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# Extended residence times for foraminifera in a marine-influenced terrestrial archaeological deposit and implications for palaeoenvironmental reconstruction

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ABSTRACT

Accelerator Mass Spectrometry (AMS) radiocarbon dating and taphonomic grading was undertaken on foraminifera preserved in the archaeological shell matrix site of Thundiy, Bentinck Island, southern Gulf of Carpentaria, Australia. Foraminifera were assigned to one of six taphonomic grades ranging from pristine to severely abraded. AMS dating demonstrates a weak relationship between preservation status and age. Foraminifera ages are inconsistent with multiple ages on marine shell from the same deposit implying significant sediment transport system residence ages (the time between death of the organism and final deposition) for foraminifera in the deposit. Results demonstrate that foraminifera cannot be assumed to be contemporary with other components of the sedimentary context in which they occur, indicating that caution is required in interpreting chronologies and palaeoenvironmental records based on foraminifera recovered from highly dynamic depositional settings. Findings point to the potential of foraminifera AMS dating of coastal archaeological deposits to contribute to evaluations of site integrity and chrono-stratigraphic analyses.



## 1. Introduction

Coastal archaeological deposits adjacent to nearshore environments are subject to highly dynamic processes that shape their formation and post-depositional alteration. Sea-level change, storm events and human and non-human impacts create multiple vectors differentially impacting coastal deposits during and after their deposition (Bird, 1992; Rowland and Ulm, 2012; Szabó, 2012). To understand the numerous site formation processes impacting coastal shell deposits and to develop an understanding of site integrity, archaeologists conventionally employ stratigraphic analyses, shell taphonomy studies, shell taxa analysis, intra-specific size analysis and shell fragmentation studies (e.g. Attenbrow, 1992; Bailey, 1983; Carter et al., 1999; Claassen, 1998; Hughes and Sullivan, 1974; O'Connor and Sullivan, 1994; Rick et al., 2006; Ulm, 2006). The potential of microfauna, such as foraminifera, to address these questions has rarely been considered (cf. Reitz and Shackley, 2012).

Foraminifera are single-celled organisms (amoeboid protists), abundant in marine environments, that secrete a hard calcium carbonate shell or 'test'. Foraminifera are routinely used in earth and oceanographic sciences for palaeoenvironmental reconstructions and directly dated to constrain depositional sequences, contributing to studies of sea-level change, climate change, reef-island accretion, sediment transport dynamics and intertidal zonation (e.g. Callard et al., 2011; Dawson et al., 2014; Ford and Kench, 2012; Gehrels et al., 2012; Herkat and Ladjal, 2013; Koutavas et al., 2002; Reymond et al., 2013; Sarnthein et al., 2015; Woodroffe and Morrison, 2001; Woodroffe et al., 2005, 2007; Woodroffe, 2009; Yamano et al., 2000). However, foraminifera are rarely used in archaeological applications (cf. Lilley et al., 1999; McNiven, 1996; Rosendahl et al., 2007, 2014; Weisler, 1999; Weisler et al., 2012), despite their potential to contribute to understandings of coastal archaeological site formation processes and palaeoenvironments.

As foraminifera are ubiquitous in marine environments, natural terrestrial deposits created, redeposited or otherwise impacted by marine action and events (e.g. tides, storm surges) should exhibit foraminifera. In contrast, sites formed by cultural processes with no natural marine depositional processes influencing their formation, should contain very few, if any, foraminifera (McNiven, 1996; Rosendahl et al., 2007). On this basis, foraminiferal density studies have been established as a

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reliable criterion for distinguishing between natural and cultural marine shell deposits (Rosendahl et al., 2007, 2014); however, the wider potential of foraminiferal analyses to contribute to understandings of foraminifera transport and depositional processes in archaeological contexts remains undeveloped. This study applies AMS radiocarbon dating and a novel taphonomic classification of foraminifera to refine understandings of site formation processes at the archaeological shell midden site of Thundiy, Bentinck Island, southern Gulf of Carpentaria. We provide a taphonomic classification of foraminifera related to the complex taphonomic histories of these tests rather than age, providing the basis for assessing the chronology and taphonomic characteristics of the foraminifera assemblage. Results call into question the validity of using foraminifera as tools for chronology-building and defining environmental characteristics in palaeoenvironmental reconstruction in highly dynamic depositional settings.

## 2. Background

Recent studies have employed AMS dating of biogenic carbonate sand grains to investigate the contribution of benthic foraminifera to reef-island accretion and to determine the depositional chronology of reef-island sand cays in the Pacific (Dawson et al., 2014; Woodroffe and Morrison, 2001; Woodroffe et al., 2007). These studies emphasise the importance of dating individual foraminifera that have undergone rapid transport from their source to the site of deposition to ensure that ages reflect the time of deposition with negligible residence times (the time lag between sediment production and either final deposition or permanent loss; see Dawson et al., 2014:69) and post-depositional reworking. 'Pristine' foraminifera tests (i.e. those assumed to have been rapidly deposited after death as indicated by morphological attributes) are preferentially selected for dating to reduce potential post-depositional age bias (Dawson et al., 2014; Woodroffe et al., 2007). For instance, Woodroffe and Morrison (2001:256) argued that due to the small radiocarbon age differences between the various reef sediment constituents (c.250–350 years), it is likely that constituent grains, particularly foraminifera, are rapidly transported and deposited soon after death in reef island contexts.

Woodroffe et al. (2007) examined the depositional chronology of Warraber Island, a small sand cay in Torres Strait, based on component-specific AMS dating of sand grains, including coral, molluscs and foraminifera. A set of 32 'pristine' single grain samples was selected for dating to reduce the potential age bias produced by post-depositional reworking (Woodroffe et al., 2007). AMS results indicated that different components yielded substantially different ages with individual foraminifera tests, despite their pristine condition, returning the oldest dates from the island (4510–6639 cal BP compared to the determined time span of island progradation in the last 3000 years). Woodroffe et al. (2007:4) hypothesised that the foraminifera samples collected from the reef flat around Warraber Island were relict, speculating that they had originated from conditions associated with the mid-Holocene fossil reef and endured intermittent entrainment and re-deposition throughout the mid-to-late Holocene.

In a similar study, Dawson et al. (2014) investigated sediment production and reef-island accretion on a sand cay on Raine Island, northern Great Barrier Reef, using an extensive collection of single-grain AMS radiocarbon age determinations. A total of 100 individual large benthic foraminifera between 500 μm and 2 mm were assigned to one of three taphonomic grades: pristine ('P'), moderately abraded ('M'), and severely abraded ('S') (Dawson et al., 2014). 'P' samples represented the initial stages of test degradation prior to fragmentation and loss of spines, while 'severely abraded' samples represented the end product of abrasion (Dawson et al., 2014). Specimens of grade 'P', 'M' and 'S' collected from nine reef flat transects were selected for AMS radiocarbon dating, along with additional grade 'P' and 'S' specimens from contemporary beach settings.

Results demonstrated that preservation (i.e. taphonomic grade) was generally related to age, implying a short time between production, mortality and deposition, typically of <10 years (Dawson et al., 2014). However, the age of severely abraded tests collected from the contemporary beach samples was found to be similar to the oldest pristine tests sampled from the reef flat. The authors suggest that the central coral zone might be a sediment sink for foraminifera which are subsequently transported to the beach zone and/or remobilised in beach sediments. In keeping with the results reported by Woodroffe et al. (2007), this implies long-term storage of foraminifera under excellent preservation conditions in certain reef flat contexts.

Elsewhere, studies have demonstrated that foraminifera can persist for thousands of years linked to favourable alkaline reservoir environments associated with high shell content (Aller, 1982; Kidwell, 1989; Kotler et al., 1992). As Martin et al. (1995) point out, foraminiferal preservation is likely to vary with depositional setting, meaning that the findings of Dawson et al. (2014) may be specific to Raine Island or detached reefs on the northern Great Barrier Reef. These results suggest that while there might be a general relationship between taphonomic condition and age, individual foraminifera follow unique sedimentary pathways requiring further investigation.

These studies highlight the need to identify differential preservation of foraminifera in specific environmental settings to reduce age biases. Unless robust chronologies and depositional models can be established these issues potentially undermine the validity of using foraminifera as tools for palaeoenvironmental reconstruction. AMS dating of foraminifera samples coupled with taphonomic assessment in an archaeological context is needed in order to assess the potential of foraminifera as accurate chronological and palaeoenvironmental indicators in archaeological deposits.

## 3. Materials and methods

### 3.1. Case study: Thundiy

Samples for this study were recovered from the archaeological shell matrix site of Thundiy, located on the northern coastline of Bentinck Island in the southern Gulf of Carpentaria (Fig. 1). Archaeological deposits at Thundiy extend over an area c.4 km long (SE-NE) and up to 150 m wide (NW-SE), with dense cultural shell deposits overlying a natural shelly-beach ridge, which in turn overlies partially consolidated beachrock. The surface of the ridge is elevated 6.5 m above the Australian Height Datum (AHD), with an adjacent wide flat supra-tidal mudflat (c.160 m-wide) and broad, thick coastal mangrove fringe (c.120 m-wide) separating the contemporary ridge from the open ocean. Sediment supply to the site derives from both natural (e.g. storm surge, wind) and cultural (e.g. disposal of food waste) actions. Three 50 cm × 50 cm test pits (Squares A, B and C) were excavated at 50 m intervals along the top of the ridge in the approximate centre of the site with ancillary Squares D and E excavated to investigate geophysical features in a related study. Square B, the focus of this analysis, was excavated to a depth of c.60 cm in 20 individual excavation units (XUs) averaging 3.2 cm in thickness. The stratigraphic profile of Square B is characterised by a dense layer of shell c.40 cm deep, overlying c.20 cm of natural sandy beach ridge material at the base of the deposit (Fig. 2). Stratigraphic profiles and ages available for Squares A and C demonstrate a similar gross chronostratigraphic structure (Table 1).

### 3.2. Analytical procedures

Sediment samples (~10 g) from each of the 20 excavation units were selected by quartering the bulk <3 mm sediment samples (after Pope and Ward, 1998). Each sample was separated into fractions using nested Endecotts sieves (2 mm, 1 mm, 500 μm, 250 μm, 125 μm and the base plate fraction at <125 μm) (Haynes, 1981). The <250 μm sieve fractions were not analysed further owing to size limitations (i.e.