mantle, a small cyst is often formed in which prismatic cells are laid down first, followed by sequential layers of nacre (Hänni 2012). This is a recognised growth mode and structure for natural pearls, and matches precisely the internal structure of the Brremangurey pearl.

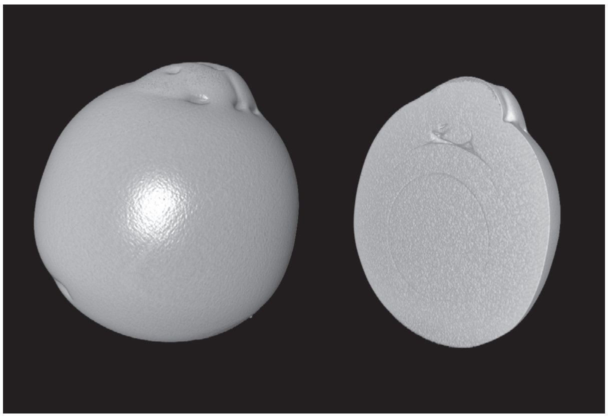

Figure 3 µ-CT surface rendering of a Cygnet Bay Pearl seeded in 2010 and recovered in 2012 (left) and showing two bands of nacre in cut-away view (right). An irregularity in banding has formed around an intrusive object during pearl growth. Scanning was undertaken at 31 µm resolution at 130 kV and 70 µA. Pearl is 10.6 mm in lateral diameter.

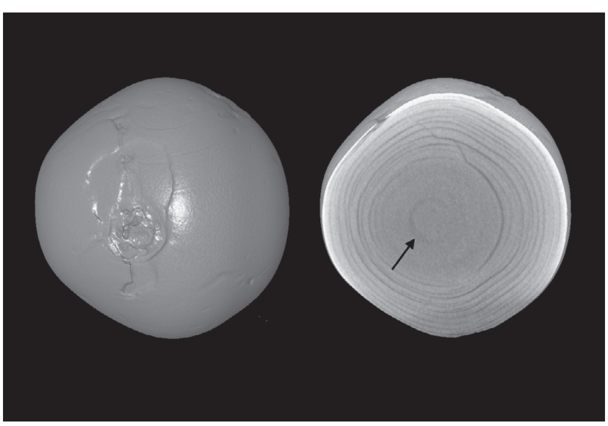

Figure 4 µ-CT surface rendering of the complete Brremangurey pearl (left) showing layers in cut-away view (right). Scanning was undertaken at 15 µm resolution at 130 kV and 70 µA. Pearl is 5.9 mm in diameter.

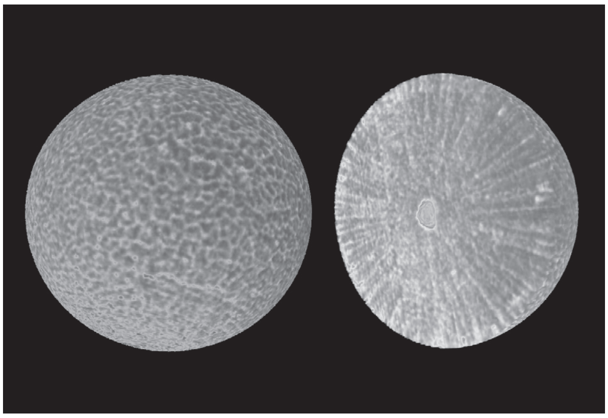

Figure 5 µ-CT rendering of the nucleus of the Brremangurey pearl, taken at 650 µm radius from the centre void (left), with cut-away view showing the centre void and radial strut-like structures (right). Scanning was undertaken at 6.7 µm resolution at 100 kV and 70 µA.

Discussion and Conclusion

The µ-CT analysis shows that the Brremangurey pearl has neither the type of banding nor internal artificial bead that we would expect to see in a cultured pearl. The extended period of growth evidenced by the high number of nacreous internal layers is also well in excess of conventional and historical culturing practices. Although the programme of non-invasive analysis did not allow us to date the pearl directly, no data generated during the course of these analyses implies intrusion from higher levels. The pearl has also been emphatically demonstrated to be of natural formation.

In terms of its archaeological context, the pearl was embedded within a dense lens of shells from the small pearl oyster species *P. albina*, with the midden both above and below this lens being dominated by the much more common soft-shore bivalve *Marcia hiantina*. Amino acid racemization analyses demonstrate that the *P. albina* lens is in situ and stratigraphically distinct from other midden formation episodes (Brent Koppel unpub. data). With the pearl likely being an incidental introduction through ancient Indigenous shell collection, the most important aspect of the pearl recovered from Brremangurey may not be the pearl itself, but the dense lens of pearl oyster shells in which it was embedded. It has been previously argued that *Pinctada* spp. pearl oysters were of cultural significance in the Kimberley (Akerman and Stanton 1994; Balme and Morse 2006; O'Connor 1999:121). The potential cultural significance of the *P. albina* layer at Brremangurey will be further explored within the larger context of the shell midden analysis in an upcoming publication.

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