Geographical Research

On the Possible Origins of an Unusual (Mid to Late Holocene) Coastal Deposit, Old Punt Bay, South-East Australia

A.D. SWITZER[1,2]*, B.L. MAMO[3,4], D. DOMINEY-HOWES[4], L.C. STROTZ[4], C. COURTNEY[4], B.G. JONES[5], S.K. HASLETT[6] and D.M. EVERETT[6]

[1]*Earth Observatory of Singapore (EOS), Nanyang Technological University, 50 Nanyang Avenue, 639798 Singapore.*

[2]*Divison of Earth Sciences, Nanyang Technological University, 50 Nanyang Avenue, 639798 Singapore.*

[3]*Department of Biological Sciences, Macquarie University, Sydney, NSW 2109, Australia.*

[4]*Natural Hazards Research Laboratory and Australian Tsunami Research Centre, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia.*

[5]*School of Earth and Environmental Sciences, University of Wollongong, Wollongong, NSW 2522, Australia.*

[6]*School of STEM, University of Wales, King Edward VII Avenue, Cathays Park, Cardiff, CF10 3NS, UK.*

**Corresponding author. Email: aswitzer@ntu.edu.sg*

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Abstract

An unusual coarse, shelly sedimentary unit is found elevated above present mean sea level in a sheltered pocket embayment at Old Punt Bay in south-eastern Australia. The coarse sediments, diverse microfauna, and large shelly macrofauna of mixed affinity suggest that the deposit is the result of high-energy deposition. The deposit was previously thought to have been deposited 1000–1300 cal BP based on one shell dated using ^{14}C and amino acid racemisation. However, additional ^{14}C dating indicates a likely age of ~2500 cal BP. Regardless of age constraints, the presence of rock-encrusting oyster shells and large articulated bivalves, suggests that the depositional event must have been capable of removing and transporting coarse sediments (rock clasts), bivalves, and oysters shells from a variety of seaward environments and depositing them with little abrasion, something storm waves are unlikely to do. The deposit may be tsunamigenic. If a tsunami origin is accepted, the new dating results indicate that it is possibly coeval with a tsunami event previously reported to have affected several other sites along the coast of New South Wales at *c.* 2900 cal BP. Consequently, this deposit provides evidence for the event at a new site and importantly, a tighter constraint on the likely date of the events occurrence. It further adds weight to the developing catalogue of palaeotsunamis that may have affected the south-eastern coast of Australia. Regardless of the deposit's origins, if viewed from a coastal planning perspective, this deposit indicates that this part of the coast has experienced large-scale overwash events in the past that if repeated, would be catastrophic. There are serious implications for risk management.

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KEY WORDS *south-east Australia; tsunami; foraminifera; estuary; sediments; Holocene; articulated bivalves; overwash*

Introduction

Research over the last 25 years proposes that the New South Wales (NSW) coast of south-east Australia has been repeatedly impacted by palaeotsunamis. This body of research can be divided into two major themes. The first, coined the 'Australian mega-tsunami hypothesis' in reviews by Goff *et al*. (2003), Dominey-Howes *et al*. (2006), Dominey-Howes (2007), Goff and Dominey-Howes (2009), and Courtney *et al*. (in review), refers to work principally by Bryant (2001; 2008) and co-workers that describe a variety of geomorphic evidence for frequent, very large events (Bryant *et al*., 1992; 1996; 1997; Young and Bryant, 1992; Bryant and Young, 1996; Young *et al*., 1996; 1997; Bryant, 2001; Bryant and Nott, 2001). The second has focused on sand sheets found in coastal embayments (Switzer *et al*., 2005; 2006; Switzer and Jones, 2008a) that appear to be the result of much smaller, less frequent tsunamis. Despite the potential difference in frequency magnitudes, debate on the genesis of coastal overwash sand sheets found in coastal lagoons or boulders and coarse deposits on rocky coastlines and cliff tops (Felton and Crook, 2003; Switzer *et al*., 2005; 2006; Dominey-Howes *et al*., 2006; Switzer and Jones, 2008a; Hutchinson and Attenbrow, 2009; Goff and Dominey-Howes, 2010; Goff *et al*., 2010a; 2010b; Switzer and Burston, 2010) continues and their presence in the landscape is indicative of high-energy marine events along this coast.

Figure 1 provides a summary of the coastal sites of NSW (including the administratively contiguous location of Lord Howe Island in the Tasman Sea – location 1 in Figure 1a) reported to preserve evidence for palaeotsunamis. Figure 1 indicates that some 60 coastal locations may have been affected. Figure 1d provides a graphic summary of the reported chronology of palaeotsunamis (Table 1) derived from the 60 sites located in Figure 1. Although the 60 sites are reported as containing evidence for palaeotsunamis, it is important to understand that studies of only 29 sites (less than half of all reported sites) actually present dated material associated with the nine palaeotsunami events listed in Table 1. Thus, our understanding of the chronology remains fragmentary and is in need of robust analysis and further work. For a detailed review of the sites, types of geological, geomorphological, and sedimentological evidence and proposed chronology of NSW palaeotsunamis, readers are referred to Courtney *et al*. (in review).

In this study, we examine a site (informally known as 'Old Punt Bay') at Batemans Bay located approximately 130 km south of Sydney previously studied by Switzer *et al*. (2010)

Table 1 Specific palaeotsunami events thought to have impacted the coast of NSW.

Palaeotsunami #	Event Date	Sites Where Actual Dated Material for Event Has Been Reported	Sites Where Event Has Been Proposed but for Which No Dated Material Has Been Presented by the Reporting Authors
1	105 000 BP	None	19, 22, 58
2	9 000 BP	42, 48, 55	33, 34, 35, 54
3	6 500 BP	15, 18, 28, 36	1, 23, 29, 32, 38, 42, 43, 58
4	5 000 BP	28, 31	5
5	2 900 BP	51, 52	1, 25, 31, 32, 38, 42, 43, 58
6	1 500 BP	16, 20, 21, 41, 44, 51, 57	25, 31, 32, 38, 42, 43, 59, 60
7	900 BP	7, 24, 47, 49, 51	1, 23, 30, 31, 32, 35, 38, 42, 43, 58
8	500 BP	1, 23, 31, 35, 47, 49, 51	10, 12, 38, 42, 43
9	250 BP	1, 12, 19, 25, 39, 57, 59, 60	30, 32, 38, 42, 43, 58

For each event, the corresponding coastal site from which this event has been reported is presented. These sites correspond to those shown on Figure 1. Importantly, we distinguish for each 'event' those sites that *actually* have dated material reported in the peer review literature from those where an event has been postulated but for which *no* dating evidence has been presented.

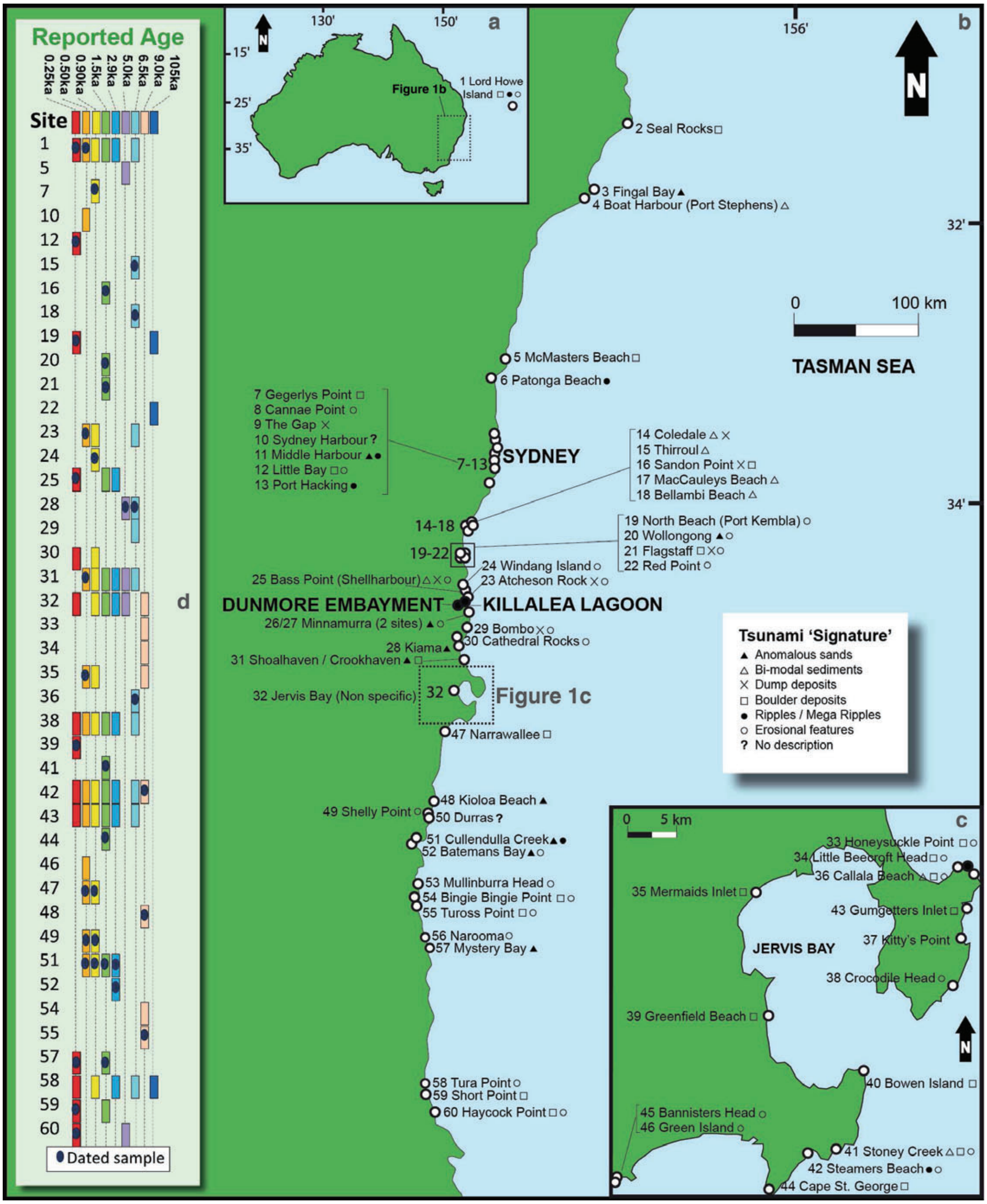

Figure 1 (a) Map of Australia showing study area of NSW, south-eastern Australia; (b) spatial distribution of sites along the coast of NSW reported to contain evidence for palaeo-mega-tsunami events; (c) inset detailing sites clustered in the area of Jervis Bay; (d) graphic representation of spatial and chronological distribution of inferred and dated (•) palaeo-mega-tsunami evidence. (Based on material compiled by Courtney *et al*., 2009; in review; and Switzer and Burston, 2010). The location of studies at Dunmore Embayment (Switzer *et al*., 2005) and Killalea Lagoon (Switzer *et al*., 2006; Switzer and Jones, 2008b) is also located on map b. These two studies indentified smaller washover sandsheets attributed to small-medium size tsunamis or extremely large storms around 200–800 BP and 3800–4800 BP.

(Figure 2). Here an elevated shell-rich sand deposit is found to drape a mid-Holocene beach sequence and occurs up to +2.8 m Australian Height Datum (AHD). The deposit contains articulated bivalves and marine microfauna (discussed in detail in *Results*) and appears anomalous in the beach stratigraphy. This study reports on its potential origin and investigates the possibility that the deposit is the result of a tsunami or exceptionally large storm. Regardless of its genesis, this deposit provides further geological and geomorphic evidence for extreme wave events on this coast. The recurrence of such events could be potentially catastrophic to seaside villages like Batemans Bay. For the first time in a study of high-energy deposits in Australia, we provide a very detailed focus on the micro- and macropalaeontology of the deposit, since recent work has indicated that palaeontology has been underutilized and may help to shed light on the nature and origins of extreme event deposits (Uchida *et al*., 2004; Nigam, 2005; Dawson and Stewart, 2007b; Hawkes *et al*, 2007; Satyanarayana *et al*., 2007; Mamo *et al*., 2009).

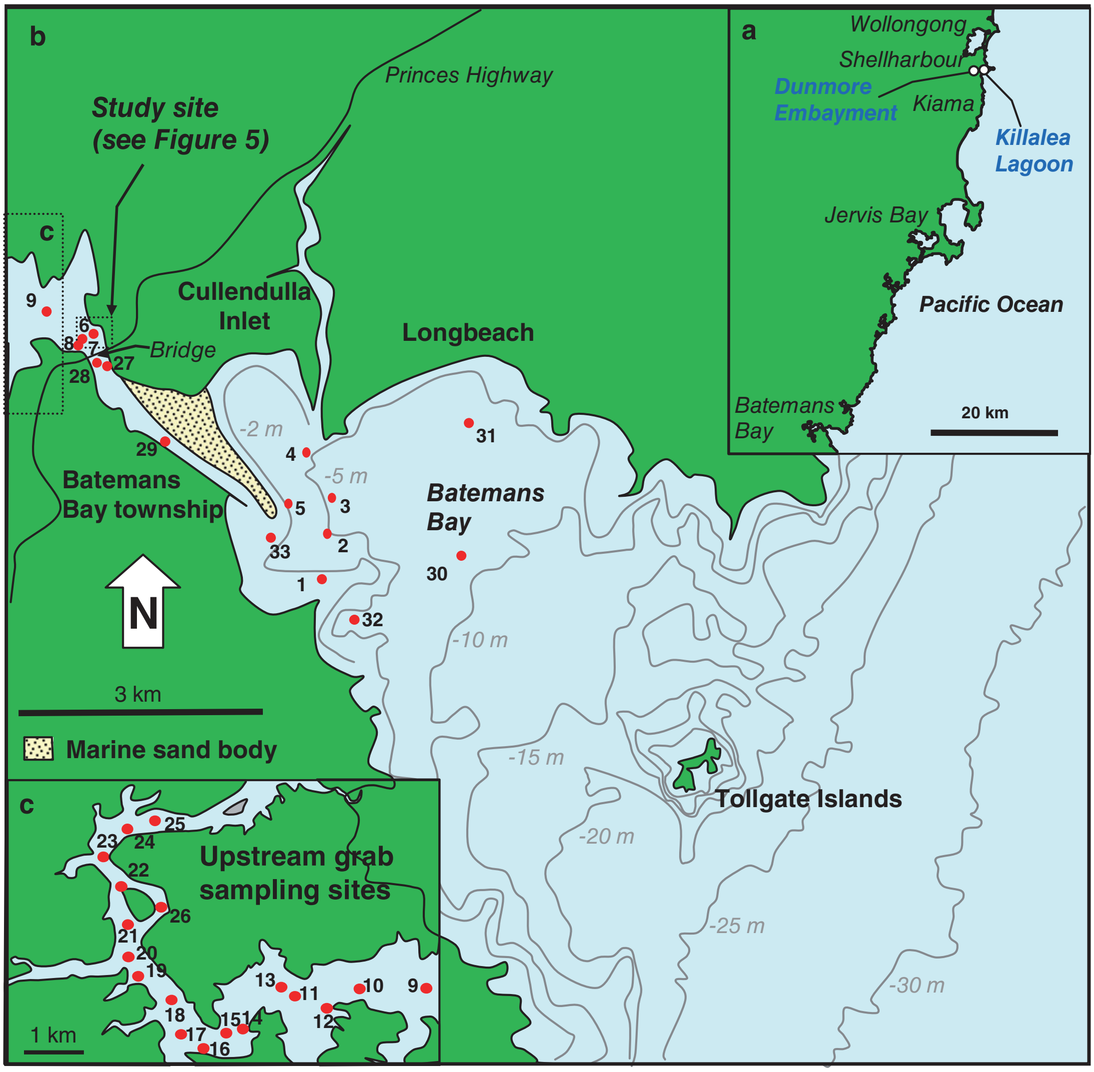

Figure 2 (a) Map of the south-east Australian coast locating Batemans Bay and other sites mentioned in the text. Dunmore embayment (Switzer *et al*., 2005) and Killalea Lagoon (Switzer *et al*., 2006; Switzer and Jones, 2008b) are highlighted in blue. The two sites provide the only other detailed studies of sediments attributed to prehistoric overwash events from this coast; (b and c) local map with details of bathymetry and location of study site. Grab sample locations for this study are numbered 1–32.

Study site

Batemans Bay, an open ocean embayment, is exposed to the predominant swell from the south-east, has a rocky and sandy shoreline and a complex bathymetry, particularly around the Tollgate Islands offshore (Figure 2b) (Hennecke, 2004). A large, presumably Holocene, marine sand body confines a narrow channel along the southern margin of the estuary. This channel averages 8 m deep at the seaward end and dramatically decreases wave energy in the inner estuary. Little research has focused on the broad-scale Quaternary evolution of Batemans Bay (Switzer, 2005, Switzer *et al*., 2010), although the embayment is most likely to have evolved in a similar fashion to other drowned river valleys along this coast (Roy *et al*., 2001; Sloss *et al*., 2006). Recent reviews of the Holocene sea level history from eastern Australia indicate that the study area (Figure 2a) lies on a tectonically stable coast where sea level attained a maximum of +1.5 m by 7400 cal BP (Jones *et al*., 1979; Sloss *et al*., 2007). This sea level maximum was followed by an extended period where sea level remained +0.5–1 m higher during the mid to late Holocene that lasted until approximately 2000 cal BP, followed by a relatively slow and smooth regression of sea level (Sloss *et al*., 2007; Lewis *et al*., 2008).

The study site examined here is a small sheltered embayment that lies some 150 m west of the Princes Highway bridge (Figure 2b,c). The present morphology of the small embayment consists of a flat-lying grassy area with small trees along the river bank (Figure 3). The early- to mid-Holocene evolution of the embayment has been presented in detail elsewhere (Switzer *et al*., 2001; 2010; Switzer, 2005). This paper investigates the genesis of an unusual shell-rich sand unit (Unit 2 – see Figures 4 and 5) that drapes the prograded beach sequence.

Methods

More than 220 onshore (cores and excavated faces) and offshore sediment samples (grab samples) were collected for analysis. Offshore grab samples Bateman Bay Grab Sample (BBGS) were taken at various points in the Batemans Bay embayment (Figure 2b,c) and onshore samples were obtained from a series of excavated faces, vibracores (Figure 3), and five early exploration hand augers between the road and VC4 (not shown in Figure 3). Sedimentological analysis outlined in Switzer (2005) and Switzer *et al*. (2010) allowed the definition of five stratigraphic units (summarized in Table 2). The detailed methodology on the stratigraphic study of the embayment is presented in Switzer *et al*. (2010) and is not repeated here. The following section outlines the additional methods that were applied to the large shelly layer – Unit 2.

Sediment recording, description, and sampling

Unit 2 was identified in the vibracores and the three excavated faces cut into the river bank (Figure 3). Samples collected from Unit 2 were analysed using conventional sedimentological techniques including particle size, mineralogy, and macro- and microfaunal analysis along with determination of organic and carbonate content (Switzer *et al*., 2009). Significantly, to compare the faunal assemblages of Unit 2 with the modern sedimentary environments of the estuary and surrounds, 32 grab samples (labelled 1–32 in Figure 2b,c) were obtained between the outer bay and the upper reaches of the estuary using a (Macintyre type) grab sampler. Three grab samples (GS28–30), proximal to the site, were taken for modern assemblage analysis of foraminifera.

A visual sediment analysis was conducted on all samples using a binocular microscope and samples were sieved at 2000 μm to remove the gravel fraction. The gravel fraction was analysed for rock clasts and recognizable shell content (macrofossils). For macro- and microfaunal analysis, sediment samples were soaked in distilled water and wet-sieved at 63 and 1000 μm.

Micro- and macropalaeontological sampling and analyses

Macrofossils were identified using the reference work of Jensen (1995). Foraminiferal analysis was completed for selected samples from Units 1, 2, and 3 (Figures 4 and 5) from Old Punt Bay to establish assemblage composition and its change through the sequence following the techniques outlined in Mamo *et al*. (2009). The taxonomic identification of foraminifera used a suite of relevant studies (Yassini and Jones, 1995; Cotter, 1996; Hayward *et al*., 1999; Strotz, 2003; Everett, 2004; Haslett, 2007).

To directly compare Units 1–3 with modern environments, selected subsamples were used for detailed foraminiferal analysis. Subsamples F2/2 from Unit 1, F2/6 and F2/9 from Unit 2, F2/11 and F2/13 from Unit 3 (Figure 5) were compared with samples GS28, GS29, and GS30 (Figure 2). These bulk subsamples (~10 g) were washed and wet sieved with 63 and 1000 μm sieves before

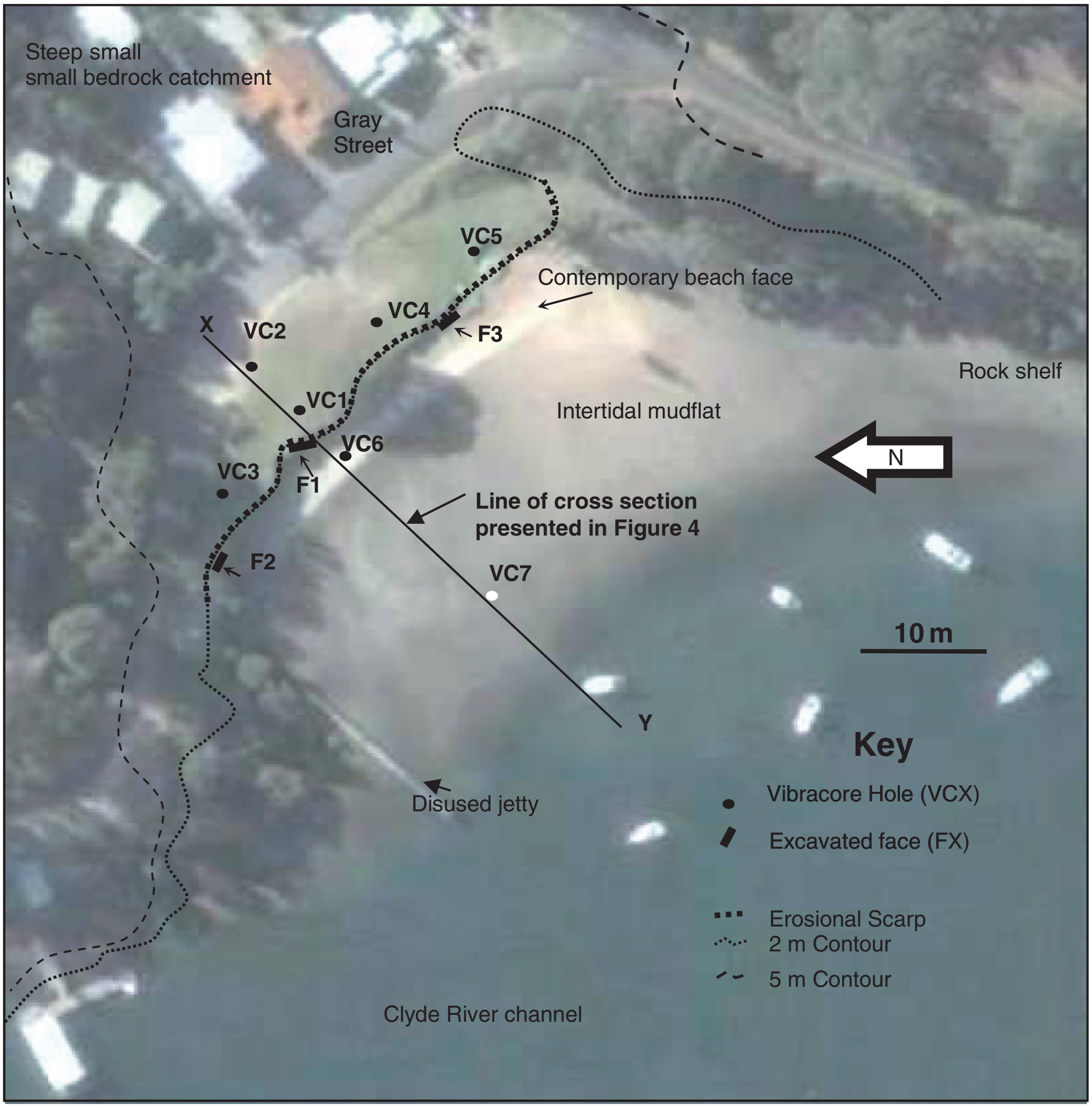

Figure 3 Schematic map of study site at Batemans Bay showing the location of vibracores (VC1 to VC7) and excavated faces (F1 to F3). The line of schematic cross section in Figure 3 is located as X–Y.

the application of standard picking techniques. Because of the weathered condition of some specimens and their lack of abundance, some taxa were only identifiable down to genus level. Other specimens were completely unidentifiable. All identified taxa were counted to obtain quantitative data and selected significant specimens were photographed using a JEOL JSM-648 OLA Analytical Scanning Electron Microscope (Figure 6). Fisher alpha index values were applied to determine species richness of the sampled locations (a log series is used to predict the number of species represented by a number of individuals, the higher the Fisher α-value the more diverse the assemblage) (Fisher *et al.*, 1943; Murray, 1973; 2006) and cluster analysis, using the Bray–Curtis similarity index was performed to distinguish foraminiferal biotopes within the area (Bray and Curtis, 1957) (Figure 7). The Bray–Curtis method was used as it is deemed the most appropriate for near-shore and estuarine foraminiferal faunas, given the high incidence of joint absences (zero counts) and its emphasis on the significance of the most dominant taxa within each assemblage (Jayalakshmy and Kameswara Rao, 2006).

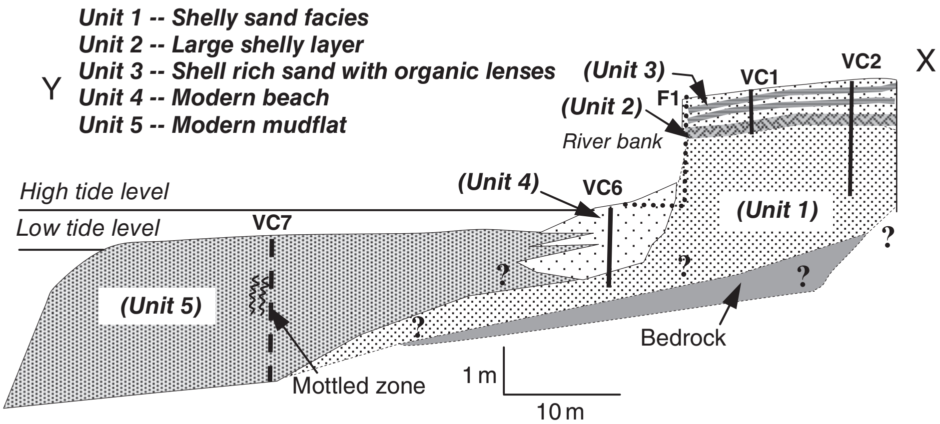

Figure 4 Summary diagram of the stratigraphy of the embayment (modified from Switzer, 2005, and Switzer *et al*., 2010). Unit 2 presents as an unusual coarse-grained marine deposit that overlies a prograded beach and is vertically confined by a finer sandy shell deposit (Unit 3) that contains organic-rich lenses of fine sand capped by a poorly developed soil.

Table 2 Facies identified in excavated faces and vibracores from the study site at Old Punt Bay, Batemans Bay.

Unit	Sediment Description	Faunal Characteristics
1	Fine- to medium-grained quartz to shell-rich quartz sand with occasional small rounded gravel pebbles.	Mostly composed of *Notospisula trigonella* (up to 70% of the sample) and shell hash with a small percentage of microfauna (almost exclusively foraminifera). Macrofauna (>2 mm) in order of abundance, *Notospisula trigonella*, *Tellina* sp. with rare *Anadara trapezia* and small fragments of *Saccostrea glomerata*. The microfauna consist of very few recognizable foraminiferal tests that are most likely *Elphidium* sp. The entire sequence is dominated by the small bivalves.
2	Coarse shelly deposit dominated by fine- to medium-grained quartz sand with large shells and occasional rock clasts (some of which are metasedimentary rock).	This unit has a diverse coarse shelly macrofauna including *A. trapezia* (several articulated) and *S. glomerata*. Microfauna include foraminifera that were well preserved but had become brittle and crumbly from *in situ* weathering. Samples retrieved from Face 2 indicate one assemblage within the shelly layer. It is distinctly dominated by the species *Ammonia aoteana*, *Elphidium crispum*, *Elphidium hawkesburiense*, and *Lamelladiscorbis dimidiatus*. Other species include *Cibicides dispars*, *Parrellina papillosa*, *Parrellina verriculata*, and *Quinqueloculina pseudoreticulata*.
3	Organic-rich soil and several lenses composed of organic-rich clays with subangular to subrounded quartz/lithic fine-grained sand.	There are minor shells and shell fragments that are heavily corroded. Sparse macrofauna (>2 mm) in order of abundance, *N. trigonella*, *Tellina* sp. with rare *A. trapezia* and small fragments of *S. glomerata*. No recognisable microfauna were identified in this unit
4	Clean (no shell) – to shelly-sand dominated by fine- to medium-grained quartz sand with a minor component of similar size lithic grains and some larger gravel clasts.	This shelly sand facies is dominated by *N. trigonella* and shell fragments but contains very few microfauna, although a few heavily weathered but unidentifiable foraminiferal tests were identified.
5	Muddy sediments dominated by silt with a small component of quartz and lithic sand. The sand content increases with depth in core VC7 and exhibits considerable mottling in the mid parts of VC7.	This unit contains a small population of bivalves, gastropods and carbonate microfauna including *A. aoteana* and several *Elphidium* species.

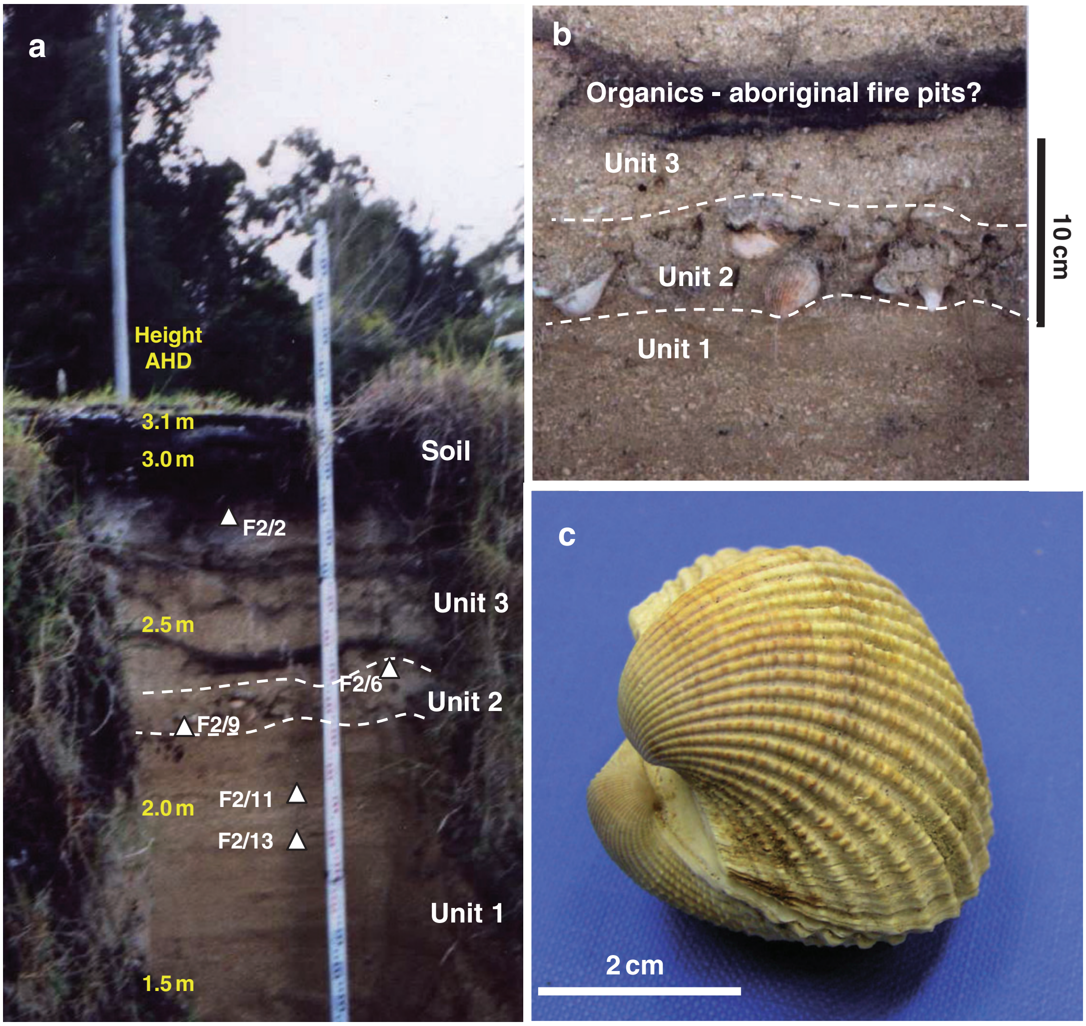

Figure 5 (a) The large shelly layer (Unit 2) lies in the upper part of the sequence exposed in the river bank found in excavated Face 2 at Batemans Bay. All heights are relative to Australian Height Datum (AHD) and Units 1–3 are clearly visible; (b) shows Unit 2 in Face 2 (F2) from which a large articulated *Anadara trapezia* (c) was extracted. This shell was dated using amino acid racemisation (UWGA702) and conventional radiocarbon (Wk9439) techniques and returned dates of 1060 ± 50 and 1284 ± 58 cal BP, respectively.

Dating materials

To obtain a chronological framework for the sequence, samples for dating were taken from Units 1, 2, and 3 (Figure 5). Initial radiocarbon samples included two separate valves of the estuarine bivalve *Anadara trapezia* (Deshayes, 1840) that were taken from Unit 1 for conventional radiocarbon (Wk9440 – taken from Face 1; Wk9441 – taken from vibracore 3: Figure 4) and an articulated *A. trapezia* (Wk9439) that was taken from Unit 2 (exposed in excavated Face 2: Figure 5). The radiocarbon ages on these initial samples were obtained from the Waikato University, New Zealand and calibrated to sidereal years using CALIB™ REV5.0.1 (Stuiver and Reimer, 1993). A second series of dating samples obtained from Units 2 and 3 were taken in January 2010. An extra two articulated bivalves of *Anadara* sp. were taken from Unit 2 (Beta-273081 and Beta-273082) from a fresh face excavated approximately 40 cm to the west of Face 2 and about 50 cm into the river bank. A charcoal sample from a carbon rich layer in the overlying Unit 3 was also taken (Beta-273083). Calibration for fossil molluscs used the marine model calibration curve (Marine04) with a Δr

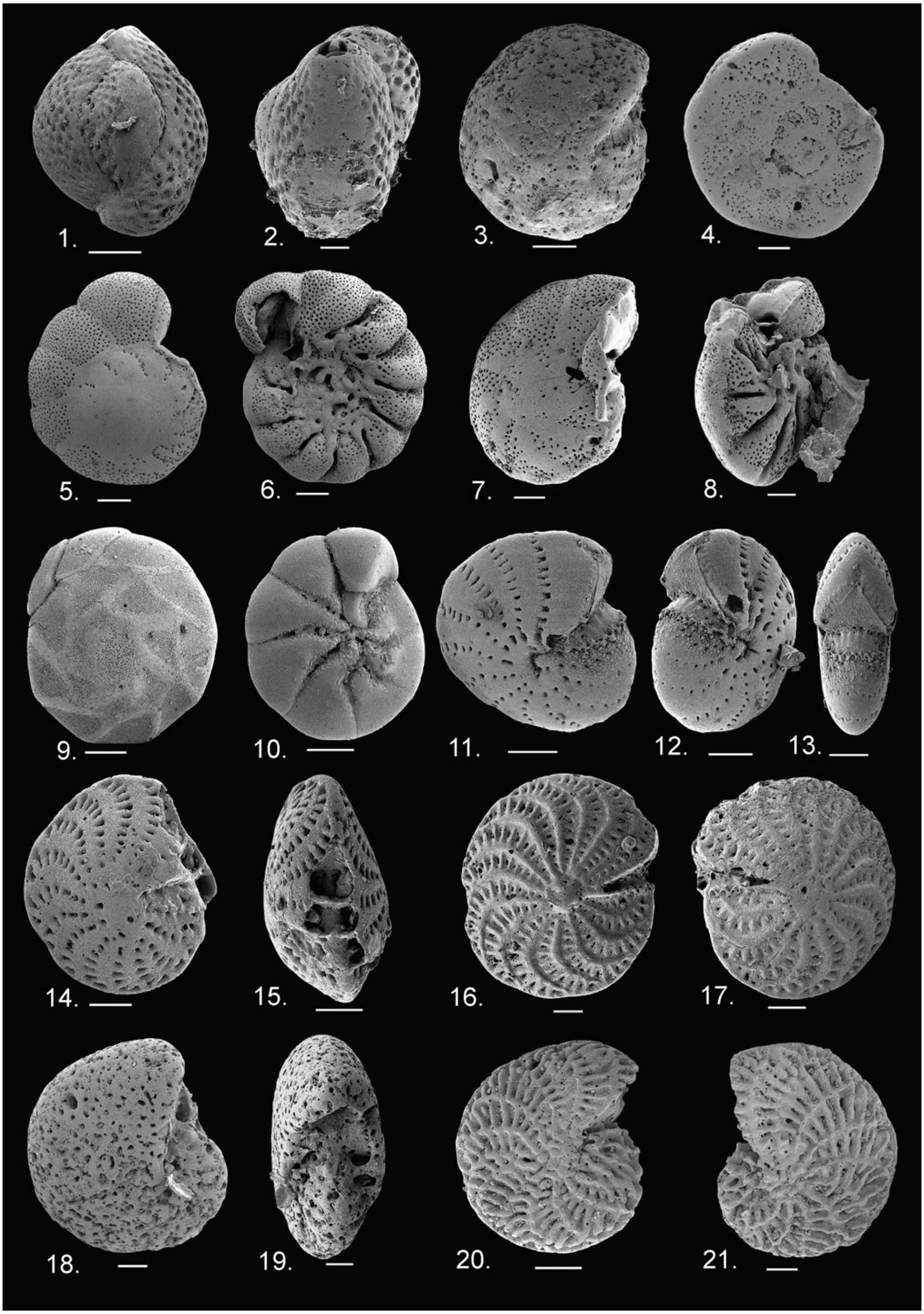
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Figure 6 Most abundant foraminiferal taxa. (Unless otherwise specified all scale bars = 100 µm) **1.** *Quinqueloculina pseudoreticulata* Parr, GS29, MU 61790 (Scale bar = 200 µm); **2.** *Quinqueloculina pseudoreticulata* Parr, F2/9, MU 61791; **3.** *Cibicides dispars* (d'Orbigny), GS28, MU 61792; **4.** *Cibicides dispars* (d'Orbigny), GS29, MU 61793; **5–8**. *Lamellodiscorbis dimidiatus* (Jones and Parker), GS29, MU 61794–61797 (Scale bar for **5–6** = 200 µm); **9.** *Ammonia aoteana* (Finlay), GS29, MU 61798; **10.** *Ammonia aoteana* (Finlay), GS28, MU 61799; **11–13.** *Elphidium hawkesburiense* Albani, GS29, MU 61800; **14–15.** *Elphidium crispum crispum* (Linne), GS28, MU 61801; **16–17.** *Elphidium crispum* (Linne) ssp., GS28, MU 61802–61803; **18–19.** *Parrellina papillosa* (Cushman), GS29, MU 61804; **20.** *Parrellina verriculata* (Brady), GS29, MU 61805 (Scale bar = 200 µm); **21.** *Parrellina verriculata* (Brady), F2/9, MU 61806.

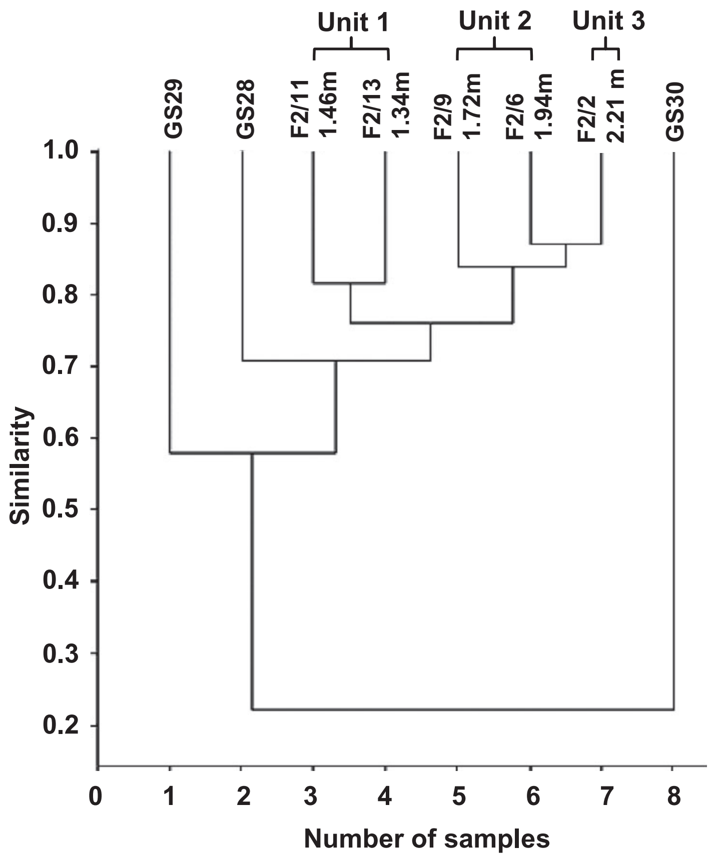

Figure 7 Bray–Curtis cluster analysis of foraminiferal assemblages found within Units 1–3 from Old Punt Bay and GS28–30.

value of 11 ± 85 year to correct for the marine reservoir effect and convert ages into sidereal years (expressed as cal BP; Gillespie, 1977; Gillespie and Polach, 1979; Stuiver *et al*., 1998; Table 3). We present all calibrated radiocarbon ages using a 2-sigma uncertainty term (95% degree of confidence).

To complement the initial radiocarbon results, amino acid racemisation analyses were run on the three individual *A. trapezia* valves collected from Unit 1 in excavated Face 1 (UWGA698 and UWGA699) and vibracore 3 (UWGA703) plus the remaining valve of the articulated bivalve dated using conventional radiocarbon (UWGA702 – taken from Unit 2 excavated Face 2). Additionally, two single valves of *A. trapezia* from Unit 2 (UWGA700 and UWGA701) were also subject to amino acid racemisation analysis. Sample preparation and analytical techniques undertaken for amino acid racemisation follow the procedures outlined in Murray-Wallace and Kimber (1987), Murray-Wallace (1993) and Sloss *et al*. (2004). The age determinations made by amino acid racemisation were based on the

Table 3 Dating results from the shell-rich unit at Batemans Bay sequence.

Sample (Height above Sea Level AHD)	Specimen Number	Technique	Material Dated	Facies/Unit	Sample Notes	Age cal BP (1σ)	Age Range BP (1σ)
ASBBF2-10-1 (2.30 m)	Beta273081	^{14}C	*Anadara* shell (articulated)	Unit 2	Articulated shell	2650 ± 40	2110–2610
ASBBF2-10-2(2.30 m)	Beta273082	^{14}C	*Anadara* shell (articulated)	Unit 2	Articulated shell	2770 ± 40	2290–2720
ASBBF2-10-3 (2.20 m)	Beta273083	^{14}C	Charcoal	Unit 3	Charcoal fragment	2490 ± 40	2360–2740
ASBBF2 (2.25 m)	UWGA702	Amino acid racemisation	*Anadara* shell (articulated)	Unit 2	Articulated shell	1060 ± 50	1010–1100
ASBBF2 (2.25 m)	Wk9439	^{14}C	*Anadara* shell (articulated)	Unit 2	Articulated shell	1284 ± 58	1226–1342
ASBBF2 (2.23 m)	UWGA700	Amino acid racemisation	*Anadara* shell	Unit 2	Single valve	2060 ± 100	1960–2160
ASBBF2 (2.25 m)	UWGA701	Amino acid racemisation	*Anadara* shell	Unit 2	Single valve	2670 ± 120	2550–2790
ASBBVC3 (1.20 m)	UWGA703	Amino acid racemisation	*Anadara* shell	Unit 1	Single valve	2540 ± 120	2420–2660
ASBBF1 (0.80 m)	UWGA698	Amino acid racemisation	*Anadara* shell	Unit 1	Single valve	3610 ± 170	3440–3780
ASBBF1 (1.20 m)	UWGA699	Amino acid racemisation	*Anadara* shell*	Unit 1	Single valve	7840 ± 350	7490–8190
ASBBF1 (2.20 m)	Wk9440	^{14}C	*Anadara* shell	Unit 1	Single valve	2506 ± 67	2439–2573
ASBBVC3 (1.80 m)	Wk9441	^{14}C	*Anadara* shell	Unit 1	Single valve	2852 ± 72	2780–2924

*possibly reworked.

Calibration for fossil molluscs used the marine model calibration curve (Marine04) with a Δr value of 11 ± 85 years to correct for the marine reservoir effect and convert ages into sidereal years. Ages from Unit 1 indicate a mid- to late-Holocene age. Dating from Unit 2 returned mixed ages. Young disparate ages provided by samples Wk9439 and UWGA702 contrast with mid-Holocene ages from UWGA700, UWGA701, and two overlapping ^{14}C ages Beta-273081 (2610–2110 BP) and Beta-273082 (2720–2290 BP). The overlapping dates are also consistent with the amino acid racemisation dates of the individual valve (UWGA701). An age of 2300–2600 BP for Unit 2 is also consistent with the lone date taken from the stratigraphically higher Unit 3 which gave an age of 2490 ± 40 BP.

AHD, Australian Height Datum.

racemisation reaction of aspartic acid, one of the fastest racemising amino acids (Sloss *et al*., 2004). The fast rate of racemisation of aspartic acid makes it particularly useful for dating fossils of Holocene age (Goodfriend, 1991, 1992; Goodfriend and Stanley, 1996; Sloss *et al*., 2004; 2006).

Results

Sedimentology of the large shelly layer (Unit 2)
Unit 2 varies in thickness of 4–28 cm in cores and excavated faces and has a matrix of fine- to medium-grained quartz sand with a varied but notable population of large shells and occasional rock clasts (B axis of 25–50 mm) of laminated sedimentary rocks and quartz (Figure 5a). This unit has a diverse coarse shelly macrofauna (Figure 5b) including *A. trapezia* (several articulated; Figure 5c) and *Saccostrea glomerata* (Sydney rock oyster) (Gould, 1850). The deposit exists in all excavated faces and vibracoring suggests that the deposit drapes Unit 1 and covers much of the embayment and exists from 0.7 m to 2.25 m AHD in elevation.

Microfauna included a broad suite of foraminiferal species with different water depth and environmental affinities. Of the eight samples subjected to microfossil examination, 70 species were found that varied greatly in their level of preservation (Table 4). The tests of many foraminiferal specimens were often brittle. Samples retrieved from Face 2 indicate a diverse assemblage (Table 4) dominated by the species *Ammonia aoteana* (Finlay, 1940) (Figure 6: 9–10), *Elphidium crispum* (Linné, 1758) (Figure 6: 14–17), *Elphidium hawkesburiense* (Albani, 1974) (Figure 6: 11–13) and *Lamelladiscorbis dimidiatus* (Jones and Parker, 1862 – from Carpenter *et al*., 1862) (Figure 6: 5–8). Other significant species include *Cibicides dispars* (d'Orbigny, 1839) (Figure 6: 3–4), *Parrellina papillosa* (Cushman, 1936) (Figure 6: 18–19), *Parrellina verriculata* (Brady, 1881) (Figure 6: 20–21), and *Quinqueloculina pseudoreticulata* Parr, 1941 (Figure 6: 1–2).

Within Units 1–3 from Old Punt Bay, the most abundant and diverse foraminiferal samples were the two lowermost samples (F2/11–F2/13) obtained from Unit 1. The upper most sample (F2/2) taken from Unit 3 contained a moderate number of specimens when compared with those directly underlying (Table 4). All specimens appeared highly broken, corroded, and were covered in fine silt. Sample F2/2 had a Fisher α-value of 4. The two samples taken from Unit 2 (F2/6 and F2/9) showed an increase in both the number of specimens and species diversity (Table 4). Porcellaneous species, in particular, are of a lower taphonomic grade, subject to higher levels of abrasion and corrosion. Samples F2/6 and F2/9 had α-values of 6.5 and 7.3, respectively. Samples taken from Unit 1 (F2/11 and F2/13) showed both significantly lower specimen numbers and diversity, particularly with respect to the dominant species of Unit 2, such as *A. aoteana* and various species of *Elphidium*. In this unit, the level of abrasion was still high, but the specimens were not covered in fine silt. The α-values for F2/11 and F2/13 were 3 and 2.75, respectively.

Comparison with fauna of offshore grab samples
Foraminifera (Figure 6) derived from Unit 2 samples, the confining facies (Units 1 and 3) and offshore grab samples GS28–30 (Figure 2b) were compared (Table 4). The three grab samples generally possessed both greater abundance and diversity than the samples from Units 1–3. Among the three samples themselves, GS30 exhibited higher diversity but lower abundance than the other two (Table 4). None of the grab samples exhibited the extensive abrasion, corrosion, and weathering of the samples obtained from excavated Face 2 and α-values for GS28, GS29, and GS30 are 9.51, 15.37, and 32.68, respectively. Very few of the species identified in GS30 were found in Units 1–3 from Old Punt Bay and generally test size of specimens was much smaller in GS30. As a trend, the abundance decreased but diversity and α-values increased as the grab samples moved away from Old Punt Bay.

Cluster analysis, using the Bray–Curtis similarity index (Bray and Curtis, 1957) revealed that Units 1–3 possessed a relatively high degree of similarity (Figure 7). However, each of the individual units form smaller subclusters. The grab samples clustered outside this main cluster, and show decreasing similarity to the main cluster with increasing geographic distance from the Old Punt Bay deposit.

Dating results
All ^{14}C and amino acid racemisation dating results from Batemans Bay are provided in Table 3. All ages from Unit 1 indicate a mid- to late-Holocene age for Unit 1 with deposition occurring *c.* 7840–2500 cal BP although the

Table 4 Comparative table of foraminifera from Units 1–3 and the offshore grab samples GS28–30.

Species	Unit 3		Unit 2		Unit 1	Grab Samples			Total
	F2/11 1.46 m	F2/13 1.34 m	F2/6 1.94 m	F2/9 1.72 m	F2/2 2.21 m	GS30	GS29	GS28	
Ammonia aoteana	21	18	51	53	43	5	53	109	353
Bulimina sp.	0	0	0	0	0	1	0	0	1
Bulminoides gracilis	0	0	1	0	0	1	0	0	2
Chrysalidinella sp.	0	0	0	0	0	1	0	0	1
Cibicides dispars	7	6	14	15	12	3	3	14	74
Cibicides reflugens	0	0	1	2	2	0	0	0	5
Cibicidoides sp.	0	0	0	0	0	4	0	0	4
Cornuspira sp.	0	2	2	0	3	0	0	2	9
Cymbaloporretta sp.	0	0	0	0	0	1	0	0	1
Elphidium crispum crispum	6	3	18	16	9	2	4	9	67
Elphidium crispum ssp.	13	19	37	40	38	3	5	61	216
Elphidium hawkesburiense	3	2	22	13	12	4	5	7	68
Elphidium macellum	1	0	1	1	0	1	0	2	6
Epistominella sp.	0	0	0	0	0	2	0	0	2
Epistominella exigua	0	0	0	0	0	20	0	0	20
Fissurina sp.	0	0	0	0	0	1	0	0	1
Fursenkonia sp.	0	0	0	0	0	0	1	0	1
Glabratella australensis	0	0	0	0	0	2	0	2	4
Glabratella sp.	0	0	0	0	0	3	0	0	3
Karreria sp.	0	0	0	0	0	0	1	0	1
Lamelladiscorbis dimidiatus	16	19	23	19	14	2	31	20	144
Miliolinella australis	0	0	0	0	0	2	1	4	7
Miliolinella oceanica	0	0	0	0	0	1	1	3	5
Misc 1	0	0	0	0	0	0	1	1	2
Misc 2	0	0	0	0	0	3	0	0	3
Misc 3	0	0	1	1	0	2	4	3	11
Misc 4	0	0	0	0	0	1	0	0	1
Misc 5	0	0	0	0	0	1	0	0	1
Misc 6	0	0	0	0	0	1	0	0	1
Misc 7	0	0	1	0	0	0	0	0	1
Misc 8	0	0	0	0	0	1	0	0	1
Misc 9	0	0	0	1	0	0	0	0	1
Misc 10	0	0	0	0	0	2	0	0	2
Misc 11	0	0	0	0	0	2	0	0	2
Misc 12	0	0	0	0	0	0	1	0	1
Parrellina papillosa	0	0	9	2	7	0	8	7	33

Table 4 *Continued*

Species	Unit 3		Unit 2		Unit 1	Grab Samples			Total
	F2/11 1.46 m	F2/13 1.34 m	F2/6 1.94 m	F2/9 1.72 m	F2/2 2.21 m	GS30	GS29	GS28	
Parrellina verriculata	3	0	11	2	6	0	9	26	57
Patellinella inconspicua	0	0	1	1	0	2	0	4	8
Pileolina australensis	0	0	0	1	0	0	1	0	2
Pileolina sp. 1	0	0	2	3	1	3	0	2	11
Pileolina sp. 2	0	0	0	0	0	2	0	0	2
Pileolina sp. 3	0	0	0	0	0	2	0	0	2
Planorbulina sp.	0	0	1	0	0	0	4	4	9
Pleurostomella sp.	0	0	0	0	0	1	0	0	1
Pyrgo sp.	0	0	0	0	0	0	1	0	1
Quinqueloculina pseudoreticulata	1	1	2	5	1	2	14	10	36
Quinqueloculina seminula	0	0	1	2	0	3	5	3	14
Quinqueloculina sp. 1	0	0	1	0	1	2	2	3	9
Quinqueloculina sp. 2	0	0	2	2	0	1	1	2	8
Quinqueloculina sp. 3	1	2	0	3	0	1	2	4	13
Quinqueloculina sp. 4	0	0	0	0	0	0	1	0	1
Quinqueloculina sp. 5	0	0	0	0	0	3	1	5	9
Quinqueloculina sp. 6	0	0	0	0	0	2	1	2	5
Quinqueloculina sp. 7	0	0	0	0	0	2	1	1	4
Quinqueloculina sp. 8	0	0	0	0	0	1	1	0	2
Rugobolivinella pendens	0	0	0	0	0	1	1	0	2
Sigmoidella sp.	0	0	0	1	0	0	1	0	2
Spirillina seymourensis	0	0	0	0	0	1	0	0	1
Spiroculina carinata	0	0	0	0	0	0	2	2	4
Sprioluculina sp.	0	0	1	2	0	1	1	3	8
Textularia pseudogramen	0	0	0	0	0	0	1	2	3
Textularia sp. 1	0	0	0	0	1	0	3	1	5
Textularia sp. 2	0	0	0	1	0	1	1	1	4
Textularia sp. 3	0	0	0	0	0	0	1	0	1
Triloculina oblonga	1	0	2	0	0	1	2	3	9
Triloculina sp. 1	0	3	0	2	0	0	2	7	14
Triloculina sp. 2	0	0	0	1	0	0	1	1	3
Trochammina inflata	0	0	0	0	0	1	0	0	1
Total	73	75	205	189	150	105	179	330	
No. of species	11	10	23	24	14	47	39	34	
Fisher α-value	3.6	3.1	6.65	7.29	3.78	32.68	15.37	9.51	

oldest sample (UWGA699) may possibly be reworked. Dating from Unit 2 returned a mix of young and old ages. A conventional radiocarbon age and aspartic acid derived amino acid racemisation age on one articulated specimen of *A. trapezia* (Wk9439 and UWGA702) gave two disparate ages of 1010–1100 and 1226–1342 BP (Table 3). However, two individual disarticulated valves of *A. trapezia* from the same unit (Unit 2) yielded amino acid racemisation derived ages of 1960–2160 (UWGA700) and 2550–2790 (UWGA701) BP at 2σ errors.

Additional dating results from the two articulated *Anadara* samples taken in January 2010 gave overlapping age ranges of 2110–2610 BP (Beta-273081) and 2290–2720 BP (Beta-273082). The overlapping dates are also consistent with the amino acid racemisation dates of the individual valve (UWGA701). A date taken from the organic lens in the stratigraphically higher Unit 3 returned a stratigraphically consistent age of 2490 $\pm$ 40 BP.

Discussion

Sedimentology of Unit 2

Unit 2 exhibits unusual sediment characteristics when compared with the confining facies. Bulk samples are considerably coarser than the confining sediments because of the presence of a population of very coarse (>2 mm) shell and rock clasts. Analysis of treated (carbonate removed) samples suggests that the matrix is very similar to the underlying beach facies and modern samples collected from both the seaward channel and beaches. Also unusual is the elevation (0.7–2.25 m AHD) and lateral extent of Unit 2 indicating that it exists as a thin sedimentary unit that drapes the underlying prograded beach system. The unit is considered 'unusual' in that there is no regional evidence of elevated sea level (i.e. 0.7–2.25 m AHD at *c.* 2500–1000 cal BP) when this facies was deposited (Sloss *et al.*, 2007).

Macro- and micropalaeontology

The macrofauna identified in the coarse shelly deposit are representative of modern shells from rock platforms, modern beaches, and tidal channels suggesting the deposit is the product of erosion from several seaward environments (Jensen, 1995; Roy *et al.*, 2001). The coarse shelly macrofauna, *A. trapezia* and *S. glomerata* (Sydney rock oyster), exist on modern sand flats, sea grass beds, and rocky outcrops, respectively. All of these environments are only found seaward of the study site. Unfortunately, no modern *A. trapezia* were found during grab sampling in the embayment.

To varying degrees, the foraminiferal assemblage within Unit 2 is different to the assemblages contained within Units 1 and 3, and the grab samples. The Fisher α-values and cluster analysis results further demonstrate this difference. Sample F2/2 (Unit 3) with a Fisher α-value of 3.78 has an assemblage suggestive or a normal marine estuarine lagoon to hypersaline lagoon environment (Table 4). Samples F2/6 and F2/9 (Unit 2), with higher Fisher α-values of 6.65 and 7.29 (Table 4), are indicative of a slightly less saline environment, such as a normal marine estuary lagoon.

Samples F2/11 and F2/13 (Unit 1) possess relatively low Fisher α-values of 3.6 and 3.1 indicative of a brackish to hypersaline lagoon. GS28 has Fisher α-value of 9.51 reflecting a more inner shelf-like environment. GS29 and GS30 have very high Fisher α-values of 15.37 and 32.68 indicating open shelf to bathyal marine conditions with normal salinity. The Fisher α-values of the grab samples are entirely expected given their geographic positions within Batemans Bay (Figure 2).

The Fisher α-values of the GS29 and GS30 are sufficiently different to those of Units 1, 2, and 3 that the Old Punt Bay deposit is not derived from the sediments within Bateman's Bay proper. However, the α-values of GS28 are similar enough to the Old Punt Bay deposit to suggest that either Units 1, 2, and 3 could be derived from the channel sediments. Given the similarities in assemblage composition, this may suggest that the Old Punt Bay deposit is actually derived from the sediments within the channel around the area of GS28 (not the other way around).

Cluster analysis (Figure 7) indicates some degree of difference in assemblage composition between Units 1, 2, and 3. However, with more than 80% similarity between the three units, they are interpreted as one distinct cluster, and it is not possible to divide them further into separate discrete assemblages.

Taphonomic comparison of material from GS28 and Units 1 and 2 indicates that the latter were subjected to heavy weathering post deposition (brittle, heavily corroded, and covered in fine silt). The GS28 specimens have not been similarly affected suggesting considerable post-depositional weathering of the material.

However, given the similarities in assemblage composition, this suggests that the Old Punt Bay deposit is actually derived from the sediments within the channel around the area of GS28.

Our foraminiferal analysis indicates some similarities between the Old Punt Bay deposits and previously described local assemblages (Cotter, 1996; Haslett, 2007). However, it is difficult to construct a clear palaeoenvironmental history from the foraminifera for several reasons. First, we have only analysed a small number of samples. Second, previous work has only focused on channel assemblages and not the open bay (Cotter, 1996). Last, Strotz (2003) demonstrated, through taxonomic synonymy, that inconsistencies exist within species nomenclature in previous studies, making effective assemblage comparisons difficult. Consequently, we recommend detailed sampling and analysis of the entire Bateman's Bay area in order to adequately evaluate the foraminiferal faunas and palaeoenvironmental history of the area. However, our results are extremely positive in indicating that detailed micro- and macropalaeontological analyses can be very useful in distinguishing the palaeoenvironmental history of a deposit and in the identification of extreme events.

The presence of fragile and articulated macrofaunal shells (Figure 5b) is also unusual because it suggests that the material in Unit 2 was emplaced with little abrasive reworking. The presence of articulated shells that are filled or partially filled with sand is probably indicative of post-depositional infilling as the organic material of the shell decomposed. If this is the case, it provides evidence that the bivalves were alive during transport. It is also important to note that several large (B axis of 25–50 mm) well-rounded clasts of quartz and folded metasediments were found incorporated in Unit 2. The presence of metasedimentary rock clasts is indicative of an easterly (seaward source) as these lithologies do not occur in outcrop within the catchment of the Clyde River and are only found to the east of the study site (Fergusson and Frikken, 2002).

One source of diverse, large shelly fauna often found on the coast is aboriginal middens (Hall and McNiven, 1999; Hutchinson and Attenbrow, 2009). It is unlikely that Unit 2 is a midden as it is much more extensive than any midden found on the coast (Hughes and Djohadze, 1980), contains no evidence of burning and contains several shells of inedible species. This deposit is different as it contains a mixed assemblage of channel and beach material. We suggest therefore, that a large-scale washover event that is capable of incorporating both beach material and channel sediments and depositing them in a flat-lying laterally extensive deposit is the most likely mechanism for deposition.

The very coarse nature of the elevated shell-rich unit appears anomalous when compared with the evolution of the underlying beach sequence. The presence of very coarse (cobble-sized) shelly sediments with numerous rock clasts is strongly suggestive of deposition under high-energy conditions. Shell and cobble deposits have been identified as evidence for washover deposition in a few places. Three notable examples include sediments attributed to large storms in the Netherlands (Jelgersma *et al*., 1995) and northern Australia (Nott and Hayne, 2001; Nott, 2003), and tsunami deposited sediments identified by Donato *et al*. (2008) in Oman. All of these studies present sediments primarily composed of shelly fauna in a matrix of sand-sized sediment.

The examples from northern Australia are from the carbonate-dominated environments of the tropical Great Barrier Reef. In contrast to the coastal sediments of the study site, the shelly carbonate-rich deposits studied by Nott and Hayne (2001) and Nott (2003; 2006) contain little terrigenous sediment. The shelly carbonate beach ridges are clearly the product of the source environment. At Batemans Bay, the nearshore zone, beach and dune are all composed of shelly carbonate material.

Jelgersma *et al*. (1995) identified a sequence of shell-rich beds that they attributed to the action of large mid-Holocene storms. The shell beds are found in coastal dune sequences and consist of beach face shells that are interspersed with accumulations of aeolian sand. Several notable similarities and contrasts exist between the deposits identified here and those of Jelgersma *et al*. (1995).

The study of Donato *et al*. (2008) provides the first taphonomic study of a shell-rich tsunami deposit and demonstrated the potential for shell-rich tsunami deposits given an adequate source of shelly material. In all three of these studies, the sediments contain shelly faunas that are distinctly different to those of their confining deposits.

The most peculiar characteristic of the coarse shell unit found at Old Punt Bay is the presence of lithic clasts, oyster shell and both single and articulated *Anadara* shells. Based on size alone, the large (>50 mm) oyster shells and rock clasts indicate that whatever environmental process led to the deposition of the deposit appear to have been able to transport very coarse clasts. Furthermore, the presence of rock encrusting oyster shells may also suggest that the event was capable of removing, or at least transporting, the top valve of oyster shells from the surrounding rocky outcrops (their primary habitat) before depositing them in this elevated deposit. Unfortunately, there are no modern examples of such erosion from this coast and this speculative hypothesis remains to be adequately tested.

The articulated *A. trapezia* shells may provide a valuable insight into the origin of the shell-rich unit. *Anadara trapezia* are often found in sea-grass meadows on sandy substrates in many estuaries along the NSW coast (Jensen, 1995). Unfortunately, no modern *A. trapezia* were obtained from the grab sampling programme for this study but it is likely that they would come from a seaward direction as they usually live in tidal flats with muddy sand that support meadows of the sea-grass *Zostera muelleri* (Irmisch ex Ascher) (Smith *et al*., 1975; Murray-Wallace *et al*., 2000). The most intriguing characteristic of the shell-rich unit is the presence of articulated shells that are often half opened and filled with shelly, fine- to medium-grained sand possibly indicating transport and deposition while still alive.

It is hypothesised here that the shells were transported to their elevated position by a depositional event with energy levels high enough to transport the material but not high enough to separate the tightly closed valves of the live shells. To fulfil this hypothesis and deposit articulated shells in an elevated position, the depositional event would require a mechanism of transport that would not cause separation of the shells. It is unlikely that a storm surge or storm waves would do this as they are characterised by individual pulses of very-high energy associated with individual wave run-ups (Switzer and Jones, 2008a). We speculate here that the shells may have opened after the organism died and the adductor muscles are no longer contracted. This would provide an explanation for the post-depositional infilling with sand. This hypothesis is partially confirmed by the over-lapping ages of the two articulated bivalve samples that gave ages of 2610–2110 BP (Beta273081) and 2720–2290 BP (Beta 273082), respectively. It is assumed that if the bivalves died during or soon after transport they would give identical (or at least overlapping) ages.

Dating results

The disparate dating results on samples from the same shell Wk9439 and UWGA702 may be indicative of possible post event contamination. The age data from the two articulated *Anadara* samples taken in January 2010 provided overlapping age ranges of 2610–2110 BP (Beta 273081) and 2720–2290 BP (Beta 273082). The overlapping dates are also consistent with the amino acid racemisation dates of the individual valve 2550–2790 BP (UWGA701). In addition to the new ages taken from Unit 2, an age obtained from the organic lens in the stratigraphically higher Unit 3 returned a stratigraphically consistent age of 2740–2360 BP. This new age sequence provides a chronological model that is consistent with the stratigraphy and suggests that the large shelly unit was deposited approximately ~2300–2600 years ago.

The original dating conducted in 2001–2002 used a single conventional radiocarbon age (Wk9439) and aspartic acid derived amino acid racemisation age (UWGA702) in one articulated specimen of *A. trapezia*. This result gave ages of 1010–1100 and 1226–1342 BP (Table 3). Based on this initial dataset and the nature of the deposit Switzer *et al*. (2001; 2005; 2009; 2010) suggested that this unit is a late-Holocene high-energy deposit (possibly tsunami) deposited 1000–1300 cal BP. Furthermore, Switzer *et al*. (2009; 2010) suggested that Unit 2 may be coeval with other high-energy deposited sediments identified at Killalea and Shellharbour (Figure 2b) by Switzer *et al*. (2005; 2006) and Switzer and Jones (2008b), approximately 130 km north of Batemans Bay. The new dating results obtained in 2010 and presented here suggest it is possible this event is actually coeval with event 5 in Table 1 and occurred *c.* 2900 BP. It is important to note that although the articulated *A. trapezia* shell dated in 2001–2002 using conventional radiocarbon (Wk9439) and amino acid racemisation (UWGA702) both gave an age of ~1000–1300 BP it is possible that this sample may have been contaminated with modern carbon or in the case of amino acid racemisation dating affected by temperature variation. The *Anadara* shell dated in 2001–2002 was taken from the surface of Face 2, and as such, would only have been at a depth of 20–30 cm from the contemporary river bank. It is possible that contamination may have affected the results of this shell as fossil molluscs taken from the near-surface location of the river bank are likely to have experienced significant fluctuations in temperature and moisture regime associated with percolating groundwater, seasonal floods and changes in temperature and soil moisture on a daily or seasonal basis (Craig Sloss, personal communication, 2011). The fossil molluscs can become highly weathered and degraded with a chalky and visibly porous appearance (Miller and Brigham-Grette, 1989; Murray-Wallace, 1993). This may affect amino acid racemisation dating as leaching of the lower molecular weight peptides and lower amino acid concentrations within the carbonate matrix of fossil mollusc may cause considerable inaccuracies in age determinations. In contrast, two single *A. trapezia valves* collected slightly further into the exposed section yielded amino acid racemisation derived ages (UWGA700 and UWGA701) in excess of 2000 BP. Switzer *et al.* (2010) suggested that these two ages may have been indicative of reworked shells. In light of the latest ages from the Units 2 and 3 this appears unlikely and it appears that the material dated by amino acid racemisation is stratigraphically consistent and more likely to be correct. As such, if our interpretation is accepted, then we have evidence for an event with a tighter chronological control dated at *c.* 2900 BP.

Explanation for the deposition of the large shelly layer (Unit 2)

The sedimentary characteristics of the shell-rich unit show that it is composed of material derived from several environments that occur in a seaward direction of the deposit. Figure 8 provides a summative explanation for the deposition of the shell-rich unit. It explains the erosion, transport, and deposition of all components of the unit along with the source area for each component. As discussed above, it is unlikely that this deposit can be attributed to a storm surge event. One mechanism that explains the transport of large amounts of material by both turbulent and laminar flow is deposition by tsunami (Nanayama and Shigeno, 2006; Dawson and Stewart, 2007a; Hori *et al.*, 2007; Morton *et al.*, 2007; Paris *et al.*, 2007a; 2007b; 2009; Choowong *et al.*, 2008a; 2008b).

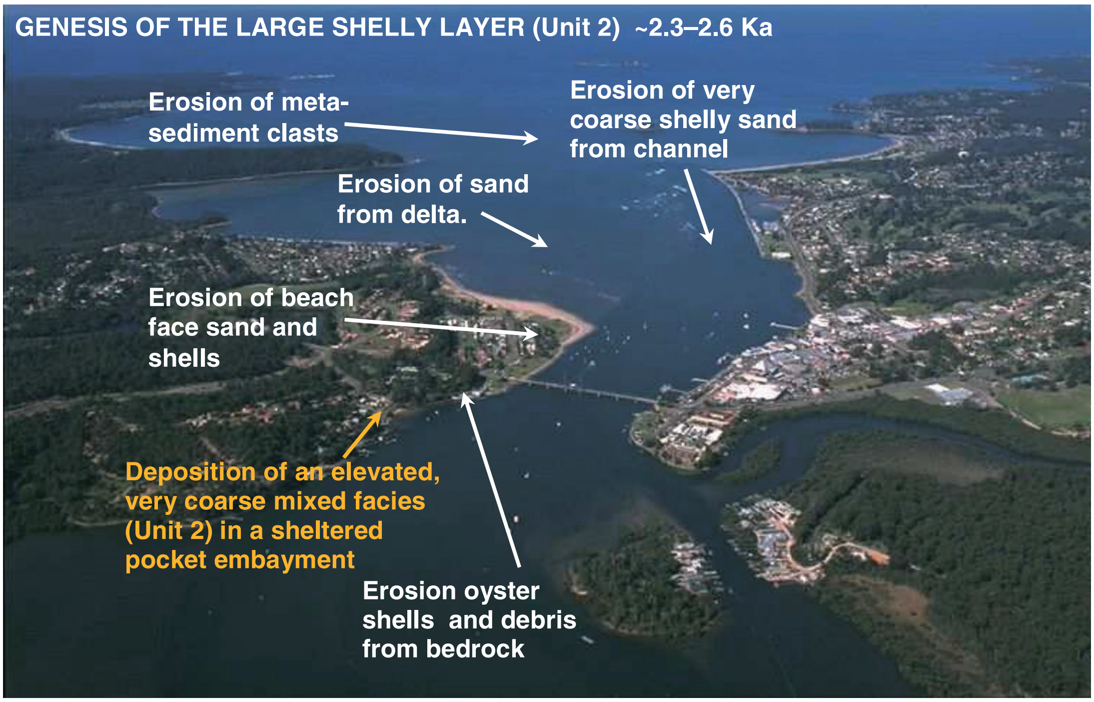

Figure 8 Schematic interpretation of the erosion and deposition of the shell-rich unit by large-scale washover. The event was capable of eroding large amounts of material from the seaward environments and transporting it to its current elevated position in the pocket embayment. The presence of articulated shells suggests that the event did this without significant turbulence that would have separated the valves of the shells. This event is attributed to a late-Holocene tsunami from the south-east.

Unlike large storm waves, a tsunami often occurs as a single surge that is capable of carrying large amounts of material in suspension considerable distances inland (Morton *et al*., 2007; Switzer and Jones, 2008b). This hydrodynamic property may explain the presence of the large articulated shells found in the shell-rich unit. The shells may have been carried in suspension with little reworking before being infilled with sand, similar to those deposited at Sur Lagoon in Oman from the 28 November 1945 Makran Trench earthquake and tsunami off Pakistan (Donato *et al*., 2008; 2009).

Relationship of Unit 2 (tsunami) deposit to existing evidence for and chronology of NSW palaeotsunamis

If our interpretation and dating is accepted, Unit 2 most closely corresponds with palaeotsunami event # 5 in Figure 1d and Table 1. That event has previously been described as occurring at *c*. 2900 BP and was reported at site 51 (Cullendulla Creek) (Bryant *et al*., 1992) and site 52 (Batemans Bay) (Bryant and Nott, 2001) (Figure 1b). These are the *only* sites where dates for this event have been provided. This 'event' is further described as having been identified at sites 1 (Lord Howe Island), 25 (Bass Point – Shellharbour), 31 Shoalhaven/Crookhaven, 32 (Jervis Bay – exact site not specified), 38 (Crocodile Head), 42 (Streamers Beach), 43 (Gumgetters Inlet), and 58 (Tura Point) (Figure 1) (Courtney *et al*., in review). However, at none of these sites are *any* dates presented. As such, this event at these sites remains speculative at best.

The detailed dating we have reported is important because it provides a much tighter control on the age of the deposit. This is significant because the previously reported age for the event (2900 BP) was actually derived from two 'calibrated age range dates' of 723–1189 and 1169–1655 cal BP (Bryant *et al*., 1992). As such, it is hard to imagine how Bryant *et al*. (1992) came to the suggestion the event occurred at 2900 BP with calibrated age range dates in the range of 723–1655 BP.

Implications for coastal planning

The identification of this deposit indicates that a very unusual process has occurred in the past in the Batemans Bay area and that this event was considerably larger than any in recorded history. This disjunct between modern records of small tsunami affecting the coast of NSW and the geological record of recent (Holocene) much larger tsunami was reported by Dominey-Howes (2007), Dominey-Howes *et al*. (2006), and Goff and Dominey-Howes (2009). Although the mid-Holocene age of the deposit places it in a period of slightly higher sea level (Sloss *et al*., 2007; Switzer *et al*., 2010) the composition of the deposit is indicative of a catastrophic marine washover event and cannot be attributed to higher sea level alone. Regardless of the genesis suggested for the large shelly deposit presented here, the reoccurrence of this type of event would cause considerable damage to the low-lying communities that surround the bay. The identification of extreme/catastrophic marine flood events far greater than anything experienced in modern history challenges our current paradigm for coastal hazards. Such event deposits have implications for devising risk management plans and assessing the needs and actions of emergency services (Dall'Osso and Dominey-Howes, 2010a; 2010b; Dall'Osso *et al.*, 2009a; 2009b; Jaffe *et al*., 2008). The recognition of such unprecedented scale catastrophic events in the past should undoubtedly raise concerns for the highly populated and developed urban setting in which we now live.

If it is accepted that Unit 2 does indeed represent a tsunami deposit and that the deposit was laid down *c*. 2500–2900 BP, then it very likely represents new evidence for an event previously poorly constrained chronologically, but which appears to have occurred *c*. 2900 BP. This adds further evidence to the developing chronology of palaeotsunamis that have affected the south-eastern coast of Australia (Goff and Dominey-Howes, 2009). Further, it is apparent that even though additional work needs to be done on these deposits, our detailed micro- and macrofaunal analyses carried out in this study provide a valuable addition to the currently accepted tools used for identification and reconstruction of palaeoextreme events.

Conclusions

A large shelly layer (Unit 2) is found in the upper fill of a small coastal embayment. The unit appears anomalous and contains large shells of mixed affinity plus rock clasts. Of particular note is the presence of articulated and fragile shells that indicate transport with little hydraulic reworking. Comparison between the sedimentary components of the shell-rich unit with the grab samples throughout the estuary suggests that the shell-rich unit is composed of material that occurs primarily in seaward environments such as the channel and the tidal delta. The foraminifera, however, indicate an affinity with channel deposits.

At the present time, insufficient data exists to enable us to draw firm conclusions concerning the origin of the unusual deposit at Old Punt Bay. The most likely source is a high-energy marine inundation event capable of eroding, transporting, and depositing live shells, mixed microfauna, and cobble sized rock clasts. Alternative hypothesis may include storm surge deposition or tsunami inundation approximately 2500–2900 BP. A tsunami could have eroded large amounts of material from the channel, delta, and surrounding rock shelves before transporting the material (with little reworking) to the elevated site of deposition. If true, the deposit provides new evidence and a tighter dating for a tsunami believed to have occurred at *c.* 2500–2900 BP. This hypothesis, however, remains to be fully tested.

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