Continental Shelf Research 134 (2017) 26–38

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Palaeoshorelines on the Australian continental shelf: Morphology, sea-level relationship and applications to environmental management and archaeology

Brendan P. Brooke[a,*], Scott L. Nichol[a], Zhi Huang[a], Robin J. Beaman[b]

[a] National Earth and Marine Observations Branch, Geoscience Australia, PO Box 378, Canberra, ACT 2601, Australia
[b] College of Science and Engineering, James Cook University, PO Box 6811, Cairns, QLD 4870, Australia

ABSTRACT

Palaeoshorelines that lie submerged on stable continental shelves are relict coastal depositional and erosional structures formed during periods of lower sea level. An analysis of the well-dated Late Quaternary (0–128 ka) sea-level record indicates that the most persistent (modal) lower sea levels were at 30 – 40 m below present, which occurred between 97 and 116 ka and at approximately 85 ka and 10 ka. A secondary modal position was at 70–90 m that occurred mostly during a period of fluctuating sea level between 30 and 60 ka, as well as at around 87 ka (70 – 80 m only) and 12–15 ka. For the tectonically stable Australian continental shelf, we show that a range of shorelines formed at each of these sea level modal positions and their morphology and degree of preservation depends on composition (carbonate vs siliciclastic) and oceanographic setting (wave, tide and wind energy). These ancient coasts record a range of oceanographic and geological regimes that existed during relatively long periods of lower sea level and provide a guide to the general depth zones in which similar features likely occur on other shelves globally. Australian palaeoshorelines represent distinctive benthic habitats that strongly influence the distribution of biodiversity across the shelf. Accurate mapping of these features provides a robust geospatial framework for investigations of marine species distributions and environmental change monitoring. These data also enable the better targeting of relict coastal areas that potentially include sand resources and sites of human occupation during periods of lower sea level.

1. Introduction

Submerged palaeoshorelines are the remnants of relict coastal depositional and erosional landforms. Depositional forms include various sedimentary deposits (e.g. beaches, coastal dunes, subtidal banks) and biogenic structures (e.g. coral reefs, algal banks) that were drowned as sea level rose. Shoreline erosional structures produced by the impact of wave action and/or bioerosion (e.g. cliffs, ledges) were likewise stranded on the shelf as sea level rose. On stable continental shelves, palaeoshorelines record the position at which sea level persisted for periods long enough for coastal processes to form these structures (e.g. Harris et al., 2005; Brooke et al., 2010a; Cawthra et al., 2014; Table 1). Where preserved, these structures capture a valuable record of environmental change and can inform our understanding of modern shelf ecosystems, particularly the distribution of seabed features that provide important habitat for benthic biological communities (Banks et al., 2008; Nichol et al., 2012; Brooke et al., 2012a). In some cases, these same features may indicate the location of relict coastal resources that were utilised by humans and so are also of archaeological significance (examples in Evans et al., 2014; Harff et al., 2015a).

Palaeoshorelines formed during the Late Quaternary glacio-eustatic sea-level cycle have the highest potential to have been preserved on the modern shelf. These structures formed during periods of lower sea level following the peak of the Last Interglacial until the middle Holocene, as represented by MIS 5d (~109 ka) through to MIS 1 (~6.5 ka) (Lisiecki and Raymo, 2005). During this period, especially with the onset of the Last Glacial Maximum lowstand of MIS 2 (~21 ka), stable shelves were emergent if not shallower and, depending on offshore gradients, narrower than present, with coastal oceanographic regimes and shoreline sedimentary environments markedly different from the present. For example, lowstand shorelines composed of oolitic and heterozoan carbonates contrast with adjacent modern photozoan coastal deposits (Wiedicke et al., 1999; Jarrett et al., 2005); lowstand temperate carbonates clearly differ from the modern siliciclastic coast (Ferland et al., 1995); and relict, drowned coastal plains of lower gradient define

* Corresponding author.
E-mail address: Brendan.Brooke@ga.gov.au (B.P. Brooke).

http://dx.doi.org/10.1016/j.csr.2016.12.012
Received 22 June 2016; Received in revised form 30 September 2016; Accepted 20 December 2016
Available online 03 January 2017
0278-4343/
Crown Copyright © 2017 Published by Elsevier Ltd.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/BY/4.0/).

Table 1
Palaeoshoreline features on the Australian continental shelf.

Feature Type and Location	Morphology and Age (where dated)	Depth Range (m)	Shelf setting	Oceanographic Regime & Sediment Type	Reference
Relict Barriers					
Rottnest Shelf, SW Western Australia	Extensive (up to 10 s km), ~shore-parallel ridges, with relief of 10–20 m (inner shelf) and 5–15 m (outer shelf).	20–30; 50–60	Relatively steep inner shelf; middle-outer shelf low gradient to break in slope at ~65 m depth	High wave energy, micro tidal, carbonate	James et al., 1999; Brooke et al., 2010a; Brooke et al., 2014; Nicholas et al., 2014
Recherche Shelf, S WA	Shore-parallel ridge, 5–8 m relief.	55–60	Wide (75 km) low gradient shelf.	High energy, micro tidal, carbonate.	Ryan et al., 2008
Lacepede Shelf, SE South Australia	Extensive (km), ~shore-parallel ridges, several metres relief.	14–32; 70; 72–126	Middle to inner shelf, low gradient, subtle uplift (shelf uplifted ~0.07 m/ka).	High energy, micro-tidal, carbonate	Sprigg, 1979; Hill et al., 2009; Murray Wallace and Woodroffe, 2014
Gippsland Shelf, Eastern Bass Strait	Parallel, low-relief (~1 m relief) ridges typical of a coastal strandplain.	65–75	Middle shelf, low gradient, adjacent to high relief granite reef.	High energy, micro-tidal, mixed quartz/carbonate.	Beaman et al., 2005
Southeast Australian Shelf, central and northern NSW	Largely buried/sub-surface, little morphological expression on seabed.	20–70	Middle shelf, low gradient, sediment covered.	High energy, microtidal, siliciclastic.	Brown, 1994; Roy, 1998; Whitehouse, 2007
Relict Sand Banks, Beaches, Ridges					
Southeast Australian Shelf, NSW	Low gradient, shore parallel sand ridges, with up to several m relief (formed as nearshore sand banks during lower sea levels).	20–40	Occur along sections of the NSW inner shelf.	High energy, microtidal, siliciclastic.	Roy, 1998; Whitehouse, 2007
Southeast Australian Shelf, northern NSW	Shore-parallel ridges, up to ~5 m relief: indurated, relict beach deposits or bedrock outcrops?	60–70	Middle shelf, low gradient.	High energy, microtidal, silicilastic	Jordan et al., 2010
Eastern Tasmanian Shelf, offshore Freycinet	Freycinet: low ridges, 1 – 5 m, possibly relict beaches.	90–100	Outer Shelf, low gradient	Moderate-high energy, microtidal, carbonate	Nichol et al., 2009
Coastal Dune Fields					
Rottnest Shelf, SW Western Australia	Irregular hardground, up to 8 km wide, with 5–15 m relief; some parabolic dune morphology preserved. Apparent surficial extensions of these dunes on nearby Rottnest Is were emplaced in MIS 3, 2.	40–50	Middle shelf	High energy, micro tidal, carbonate	Brooke et al., 2010a, 2014; Nicholas et al., 2014
Carnarvon Shelf, central Western Australia	Field of mounds, 2–5 m relief, and ridges, up to 16 m relief and 1.5 km long, ~shore normal (remnants of large parabolic dunes).	Mounds: 28–40; Ridges: 35–40	Features extend across inner shelf.	High energy, micro tidal, carbonate	Brooke et al., 2009; Nichol and Brooke, 2011;
Coral Reefs *Platform, Barrier and Fringing Reefs*					
Great Barrier Reef Shelf, Queensland	Extensive liner, oval and irregular shaped banks, with ~26 – 44 m of relief. The base of the relict reef at Noggin Passage is 12.8 ka (~60 m depth).	~27 (middle shelf) ~60 (outer shelf)	Broad, low gradient shelf with steeper outer margin. Banks/relict reefs occur dominantly outboard of the modern reef, along several segments of the outer shelf.	Moderate to high energy, micotidal, carbonate.	Abbey and Webster; 2011; Yokoyama et al., 2011; Harris et al., 2012; Hinestrosa et al., 2014, 2016
Lord Howe Is and Balls Pyramid shelves, offshore NSW	Series of elongate banks and reefs, ~5 – 20 m relief, that sit a few km offshore and surround Lord Howe Is and Balls Pyramid. Reefs mostly early Holocene, ~9 ka.	25–35	Carbonate shelves that surround volcanic islands.	High energy, micro tidal, carbonate	Brooke et al., 2010b; Woodroffe et al., 2010; Linklater et al., 2015
Carnarvon Shelf, central Western Australia	Approximately shore parallel ridges, up to 22 km long, 6–20 relief.	60	Inner shelf, low gradient	High energy, micro tidal, carbonate.	Brooke et al., 2009; Nichol and Brooke, 2011
Londonderry Rise, NW Shelf, northern WA	Numerous oval-shaped carbonate banks, surface areas of several to a few tens of km^2, with a few	Most often at 75–78, 84–85, and ~90. A few others	Very broad, low gradient	Low energy, meso to macro tidal, carbonate	Nichol et al., 2013; Picard et al., 2014

(continued on next page)

Table 1 *(continued)*

Feature Type and Location	Morphology and Age (where dated)	Depth Range (m)	Shelf setting	Oceanographic Regime & Sediment Type	Reference
	10 s m relief. Shallower banks have terraces at ~75 and 85 m	at 35, 52 and ~60			
Sahul Shelf, NW WA	Relict barrier reef, few 10 s metres relief, surface area 10 s km^2. Relict lagoon and patch reefs leeward of reef.	Reef crest, 90. Lagoon floor 115. Patch reefs crests, 90	Outer shelf, low gradient	Low energy, meso tidal, carbonate	Howard et al., 2016
Gulf of Carpentaria	Oval shaped carbonate banks, often with a cap of living coral; surface areas up to 72 km^2, relief 10–20 m. Reefs last grew in early Holocene, ~9–7 ka.	27–31	Broad, low gradient	Low energy, mesotidal, carbonate.	Harris et al., 2004, 2008
Torres Strait – Northern Great Barrier Reef	Submerged coral reef platforms, middle to outer shelf.	45–55	Broad shelf, with deep channels between some platforms.	Low-moderate energy, mesotidal, carbonate (outer shelf); carbonate-siliciclastic (middle shelf).	Harris et al., 2005
Estuarine & Tidal Channels					
Northwest Shelf, Outer Bonaparte Gulf Leveque Shelf	Bonaparte Gulf: Meandering to sinuous channels, 5 – 10 m relief, 200 m – 1 km wide; Leveque Shelf: Straight to meandering channels up to 2 km wide, up to 10 m relief.	80–90	Very broad, low gradient	Low wave energy, meso to macro tidal, carbonate	Carroll et al., 2012; Nichol et al., 2013; Picard et al., 2014; Anderson et al., 2011; Heap et al., 2010
Capricorn Shelf, southern GBR	Wide (836 – 1378 m), partially infilled estuarine/fluvial channel, 1.2 – 9.2 m relief, extends across the middle and outer shelf.	30–55	Broad, low gradient middle shelf.	Moderate energy, meso tidal, mixed siliciclastic-carbonate	Ryan et al., 2007
Torres Strait - Northern Great Barrier Reef (similar features at Banks Strait, NE Tasmania, and Van Dieman's Gulf, Northern Territory).	Relict, tidally-incised channels on middle and outer shelf, up to 220 m deep.	30–50 m (modelled depth when channels were incised)	Very broad; low-relief inner shelf, high-relief middle & outer shelf.	Low-moderate energy, mesotidal, mixed siliciclastic-carbonate.	Harris, 1994; Harris et al., 2005
Shoreline Cliffs, Benches, Platforms, Ridges					
Rottnest Shelf, SW Western Australia	Bench cut in outer shelf, below break in slope.	70	Below break in slope on mid-outer shelf.	High energy, micro tidal, carbonate	Brooke et al., 2010a
Lacepede Shelf, SE South Australia	Erosional 'nick point' (cliff/bluff), up to ~10 m relief, that extends along the shelf.	100	Middle shelf	High energy, micro tidal, carbonate	Sprigg, 1979; Hill et al., 2009
Otway Shelf, Victoria	Prominent relict shoreline cliffs, 14 m relief, and adjacent remnant sea stacks.	60	Middle shelf	High energy, micro tidal, carbonate	Bezore et al., 2016
Northeast Tasmanian Shelf	Ridges with 1–2 m relief, likely erosional (bedrock), inter- to shallow subtidal origin.	60–90	Outer shelf	High energy, micro tidal, siliciclastic	Monk et al., 2016
Lord Howe Island and Balls Pyramid shelves, offshore NSW	Prominent benches, cut in the outer shelf basalt? , 5 – 10 m relief.	70; less prominent benches between 65 – 100	Outer shelf plunges to deep water.	High energy, micro tidal, carbonate	Brooke et al., 2010b; Linklater et al., 2015
Northwest Shelf, NW Western Australia	Seafloor cliff up to ~8 m relief (single beam echosounder profiles).	~125	Broad, low gradient shelf.	Low energy, meso to macro tidal, carbonate	James et al., 2004

a different shoreline configuration compared to the modern compartmentalized coast (Cawthra et al., 2015). Hence, depositional palaeoshoreline structures are likely to differ in morphology from their modern counterparts on any given coast. Further, the degree of preservation of these relict features will also vary depending on the intensity of coastal erosional processes during subaerial exposure and marine transgressions, and the volume and degree of resistance to erosion of the features (Bateman et al., 2004, 2011; Cawthra et al., 2014; Nichol and Brooke, 2011; Brooke et al., 2010a, 2014).

In this paper, we analyse Late Quaternary sea-level data to identify the most frequent lower sea levels - those modal elevations (depth intervals on the shelf) at which shoreline processes were most focused globally. We compare these data with the depth of occurrence of palaeoshoreline features that have been mapped in detail at a number of locations around the Australian continental shelf and adjacent islands to ascertain the effectiveness of these past sea levels in forming shoreline structures. The potential for some of these structures to have formed over multiple glacial cycles, as the integrated product of multiple sea level stillstands, is also considered.

We classify the morphology of palaeoshorelines based on their likely original environmental settings and formative processes (e.g. coastal dune, coral reef), and indicate their likely time of formation by comparing their elevation (depth) with the well-dated sea-level records. The influence of these features on benthic biodiversity and, therefore, relevance for environmental management is briefly examined. We also outline the utility of fine-scale bathymetric data for the study of human occupation of the coast during periods of lower sea level, the identification of offshore sand deposits and note the distribution of palaeoshorelines on a range of other continental shelves.

2. Study area

The Australian continental shelf forms a mostly broad, shallow sea (0–250 m) around the continent. It ranges in width from a few kilometres (e.g. southern New South Wales; central Western Australia) to hundreds of kilometres (e.g. north western WA); and from flat and mostly sediment covered (northern WA), to rocky and rugose (southern Tasmania) (Heap and Harris, 2008; Nichol et al., 2009; Fig. 1). The shelf occurs across 33 degrees of latitude and 40 degrees of longitude, encompassing tropical to cool temperate waters that are predominantly oligotrophic, and range from high-energy, micro-tidal, wave-dominated environments in the south to macro-tidal, tide-dominated in the north (Brooke et al., 2012b).

The Australian shelf receives little terrigenous sediment due to the relatively low discharge of Australian rivers (McMahon and Finlayson, 2003) and has extensive carbonate provinces (James and Bone, 2011; Hopley et al., 2007). During the Late Quaternary, the shelf has been tectonically stable due to the Australian continent's intra-plate setting (Pain et al., 2012). Being a far-field location from ice sheets that formed during the last glacial period, the shelf has been little influenced by glacio-isostatic processes (Murray-Wallace and Woodroffe, 2014). Postglacial hydro-isostatically induced vertical movements of the shelf have been relatively small, resulting in less than 2 m of adjustment on the coast (Lambeck and Nakada, 1990; Lambeck et al., 2014).

This combination of shelf characteristics – mostly broad and largely low-gradient morphology, sediment starved, extensive carbonate-dominated regions, tectonic stability, wide range of oceanographic regimes – gives the Australian shelf a high potential to retain a wide range of palaeoshoreline forms that are representative of structures likely to occur on a variety of continental shelves globally.

3. Methods

3.1. Sea-level data

The Late Quaternary relative sea-level reconstructions of Grant et al. (2012, 2014; data published in Grant et al., 2014) and Lambeck et al. (2014) are based on robust, well-dated and detailed sets of palaeo sea-level indicator data. The Grant et al. (2014) data are based on sediment cores from the Red Sea that span the period from modern to the Middle Quaternary. The Lambeck et al. (2014) data comprise a range of Late Quaternary sea-level indicator data, including from the Australian/South Pacific region, that provide additional records for the Last Glacial, especially for the periods represented by Marine Isotope

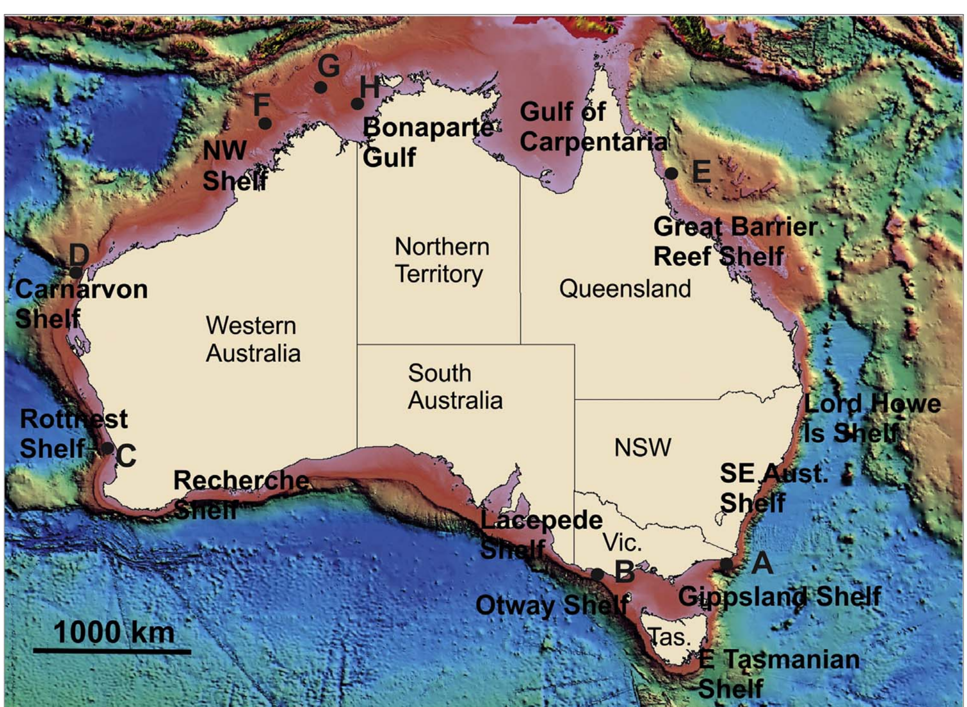

Fig. 1. A digital elevation model of the Australian continental shelf and the surrounding ocean floor. The names and locations of shelf regions referred to in the text are shown, and the locations of palaeoshoreline features presented in Fig. 4 are indicated by the letters A – H (Fig. 4A – H).

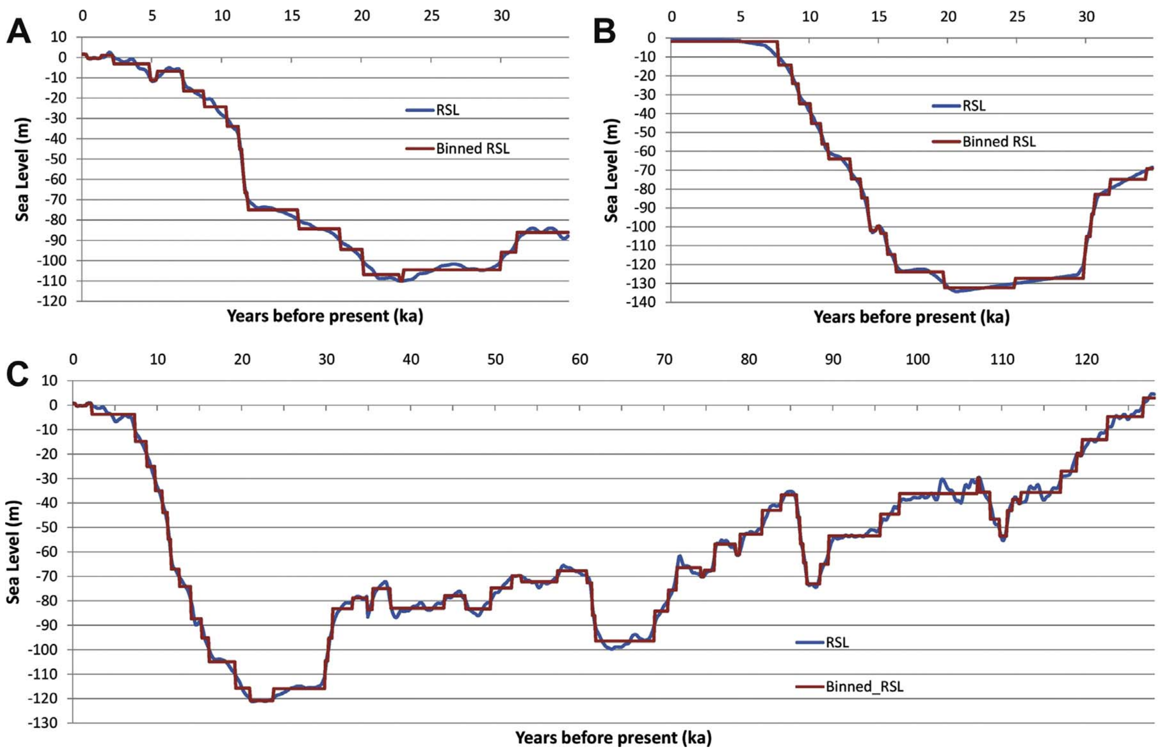

Fig. 2. Sea-level curves and estimates of the duration of specific sea levels for the Late Quaternary. A and B: Sea-level curves (relative sea level, RSL, and sea level plotted in 10 m bins) for the last 35 ka based on detailed, well dated sea-level records from Grant et al. (A; 2014) and Lambeck et al. (resampled, B; 2014). The main discrepancies are at around 20 ka, the Last Glacial Maximum lowstand, and the rate of rise in sea level following the LGM. However, given the uncertainties in the datasets (~ ± 6 m), the curves are similar. C: A composite relative sea-level curve and 10 m binned sea-level curve for the last 130 ka based on Grant et al. (2014) and resampled Lambeck et al. (2014) data.

Stages (MIS) 2 and 3. We use these data sets to identify significant modes in sea-level elevation since the Last Interglacial by analyzing the frequency distribution of the elevation estimates. To achieve this, we merged and harmonized the two datasets to provide a record that spans the period from 128 ka to the present. This required resampling the Lambeck et al. (2014) sea-level data (range: 0–34.75 ka) at intervals of 0.125 ka to match the time intervals of the Grant et al. (2014) dataset (range: 0–128 ka). Thus, each data point of Lambeck et al. (2014) was matched to the nearest corresponding record in the Grant et al. (2014) data. If multiple records of Lambeck et al. (2014) matched with the same record of Grant et al. (2014), the mean value of the Lambeck et al. (2014) records was calculated to represent the matching sea-level estimate. A combined sea-level dataset was generated between 0 and 128 ka by calculating the mean sea-level value from that of Grant et al. (2014) and the resampled Lambeck et al. (2014) datasets.

We classified the composite sea-level data into 10 m depth bins to account for uncertainties in the sea-level estimates (e.g. ± 6 m, Lambeck et al., 2014). The sea-level dataset of Grant et al. (2014) between 0 and ~35 ka and the associated binned sea-level dataset are depicted in Fig. 2a. Similarly, Fig. 2b shows the Lambeck et al. (2014) resampled sea-level dataset between 0 and ~35ka and the associated binned dataset. The combined dataset for the period 0 to 128ka, and the associated binned sea-level dataset, are displayed in Fig. 2c. The modes in these data represent the more frequent sea-level elevations at which shoreline constructional or erosional processes are likely to have been focused during the Late Quaternary.

3.2. Palaeoshoreline structures and seabed biodiversity

The coverage of high-resolution bathymetry data for areas of the continental shelf, especially those collected using multibeam echo sounders (MBES), enables the identification of relatively subtle seabed structures (e.g. Nichol and Brooke, 2011; examples in Harris and Baker, 2012). Here we utilize the information published for areas of the Australian shelf mapped at spatial resolutions high enough to accurately delineate relict coastal structures (ideally, bathymetry grids of spatial resolution less than a few tens of metres), with descriptions based on well-established morphological terms for modern coastal landforms (Woodroffe, 2002). For comparison with the sea-level curve, the depths of these features are given as a range for the base (drowned dunes, barriers) or as a crestal depth (reefs, benches, terraces). Examples of the influence of palaeoshoreline features on the spatial distribution of shelf biodiversity are drawn from the literature on the benthic biological communities that occur on palaeoshoreline features on the Australian shelf.

4. Results

4.1. Sea-level modes

The primary mode identified in the Late Quaternary sea-level data is the 30–40 m depth (below present sea-level) interval (Fig. 3b). Sea level was within this range during six episodes, with a total duration of 19 ka, including the longest episode of any single depth interval which lasted 9 ka (between 107 and 98 ka; Fig. 2c). Secondary modes are the depth intervals of 70–80 m (18 ka total duration) and 80–90 m (16 ka; Fig. 3b). The three next most frequent sea levels are 50–60 m (13 ka total duration), 60–70 m (12 ka) and 0–10 m (within the modern littoral zone; Fig. 3b). Overall, sea level during the Late Quaternary was most frequently between 30 and 40 m and, more broadly, between 70 and 90 m below the present level (Fig. 3b). A similar result was found by Harris et al. (2005; their Fig. 9b) using a 150 ka sea-level curve (modal peaks at 10 and 30–50 m) and by Harris and Macmillan-Lawler (2016; their Fig 7.17) using a 516 ka sea-level curve (modal peaks at 5, 40 and 85 m).

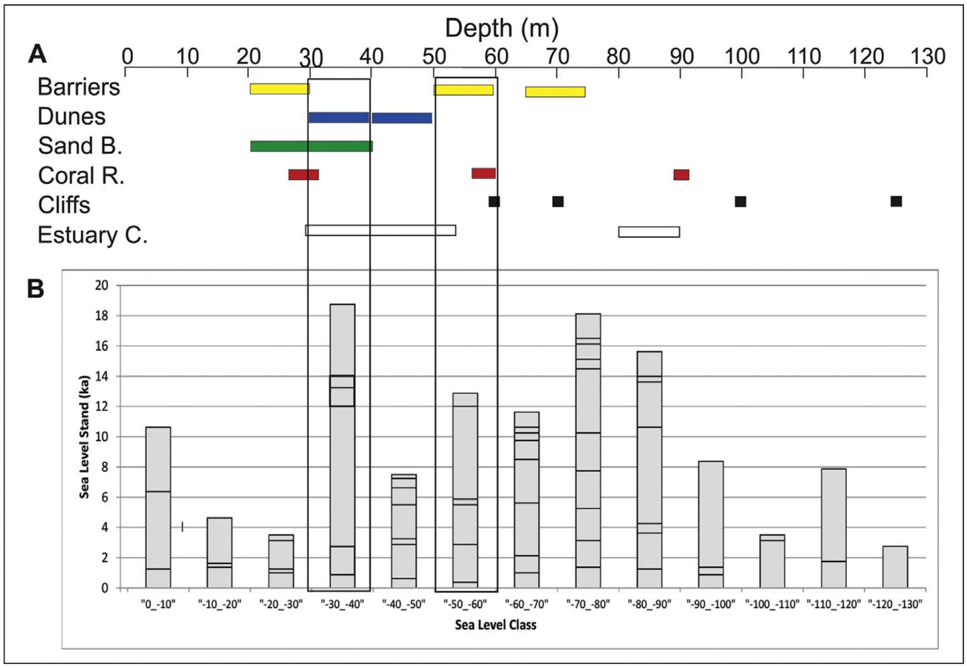

Fig. 3. The depth of palaeoshoreline features on the Australian shelf and Late Quaternary sea-level stands. A: The depth of various well-mapped palaeoshoreline features, Barriers: beach and barrier deposits; Dunes: coastal dune fields; Sand B.: nearshore sand banks; Coral R.: coral reefs and islands; Cliffs: shoreline cliffs and benches; Estuary C.: estuarine channels (data summary in Table 2, details in Table 1). B: Histograms of the frequency of the combined sea-level data of Grant et al. (2014) and Lambeck et al. (2014) binned in 10 m intervals (sea-level curve shown in Fig. 2C). Segments in the columns of the histogram represent the duration of discrete periods when sea level was within the depth range of the 10 m bins. Sea-level modes at 30–40 m and 50–60 m (large rectangles) align well with the depths of several palaeoshoreline features.

4.2. Shoreline morphology and inferred age

Palaeoshoreline features mapped on the Australian shelf include barriers (shore-parallel beach and dune deposits), coastal dune fields, coral reefs, estuarine channels and shoreline cliffs (Table 1). The depths at which the well-mapped features occur broadly align with the major modes in the Late Quaternary sea-level data. The features likely formed over a number of episodes that comprise the modes (Fig. 3.b) and possibly were initiated during an earlier Pleistocene sea-level cycle (discussed in Section 5.1). Relict barriers, coastal dunes, sand banks, coral reefs and estuary channels all occur within, or partly intersect, the primary sea-level mode of 30 – 40 m (e.g. dunes: 30–50 m; Table 2; Fig. 3b;). That some features only partly intersect the modal sea level can be explained by the typical elevation range of those landforms, especially barriers and dunes. Relict barriers and cliffs also occur within the deeper 60–70 m depth mode; and barriers, coral reefs, cliffs and estuary channels have been recorded within the range of the mode at 50–60 m. However, the relatively broad depth range of some structures (e.g. estuarine channels; Table 1) spans several depth classes (Fig. 3a). In contrast, the mapped relict coral reef and shoreline cliffs have a much narrower range of depths (discussed in Sections 5.2–5.5).

Based on the well-dated sea-level records, mapped structures currently in depth intervals of 20–30 m likely formed during intermediate stands of sea level between 115 and 120 ka and/or at around 9 ka, in the later stage of the last marine transgression; those in the 30 – 40 m depth interval formed between 97 and 116 ka and/or at around 85 and/or 10 ka (Fig. 2c). Features in depths of 60 – 70 m relate to sea levels that occurred between 52 and 62 ka, 72 – 77 ka and/or at around 97 ka, as well as approximately 12 ka; and those in depths of 50 – 60 m likely relate to sea levels reached between 75 and 80 ka and 90–95 ka, as well as at approximately 110 and 12 ka. Cliffs mapped at depths around 125 m would have formed during the Last Glacial Maximum at approximately 20 ka (Fig. 2c; Fig. 3a).

5. Discussion

5.1. Past sea levels and shorelines

The more frequent sea-level stands broadly match the depth ranges of palaeoshorelines that have been mapped on the Australian continental shelf (Fig. 3). Given the stability of the shelf, its wide range of oceanographic regimes and high potential to preserve drowned structures, the results are useful as a global indicator of the depth zones in which shoreline structures were well-developed during the Late Quaternary. The sea-level modes identified indicate the range of depths in which palaeoshorelines, if preserved, are likely to occur on other shelves. For example, early Holocene coral reefs sit in depths of around 30–40 m at many locations on the shelf of northern Australia (e.g. Harris et al., 2004, 2008; Table 1; Fig. 3a) and similar structures at these depths have been recorded in Florida (Banks et al., 2008) and throughout the Caribbean (Hubbard et al., 2008; discussed in Section 5.8).

Some palaeoshorelines may include remnants of shoreline structures formed during earlier glacial/interglacial cycles, as recorded for onshore remnant deposits such as barriers and dunes (e.g. Murray-Wallace et al., 2001; Bateman et al., 2011). However, unlike onshore deposits, shoreline features on the shelf that formed under past glacial/interglacial cycles have been subject to multiple episodes of marine erosion and therefore have a lower potential for preservation. The more robust structures, such as coral reefs and cliffs, have a much higher potential to be preserved over multiple sea-level fluctuations (discussed in Section 5.3). Assessing the influence on the formation of these 'hard' features of shoreline processes that operated during the last glacial cycle compared to previous cycles requires the feature to be dated (e.g. coral reefs; Hinestrosa et al., 2016), which is a challenge for many features (Table 1).

Table 2
Summary of palaeoshoreline structures on the Australian Shelf.

Palaeoshoreline Types	Defining characteristics	Typical Depth Range (metres)
Constructional		
Beach & Barrier Deposits	Elongate (km), approximately shore-parallel broad (100 s m – 10 s km) ridge structures that comprise beach, foredune and dune deposits, up to several metres high.	20–30 50–75
Coastal Dune Fields	Remnant dune structures that extend 100 s metres to several kilometres across the shelf with relief up to 10 m (e.g. parabolic dunes that migrated landward).	30–50
Nearshore Banks	Low-profile, stranded sand banks or buried deposits on the inner-middle shelf that formed in the littoral zone as subtidal banks and bars, less than 5 m high.	20–40
Estuarine Basins/Deltas	Sediment bodies on the shelf that were deposited in estuarine environments.	?
Fringing, Barrier & Platform Coral Reefs	Coral reef structures that developed within the intertidal to shallow sub-tidal zone; several to tens of kilometres m in length and 10 s of metres high.	27–31 58–60 25–35 90
Erosional		
Shoreline Cliffs and Benches	Planar bedrock structures that formed in the intertidal zone through wave erosion and weathering; often parallel to the coast and several to tens of metres high.	60 70 100 125
Estuarine channels	Channel structures on the shelf that were cut into the seabed by tidal currents in or near the mouth of an estuary; and maintain a negative relief.	80–90 30–55

5.2. Sediment type and preservation of barriers and dunes

Geological and oceanographic factors also influence the development and preservation of relict coasts (e.g. sediment type, sediment load to shelf, current and wave regimes). In particular, the degree of preservation is influenced by sediment type and the time since formation, the latter which defines the number of sea-level fluctuations (statidals and interstadials; glacials and interglacials) a particular relict feature will have experienced. Thus, the most recently formed and strongly-indurated deposits (e.g. Holocene coral reefs) are more likely to be preserved as they have been subjected to shorter or relatively less effective periods of erosion. Whereas older barriers that are weakly indurated (e.g. formed during early MIS 3), will have experienced multiple episodes of erosion associated with fluctuations in sea level.

Carbonate-producing marine biota (e.g. coral, algae, bryozoans, foraminifera, molluscs) have played a key role in the formation and distribution of palaeoshoreline structures on the Australian shelf, especially in regions where there is a low input of terrestrial sediment. These biota have formed reefs and banks, and their skeletal fragments accumulated into extensive, large coastal barriers and dune fields (Table 1; Brooke et al., 2012b). Carbonate sediment that forms barriers and dunes, although initially highly mobile, can be rapidly cemented by meteoric and vadose zone processes in coastal environments (e.g. Kindler and Hearty, 1997; Kindler and Mazzolini, 2001), which enhances the preservation of these deposits through periods of subaerial exposure, marine transgression and submergence (James et al., 2004; Brooke et al., 2010a; Nichol and Brooke, 2011; Cawthra et al., 2015).

In the temperate waters of southern Australia, relict coastal barriers are the most prominent type of palaeoshoreline structure. They occur along the carbonate-dominated Rottnest Shelf on the southwest margin (e.g. Brooke et al., 2010b; Nichol and Brooke, 2011), the Esperance Shelf in the south (Ryan et al., 2008) and the Lacapede Shelf (Sprigg, 1979; Hill et al., 2009) and Gippsland Shelf (Beaman et al., 2005) in the southeast. Similarly, coastal dune fields composed of carbonate sand have been partially preserved on the Rottnest and Carnarvon shelves of Western Australia (Table 1; Fig. 4c, d). These deposits were emplaced during periods of lower sea level and became cemented prior to being partially eroded and drowned by the last marine transgression. They form structures with up to 16 m of relief that extend across several kilometres of seabed, having migrated inland from shorelines that occurred when sea level was at least 40 m (Carnarvon Shelf) and 50 m (Rottnest Shelf) below the present level. Although undated, their depth, morphology and ages for nearby, subaerial exposures of similar features suggest that they were deposited during the period from MIS 4 to MIS 2 as mobile dune fields under southwesterly wind (Fig. 4c, d; Brooke et al., 2010a, 2014; Nichol and Brooke, 2011; Nicholas et al., 2014). More subtle barrier deposits, with a few metres of relief, have been preserved on the carbonate-dominated Gippsland Shelf in the form of a beach-ridge strandplain (depth ~65 m, Table 1; Beaman et al., 2005; Fig. 4a).

In contrast, the siliciclastic-dominated eastern shelf offshore New South Wales and southeastern Queensland, where large remnants of Late Quaternary barriers occur on the modern coast, appears to have no equivalent large relict structures on the adjacent shelf, rather only low-relief remnants and buried deposits (Roy, 1998; Whitehouse, 2007; Brooke et al., 2015; Table 1). Clearly, sediment type plays a key role in determining the preservation of depositional palaeoshoreline structures. Sediment type also influences the rate of lithification. For example, coral reef builds a structure which is lithified during formation, while other carbonates (e.g. foraminifera and molluscs) contribute to landforms that subsequently become cemented because of their calcareous nature.

5.3. Coral reefs

In tropical waters of north, northwestern and northeastern Australia, drowned coral reefs are prominent shelf structures that record past periods of relatively stable sea-level that persisted long enough for the distinctive reef crest morphology to develop (or rose slowly enough for the reef to 'keep up'; Table 1; Figs. 3, 4d-g). Across these regions, relict reefs are preserved at depths consistent with the primary sea-level modes (30–40 and 70–90 m below present). Thus, offshore the modern Ningaloo Reef on the Carnarvon Shelf of Western

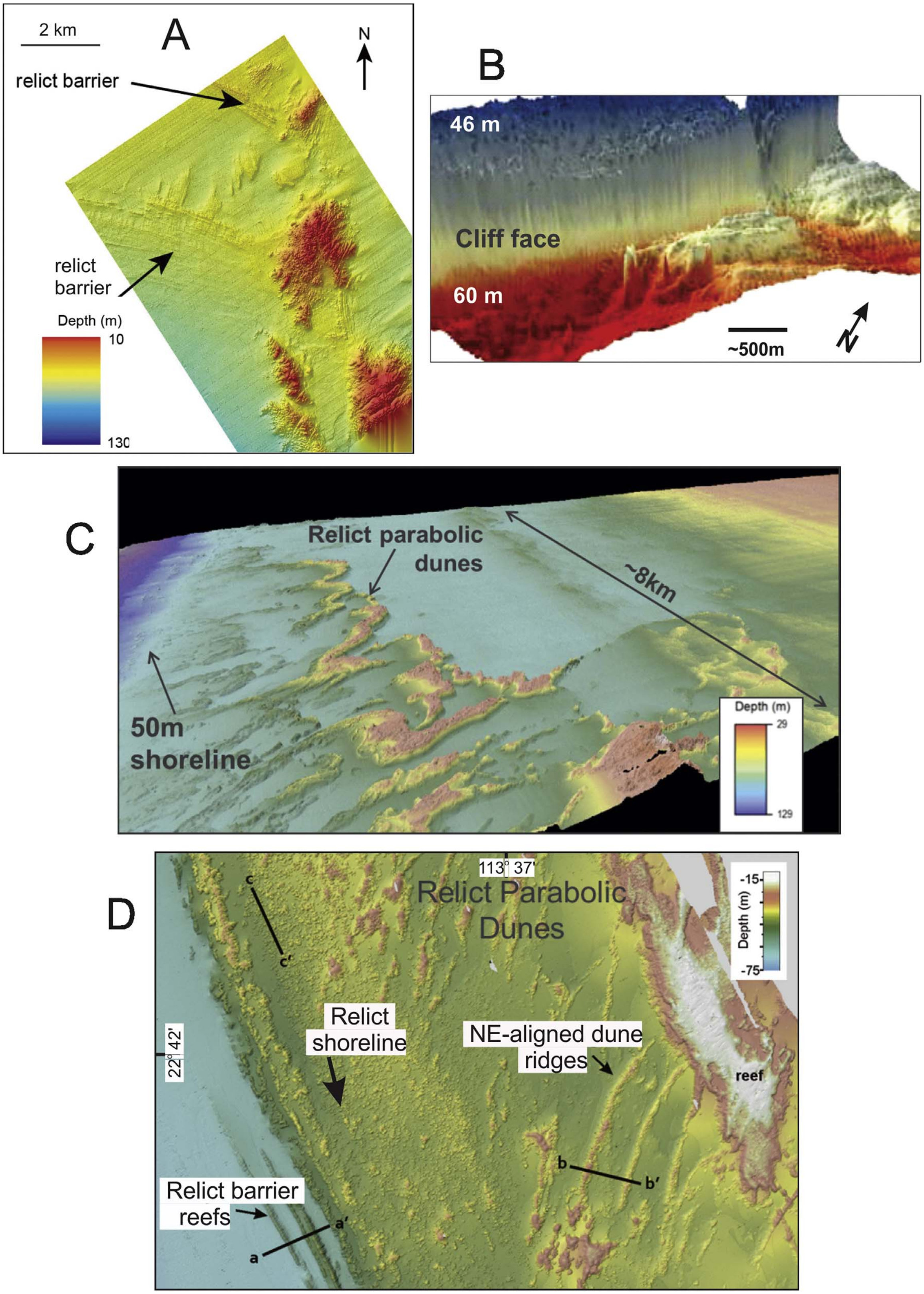

Fig. 4. Acoustic images of example palaeoshoreline structures mapped with MBES systems on the Australian continental shelf. A: Beach-ridge strandplain on the Gippsland Shelf (after Beaman et al., 2005). B: Shoreline cliff, Otway Shelf (after Bezore et al., 2016). C: Dune remnants, Rottnest Shelf (after Nicholas et al., 2014). D: Parabolic dune remnants and linear reef, Carnarvon Shelf (after Nichol and Brooke, 2011). E: Relict barrier reef, Great Barrier Reef Shelf (after Hinestrosa et al., 2016). F: Drown platform reef, Londonderry Rise, NW Shelf (after Nichol et al., 2013). G: Drown barrier reef, Sahul Shelf/NW Shelf (after Howard et al., 2016). H: Relict macro-tidal estuarine channels, outer Bonaparte Gulf, NW Shelf (after Carroll et al., 2012).

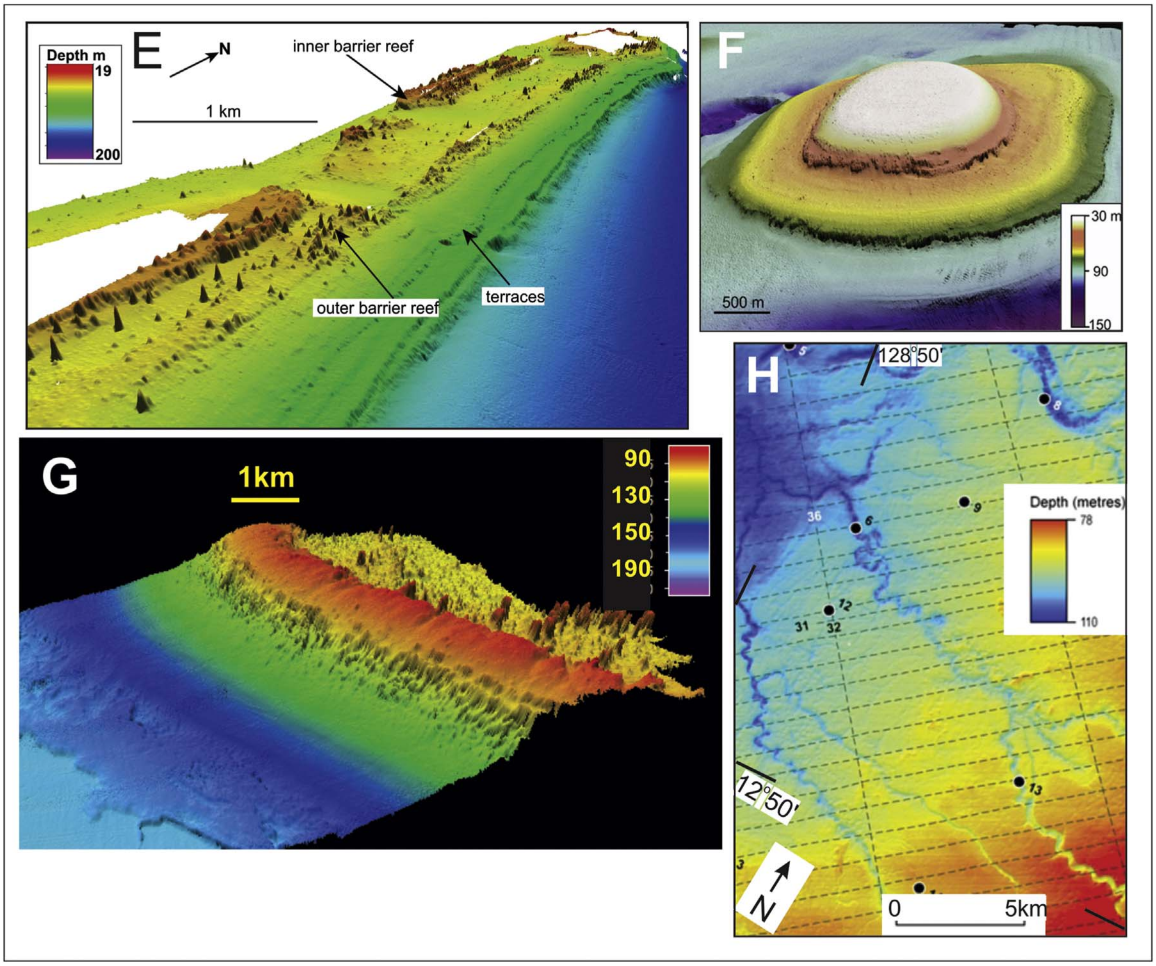

Fig. 4. (*continued*)

Australia, the crest of extensive, approximately shore-parallel linear structures lie ~40 m below present sea level (Fig. 4d). Their morphology indicates the ridges formed as fringing reefs, similar to the adjacent modern fringing reefs. Although they have not been cored and dated, their depth indicates that they last grew in the early Holocene or earlier in an interstadial period (e.g. MIS 3; Nichol and Brooke, 2011). Potentially, at least part of these reef structures formed in an earlier glacial cycle. In the Gulf of Carpentaria on the northern shelf, numerous carbonate banks at a depth of approximately 30 m are composed of drowned coral reefs that developed during the early Holocene, during the later stage of the last marine transgression, and earlier in the Pleistocene (Harris et al., 2008). An example of a barrier reef within the deeper sea-level mode is found on the Sahul Shelf in the northwest where an extensive relict barrier reef is preserved at a depth of 90 m (Howard et al., 2016; Fig. 4g).

On the shelf edge seawards of the Great Barrier Reef (GBR), a series of coast-parallel banks and terraces are drowned reefs that last grew when sea level was tens of metres lower than present, and align with a number of sea-level modes (Table 1; Fig. 4e). Extensive carbonate banks on the middle to outer shelf, at a depth of approximately 27 m, appear to represent drowned coral reefs (Harris et al., 2013; Abbey et al., 2011). On the GBR shelf edge, terraces also occur at depths of approximately 40–50 m, 80–90 m and between 100 and 120 m (Beaman et al., 2008; Yokoyama et al., 2011), and record phases of reef growth that occurred from shortly before the Last Glacial Maximum lowstand (~25 ka) to near the end of the post-glacial marine transgression (~10 ka) (Yokoyama et al., 2011; Hinestrosa et al., 2014, 2016; Table 1; Fig. 3b). Further south, drowned reefs also occur on the shelf that surrounds the remote Lord Howe Island (offshore northern NSW) at depths of 25–50 m and largely formed during the early Holocene (Woodroffe et al., 2010; Linklater et al., 2015).

Relict coral reefs may have formed some distance from a continental coast, as occurs with the modern Great Barrier Reef that sits tens of kilometres off the Queensland coast and with platform reefs on the Northwest Shelf. Relict reefs often have terraces around their margins, recording multiple phases of lower sea level during which the reefs were exposed, their margins eroded and in some locations they formed islands (e.g. Harris et al., 2007; Woodroffe et al., 2010; Abbey et al., 2011; Yokoyama et al., 2011; Nichol et al., 2013; Fig. 4e, f). Thus drowned reefs and large-scale terraces on the shelf edge can be complex structures that record both erosional (wave-cut features) and constructional (reef building) processes during repeated periods when sea level was tens of metres lower than present and relatively stable (Hinestrosa et al., 2016).

5.4. *Estuarine structures*

Channels and associated sediment bars and banks that are characteristic of estuarine environments can form prominent shelf features that extend over a relatively broad range of depths (Ryan et al., 2007; Fig. 3a). It may therefore be difficult to associate drowned estuarine structures with a sea-level modal position in the absence of robust dating of in situ deposits. Macro- and meso-tidal estuarine morphologies (meandering or sinuous channels, often funnel shaped; multiple channels, bars and banks) occur extensively on the northern area of the Northwest Shelf (Fig. 4h; Heap et al., 2010; Anderson et al., 2011; Carroll et al., 2012; Nichol et al., 2013; Picard et al., 2014) and the GBR Shelf offshore central Queensland (Ryan et al., 2007). On the

Lacepede Shelf of southern Australia, the channel of the ancestral Murray River still cuts across the middle and outer shelf and is partly infilled with sediments emplaced in a micro-tidal estuarine environment (Hill et al., 2009). While the age of these relict estuarine features remains to be determined, they likely represent estuaries that formed during periods of intermediate and low sea level, for example when sea level was 30–55 m and 80–90 m below the present level (Table 1).

5.5. Erosional features

Evidence for erosion is observed across a range of modal depths on the Australian shelf, indicating repeated episodes of shoreline sculpturing during the Late Quaternary. Thus, benches cut into the seabed on the Rottnest and Lord Howe Island shelves occur at around the 70 m isobath (Brooke et al., 2010a, b). However, on the Lord Howe Island Shelf, there is a series of benches between 65 and 100 m depth (Woodroffe et al., 2010) that likely relate to interstadial periods of lower sea level, possibly in MIS 3. On the Northwest Shelf, a submarine cliff with up to 8 m of relief occurs in segments along hundreds of kilometres of shelf, approximately parallel to the modern coast, at a depth of around 120 m (James et al., 2004). This structure likely represents the shoreline that formed during the Last Glacial Maximum, around 21 ka. On the Lacepede Shelf erosional 'nick points' that likely represent cliffs have been identified in singlebeam echosounder profiles at depths of approximately 68 and 100 m (Sprigg, 1979). Further east on the Otway Shelf, a relict shoreline cliff with up to 14 m of relief lies in depths of around 60 m, the depth indicating the cliff was most recently cut during the first half of MIS 3 (~60–50 ka; Bezore et al., 2016; Fig. 4b).

Deep, tidally-incised channels have been recorded at a number of locations on the Australian shelf (Harris, 1994; Harris et al., 2005; Table 1). In the Torres Strait – northern Great Barrier Reef and outer Bonaparte Gulf regions these channels, with depths of up to 230 m, are inferred to have formed when sea level was 30–50 m below the present position and tidal currents between platform reefs were enhanced (Harris et al., 2005; Courgeon et al., 2016). Continental shelves globally also appear to record erosion when sea level was around 40 m lower, matching the second most persistent sea level over the last 516 ka (Harris and MacMillan-Lawler, 2016).

5.6. Benthic habitats, biodiversity patterns and environmental management

Palaeoshorelines form distinct zones of seabed complexity, especially where they comprise hard, three dimensional structures that contrast with adjacent sandy sediment or relatively flat seabed (Banks et al., 2008; Bax and Williams, 2001; McArthur et al., 2009; Fig. 4c, e, g). Benthic communities associated with rocky seabed can be distinctly different to those living on adjacent flat, unconsolidated substrate (Ke et al., 1994; Green et al., 1998; Williams and Bax, 2001; Garza-Pérez et al., 2004; Beaman et al., 2005; Post et al., 2006; McArthur et al., 2009; Przeslawski et al., 2011, 2015). The physical complexity and associated interaction with bottom currents provides habitat and food for sessile biota and a range of other organisms that utilize the food and shelter they provide (Greene et al., 2007a, b; Wedding et al., 2008; Kracker et al., 2008). For example, rugose hard features (e.g. relict cliffs, benches, cemented barrier remnants) and drowned biogenic reefs offer refuge from predators and settlement surfaces not available on flat seabed (Reise, 1981; Tsuchiya and Nishihira, 1986; Nakamura and Sano, 2005; Callaway, 2006), provide habitat structure for juvenile and adult animals (Kostylev et al., 2003) and influence foraging patterns (Erlandsson et al., 1999).

Habitat heterogeneity is often associated with high species richness (Gladstone, 2007; Guevara-Fletcher et al., 2011), resulting in greater diversity than would occur on less complex seabed (Peterson et al., 1998; Wedding et al., 2008; McArthur et al., 2010). Numerous studies have shown that palaeoshoreline features on the Australian shelf provide three-dimensional structures supporting benthic communities that contrast with the adjacent seabed, which is often flat and sediment covered (e.g. Beaman et al., 2005; Post et al., 2006; Beaman and Harris, 2007; Harris et al., 2007, 2013; Brooke et al., 2012a; Nichol et al., 2012; Anderson et al., 2013). On the northern Australian shelf, carbonate banks that originally formed as near-surface coral reefs during periods of lower sea level (Fig. 4f), in combination with other environmental variables, support biodiversity 'hot spots' (Przeslawski et al., 2015).

The presence of palaeoshoreline structures on continental shelves may help explain broad patterns of seabed biodiversity that do not reflect the pattern expected when considering typical across-shelf variations in environmental variables (e.g. temperature, salinity, oxygen concentration, light availability, sediment type; Snelgrove, 2001; Williams et al., 2010). For example, at the regional- to continental-scale, extensive, elongate biomes of demersal fish on the Australian shelf occur in depth zones of 70–100 m and 120–150 m (Lyne et al., 2009), which overlap the depths at which large-scale palaeoshoreline structures occur on the Australian shelf (e.g. relict barriers and shoreline cliffs; drowned coral reefs; Table 1; Fig. 3a). It may therefore be the case that these structures provide attractive habitat for these fish communities because it is an environment where food and shelter are available, particularly where benthic biodiversity is well developed such as in sponge gardens and kelp forests.

The key role of palaeoshorelines as fundamental components of large-scale benthic ecosystems highlights the importance of knowledge of the form and distribution of these features for marine environmental management and conservation plans (Riegl and Piller, 2003; Department of Sustainability, Environment, Water, Population and Communities, 2012). In particular, these features provide hard benthic habitats for long-lived epifaunal communities that are suitable for non-destructive monitoring (e.g. using underwater cameras; AUVs). Accurate maps of these features can also improve the efficiency of biological sampling for characterizing biodiversity patterns (Nichol et al., 2013; Monk et al., 2016). Palaeoshoreline features have also been employed as useful physical surrogates in predictive modelling of communities and species (Beaman et al., 2007; Post et al., 2006; Huang et al., 2014; Przeslawski et al., 2015).

5.7. Examples from other shelves

Palaeoshoreline structures have been reported on a range of shelves in both hemispheres and there is potential to link these to the sea-level modal positions identified in this study. Extensive linear features, similar to the drowned barriers on the shelf of southwestern Western Australia (Table 1), have been reported at similar depths on continental shelves of southern and eastern South Africa (Birch et al., 1978; Martin and Flemming, 1986; Bateman et al., 2004, 2011; Cawthra et al., 2012, 2014, 2015) and Mozambique (Ramsay, 1994). These features were originally coastal barriers and transgressive dune fields that have partially withstood erosion during the post-glacial marine transgression due to their lithification into eolianite ridges, which were emplaced during stadial and interstadial periods of MIS 5 (after the highstand of MIS5e) and possibly earlier (Cawthra et al., 2012, 2014).

Wave-cut terraces and cliffs formed during lower sea levels have also been mapped on the South African shelf (Cawthra et al., 2014, 2015) and in detail at several sites on shelves around the Iberian Peninsula and the Balearic Islands (Fernández-Salas et al., 2015). These include a series of terraces on the Cantabrian Shelf at depths of 37 m, 52–56 m, 70–75 m and 87–90 m (Galparsoro et al., 2010); several terraces between 50 and 84 m on the Gulf of Cadiz Shelf; and terraces on the middle and outer areas of the southeastern and Balearic shelves (Fernández-Salas et al., 2015). In all cases, these features generally align with the primary sea-level modes of the Late Quaternary (Fig. 3b). Similarly, wave-cut shore platforms have also been reported on shelves around the Maltese Islands at depths of 130 m, cut during the Last Glacial Maximum, and at 15, 49 and 76 m, likely related to periods during the post-glacial marine transgression (Foglini et al., 2015).

Extensive, linear Holocene shelf reefs, which developed as near-sea-surface coral reefs between 9000-7000 years ago, form prominent approximately shore-parallel structures in depths of approximately 30-40 m on the shelf of southeast Florida (Toscano and Lundberg, 1998; Finkl et al., 2005; Banks et al., 2008). Similar relict, submerged coral reefs and carbonate banks are common throughout the Caribbean (Macintyre, 1988; Macintyre et al., 1991; Hubbard et al., 2008).

These initial observations of the depth distribution of palaeoshoreline features on a number of different continental shelves suggest that patterns in the depth range of these structures are predictable because they are reasonably consistent with the Late Quaternary sea level record, similar to the Australian shelf (Table 1). Variations are likely related to tectonic movements at the local to regional scale (Murray-Wallace and Woodroffe, 2014).

5.8. Applications of palaeoshoreline data

Knowledge of the depths at which palaeoshorelines occur on the Australian shelf (Table 2) provides a first-order indication of the depths at which past human occupation under lower sea levels may have occurred. The environmental regime that ancient humans experienced on some subaerially exposed continental shelves was different to that of modern continental margins (e.g. cooler sea-surface temperatures; different wind regimes, less compartmentalized shoreline morphology; Harff et al., 2015b). Therefore, archaeological records that may be preserved on the shelf have the potential to provide a range of new information on the impacts on ancient societies of a ‘glacial’ climate and the associated periods of rapid environmental change (e.g. rapid marine transgression following the Last Glacial Maximum; Harff et al., 2015b). Also, acoustic seabed mapping instruments (MBES, side-scan sonar, sub-bottom profilers) have the ability to resolve finer scale structures that may record past occupation, such as submerged rock overhangs and stone fish traps (Ward et al., 2014; Nutley, 2014).

Accurate data on the location and form of ancient coastlines is also important in the mapping of potential seabed resources, for example the location of sand resources suitable for beach nourishment and construction material (e.g. Roy, 1998; Whitehouse, 2007). These morphological data are also essential for accurate modelling of hydrodynamic processes on the shelf and coast, such as sediment transport and coastal inundation (e.g. Nielsen et al., 2005; Moriarty et al., 2014).

6. Conclusions

Palaeoshorelines on the tectonically stable Australian continental shelf occur in depth zones that reflect stands of Late Quaternary sea level tens of metres lower than present with a relatively long duration. These relict coasts record a wide range of distinctive coastal and marine environmental regimes. This diversity of coastal structures and the stability of the shelf over the last interglacial/glacial cycle provide a rich dataset from the Australian shelf that can be used as a first-order predictor of the depths at which palaeoshorelines are likely to occur on other shelves globally.

Palaeoshoreline structures can form zones of physically complex seabed that provide habitat for a range of biological communities that contrast with communities found on adjacent unconsolidated sedimentary or flat seabed. Similar structures have been reported at several locations in both hemispheres, indicating the wide utility of palaeoshoreline data for informing marine environmental management and conservation. Palaeoshoreline data can also provide a useful geospatial framework for targeting areas with potential to contain offshore resources and sites of human occupation during periods of lower sea level, an important objective in archaeological studies of human migration and adaptation to rapidly changing sea level.

Acknowledgements

This paper is a contribution to the Marine Biodiversity Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Science Program. The manuscript was significantly improved thanks to constructive reviews by Dr Jodie Smith, Dr Peter Harris, Professor Nic Bax and two anonymous reviewers. This paper is published with permission of the CEO, Geoscience Australia.

References

Abbey, E., Webster, J., 2011. Submerged Reefs. In: David Hopley (Ed.), Encyclopedia of Modern Coral Reefs: Structure, Form and Process. Springer, Dordrecht, The Netherlands, 1058–1062.

Anderson, T.J., Nichol, S.L., Radke, L., Heap, A.D., Battershill, C., Hughes, M., Siwabessy, P.J., Barrie, V., Glasby, B., Tran, M., Daniell, J., 2011. Seabed environments of the eastern Joseph Bonaparte Gulf, Northern Australia, GA0325-SOL5117 Post-Survey Report (Geoscience Australia Record 2010/08). Geoscience Australia, Canberra, 61.

Anderson, T.J., McArthur, M.A., Syms, C., Nichol, S., Brooke, B., 2013. Infaunal biodiversity and ecological function on a remote oceanic island: the role of biogeography and bio-physical surrogates. Estuar., Coast. Shelf Sci. 117, 227–237.

Banks, K.W., Riegl, B.M., Richards, V.P., Walker, B.K., Helme, K.P., Jordan, L.K.B., Phipps, J., Shivji, M.S., Speiler, R.E., Dodge, R.E., 2008. In: Riegl, B.M., Dodge, R.E. (Eds.), The reef tract of continental southeast Florida (Miami-Dade, Broward and Palm Beach counties, USA), in Coral Reefs of the USA. Springer, Dordrecht, Netherlands, 175–220. http://dx.doi.org/10.1007/978-1-4020-6847-8_5.

Bateman, M.D., Holmes, P.J., Carr, A.S., Horton, B.P., Jaiswal, M.K., 2004. Aeolianite and barrier dune construction spanning the last two glacial–interglacial cycles from the southern Cape coast, South Africa. Quat. Sci. Rev. 23, 1681–1698.

Bateman, M.D., Carr, A.S., Dunajko, A.C., Holmes, P.J., Roberts, D.L., McLaren, S.J., Bryant, R.G., Marker, M.E., Murray-Wallace, C.V., 2011. The evolution of coastal barrier systems: a case study of the middle-late Pleistocene Wilderness barriers, South Africa. Quat. Sci. Rev. 30, 63–81.

Bax, N.J., Williams, A., 2001. Seabed habitat on the southeastern Australian continental shelf: context, vulnerability and monitoring. Mar. Freshw. Res. 52, 491–512.

Beaman, R.J., Harris, P.T., 2007. Geophysical variables as predictors of megabenthos assemblages from the northern Great Barrier Reef, Australia. In: Todd, B.J., Greene, H.G. (Eds.), Marine Geological and Benthic Habitat Mapping. Special Publication 47. Geological Association of Canada, St John's, Canada, 247–264.

Beaman, R.J., Daniell, J., Harris, P.T., 2005. Geology-benthos relationships on a temperate rocky bank, eastern Bass Strait, Australia. Mar. Freshw. Res. 56, 943–958.

Beaman, R.J., Webster, J.M., Wust, R.A.J., 2008. New evidence for drowned shelf edge reefs in the Great Barrier Reef, Australia. Mar. Geol. 247, 17–34.

Bezore, R., Kennedy, D.M., Ierodiaconou, D., 2016. The drowned Apostles: the longevity of Sea stacks over Eustatic cycles. J. Coast. Res., Spec. Issue 75, 592–596.

Birch, G.F., De Plessis, A., Willis, J.P., 1978. Off shore and on land geological and geophysical investigations in the Wilderness lakes region. Trans. Geol. Soc. South Afr. 81, 339–352.

Brooke, B., Nichol, S., Hughes, M., McArthur, M., Anderson, T., Przeslawski, R., Siwabessy, J., Heyward, A., Battershill, C., Colquhoun, J., Doherty, P., 2009. Carnarvon Shelf Survey, Post-Survey Report (Geoscience Australia Record 2009/02). Geoscience Australia, Canberra, 89.

Brooke, B., Creasey, J., Sexton, M., 2010a. Broad-scale geomorphology and benthic habitats of the Perth coastal plain and Rottnest Shelf, Western Australia, identified in a merged topographic and bathymetric digital relief model. Int. J. Remote Sens. 31 (23), 6223–6237.

Brooke, B., Harris, P.T., Heap, A.D., Haese, R., Nichol, S.L., Sexton, J., Hazelwood, M., Arthur, C., Radke, L.C., 2012b. Living on the edge – waterfront views. In: Blewett, R. (Ed.), Shaping a Continent, Building A Nation: A Geology of Australia.. Geoscience Australia and ANU E Press, Canberra, 277–331.

Brooke, B.P., Woodroffe, C.D., Linklater, M., McArthur, M.A., Nichol, S.L., Jones, B.G., Kennedy, D.M., Buchanan, C., Spinoccia, M., Mleczko, R., Cortese, A., Atkinson, I., Sexton, M., 2010b. Geomorphology of the Lord Howe Island shelf and submarine volcano, SS06-2008 Post-Survey Report (Geoscience Australia Record 2010/26). Geoscience Australia, Canberra, 125.

Brooke, B.P., McArthur, M.A., Woodroffe, C.D., Linklater, M., Nichol, S.L., Anderson, T.J., Mleczko, R., Sagar, S., 2012a. Geomorphic features and infauna diversity of a subtropical mid-ocean carbonate shelf: lord Howe Island, Southwest Pacific Ocean. In: Harris, P.T., Baker, E. (Eds.), Atlas of Seafloor Geomorphology as Habitat. Elsevier Insights.

Brooke, B.P., Olley, J.M., Pietsch, T., Playford, P.E., Haines, P.W., Murray-Wallace, C.V., Woodroffe, C.D., 2014. Chronology of Quaternary coastal aeolianite deposition and the drowned shorelines of southwestern Western Australia – a reappraisal. Quat. Sci. Rev. 93, 106–124.

Brooke, B.P., Pietsch, T.J., Olley, J.M., Sloss, C.R., Cox, M.E., 2015. A preliminary OSL chronology for coastal dunes on Moreton Island, Queensland, Australia – marginal deposits of a large-scale Quaternary shelf sediment system. Cont. Shelf Res. 105,

79–94.
Brown, I., 1994. Seismic stratigraphy and relict coastal sediments off the east coast of Australia. Mar. Geol. 121, 81–107.
Callaway, R., 2006. Tube worms promote community change. Mar. Ecol.-Prog. Ser. 308, 49–60.
Carroll, A.G., Jorgensen, D.C., Siwabessy, P.J.W., Jones, L.E.A., Sexton, M.J., Tran, M., Nicholas, W.A., Radke, L.C., Carey, M.P., Howard, F.J.F., Stowar, M.J., Heyward, A.J., Potter, A., Shipboard Party, 2012. Seabed Environments and Shallow Geology of the Petrel Sub-basin, Northern Australia: sol5463 (GA0335) – Post Survey Report (Record 2012/66). Geoscience Australia, Canberra.
Cawthra, H.C., Uken, R., Ovechkina, M.N., 2012. New insights into the geological evolution of the Durban Bluff and adjacent Blood Reef, South Africa. South Afr. J. Geol. 115, 291–308.
Cawthra, H.C., Bateman, M.D., Carr, A.S., Compton, J.S., Holmes, P.J., 2014. Understanding Late Quaternary change at the land–ocean interface: a synthesis of the evolution of the Wilderness coastline, South Africa. Quat. Sci. Rev. 99, 210–223.
Cawthra, H.C., Compton, J.S., Fisher, E.C., MacHutchon, M.R., Marean, C.W., 2015. Submerged shorelines and landscape features offshore of Mossel Bay, South Africa. In: Harff, J., Bailey, G., Luth, F. (Eds.), Geology and Archaeology: Submerged Landscapes of the Continental Shelf. Geological Society. Special Publications, London, 411. http://dx.doi.org/10.1144/SP411.11, (The Geological Society of London).
Courgeon, S., Bouret, J., Jorry, S.J., 2016. A Pliocene-Quaternary analogue for ancient epeiric carbonate settings: the Malita intrashelf basin (Bonaparte Basin, northwest Australia). AAPG Bull. 100, 565–595.
Department of Sustainability, Environment, Water, Population and Communities, 2012. Marine bioregional plan for the North-west Marine Region. Australian Government, Canberra⟨http://www.environment.gov.au/system/files/pages/1670366b-988b-4201-94a1-1f29175a4d65/files/north-west-marine-plan.pdf⟩.
Erlandsson, J., Kostylev, V., Williams, G.A., 1999. A field technique for estimating the influence of surface complexity on movement turtuosity in the tropical limpet Cellana grata gould. Ophelia 50, 215–224.
Evans, A., Flatman, J., Flemming, N. (Eds.), 2014. Prehistoric Archaeology on the Continental Shelf, a Global Review.. Springer, 307.
Ferland, M.A., Roy, P.S., Murray-Wallace, C.V., 1995. Glacial lowstands on the outer continental shelf of southeastern Australia. Quat. Res. 44, 294–299.
Fernández-Salas, L.M., Durán, R., Mendes, I., Galparsoro, I., Lobo, F.J., Bárcenas, P., Rosa, F., Ribó, M., García-Gil, S., Ferrín, A., Carrara, G., Roque, C., Canals, M., 2015. Shelves of the Iberian Peninsula and the Balearic Islands (I): morphology and sediment types. Bol. Geológico Y. Min. 126 (2–3), 327–376.
Finkl, C.W., Benedet, L., Andrews, J.L., 2005. Interpretation of seabed geomorphology based on spatial analysis of high-density airborne laser bathymetry. J. Coast. Res. 21 (3), 501–514.
Foglini, F., Prampolini, M., Micallef, A., Angeletti, L., Vandelli, V., Deidun, A., Soldati, M., Taviani, M., 2015. Late Quaternary coastal landscape morphology and evolution of the Maltese Islands (Mediterranean Sea) reconstructed from high-resolution seafloor data. In: Harff, J., Bailey, G., Luth, F. (Eds.), Geology and Archaeology: Submerged Landscapes of the Continental Shelf. Geological Society, London, Special Publications 411.
Galparsoro, I., Borja, A., Legorburu, I., Hernández, C., Chust, G., Liria, P., Uriarte, A., 2010. Morphological characteristics of the Basque continental shelf (Bay of Biscay, northern Spain); their implications for Integrated Coastal Zone Management. Geomorphology 118, 314–329.
Garza-Pérez, J.R., Lehmann, A., Arias-González, J.E., 2004. Spatial prediction of coral reef habitats: integrating ecology with spatial modeling and remote sensing. Mar. Ecol. Prog. Ser. 269, 141–152.
Gladstone, W., 2007. Requirements for marine protected areas to conserve the biodiversity of rocky reef fishes. Aquat. Conserv.-Mar. Freshw. Ecosyst. 17 (1), 71–87.
Grant, K.M., Rohling, E.J., Bar-Matthews, M., Ayalon, A., Medina-Elizalde, M., Bronk Ramsey, C., Satow, C., Roberts, A.P., 2012. Rapid coupling between ice volume and polar temperature over the past 150,000 years. Nature 491, 744–747.
Grant, K.M., Rohling, E.J., Bronk Ramsey, C., Cheng, H., Edwards, R.L., Florindo, F., Heslop, D., Marra, F., Roberts, A.P., Tamisiea, M.E., Williams, F., 2014. Sea-level variability over five glacial cycles. Nat. Commun. 5. http://dx.doi.org/10.1038/ncomms6076.
Green, M.O., Hewitt, J.E., Thrush, S.F., 1998. Seabed drag coefficient over natural beds of horse mussels (Atrina zelandica). J. Mar. Res. 56, 613–637.
Greene, H.G., O'Connell, V.M., Wakefield, W.W., Byrlinsky, C.K., 2007a. The offshore Edgecumbe lava field, southeast Alaska: geologic and habitat characterization of a commercial fishing ground. (St Johns)In: Todd, B.J., Greene, H.G. (Eds.), Mapping the Seafloor for Habitat Characterization. 47. Geological Association of Canada, Canada, 277–295.
Greene, H.G., Vallier, T.L., Bizzarro, J.J., Watt, S., Dieter, B.E., 2007b. Impacts of bay floor disturbances on benthic habitats in San Francisco Bay. (St Johns)In: Todd, B.J., Greene, H.G (Eds.), Mapping the Seafloor for Habitat Characterization 47. Geological Association of Canada, Canada, 401–419.
Guevara-Fletcher, C.E., Cantera Kintz, J.R., Mejia-Ladina, L.M., Cortes, F.A., 2011. BenthicMacrofauna Associated with submerged bottoms of a tectonic estuary in tropical eastern Pacific. J. Mar. Biol. 2011, 193759.
Harff, J., Bailey, G.N., Luth, F. (Eds.), 2015. Geology and Archaeology: Submerged Landscapes of the Continental Shelf. Geological Society, London, 411.
Harff, J., Bailey, G.N., Luth, F., 2015. Geology and archaeology: submerged landscapes of the continental shelf, an introduction. In: Harff, J., Bailey, G.N., Luth, F. (Eds.), Geology and Archaeology: Submerged Landscapes of the Continental Shelf. Geological Society, London, 411.
Harris, P.T., 1994. Incised valleys and backstepping deltaic deposits in a foreland-basin setting, Torres Strait and Gulf of Papua, Australia. In: Dalrymple, R.W., Boyd, R., Zaitlin, B. (Eds.), Incised Valley Systems: Origin and Sedimentary Sequences, SEPM Special Publication 51. SEPM, Tulsa, OK, 97–108.
Harris, P.T., Baker, E.K. (Eds.), 2012. Seafloor Geomorphology as Benthic Habitat: GeoHAB Atlas of Seafloor Geomorphic Features and Benthic Habitats.. Elsevier, 936.
Harris, P.T., MacMillan-Lawler, M., 2016. Global Overview of Continental Shelf Geomorphology Based on the SRTM30_PLUS 30-Arc Second Database. In: Finkl, C.W., Makowski, C. (Eds.), Seafloor Mapping along Continental Shelves. Springer International Publishing Switzerland, 169–190.
Harris, P.T., Heap, A.D., Wassenberg, T., Passlow, V., 2004. Submerged coral reefs in the Gulf of Carpentaria, Australia. Mar. Geol. 207, 185–192.
Harris, P.T., Heap, A., Passlow, V., Hughes, M., Daniell, J., Hemer, M., Anderson, O., 2005. Tidally-incised valleys on tropical carbonate shelves: an example from the northern Great Barrier Reef, Australia. Mar. Geol. 220, 181–204.
Harris, P.T., Heap, A.D., Marshall, J., Hemer, M., Daniell, J., Hancock, A., Buchanan, C., Sbaffi, L., Brewer, D., Heales, D., 2007. Submerged Coral Reefs and Benthic Habitats of the Southern Gulf of Carpentaria: post-survey Report - GA Survey 276, RV Southern Surveyor (Record 2007/002). Geoscience Australia, Canberra.
Harris, P.T., Heap, A.D., Marshall, J., McCulloch, M., 2008. A new coral reef province in the Gulf of Carpentaria, Australia: colonisation, growth and submergence during the early Holocene. Mar. Geol. 251, 85–97.
Harris, P.T., Bridge, T.C.L., Beaman, R.J., Webster, J.M., Nichol, S.L., Brooke, B.P., 2013. Submerged banks in the Great Barrier Reef, Australia, greatly increase available coral Reef habitat. ICES J. Mar. Sci. 70, 284–293.
Harris, P.T., Bridge, T.C.L., Beaman, R., Webster, J.M., Nichol, S.L., Brooke, B.P., 2012. Submerged banks in the Great Barrier Reef, Australia, greatly increase available coral reef habitat. ICES J. Mar. Sci.. http://dx.doi.org/10.1093/icesjms/fss165.
Heap, A.D., Harris, P.T., 2008. Geomorphology of the Australian margin and adjacent seafloor. Aust. J. Earth Sci. 55, 555–585.
Heap, A.D., Przeslawski, R., Radke, L.C., Trafford, J., Battershill, C., 2010. Seabed Environments of the Eastern Joseph Bonaparte Gulf, Northern Australia: sol4934 - Post Survey Report (Geoscience Australia Record 2010/09). Geoscience Australia, Canberra, 81.
Hill, P., De Deckker, P., von der Borch, C., Murray-Wallace, C.V., 2009. Ancestral Murray River on the Lacepede Shelf, southern Australia: Late Quaternary migrations of a major river outlet and strandline development. Aust. J. Earth Sci. 56 (2), 135–157.
Hinestrosa, G., Webster, J.M., Beaman, R.J., Anderson, L.M., 2014. Seismic stratigraphy and development of the shelf-edge reefs of the Great Barrier Reef, Australia. Mar. Geol. 353, 1–20.
Hinestrosa, G., Webster, J.M., Beaman, R.J., 2016. Postglacial sediment deposition along a mixed carbonate-siliciclastic margin: new constraints fromthe drowned shelf-edge reefs of the Great barrier reef, Australia. Palaeogeogr., Palaeoclimatol., Palaeoecol. 446, 168–185.
Hopley, D., Smithers, S.G., Parnell, K., 2007. The Geomorphology of the Great Barrier Reef: Development, Diversity and change. Cambridge University Press, 532.
Howard, F.J.F., Nicholson, C., Bernardel, G., Carroll, A., Hackney, R., Lech, M., Melrose, R., Nichol, S., Picard, K., Rollet, N., Romeyn, R.P., Siwabessy, P.J.W., Trafford, J., 2016. A Marine Survey to Investigate Seal Integrity Between Potential CO_2 Storage Reservoirs and Seafloor in the Caswell Sub-basin, Browse Basin, Western Australia: ga0345/ga0346/tan1411 - Post-survey Report (Record 2016/05). Geoscience Australia, Canberra, 149. http://dx.doi.org/10.11636/Record.2016.005.
Huang, Z., McArthur, M., Przeslawski, R., Siwabessy, P.J.W., Nichol, S., Anderson, T., Brooke, B., 2014. Predicting mapping of soft bottom benthic biodiversity using a surrogacy approach. Mar. Freshw. Res. 65, 409–424.
Hubbard, D.K., Burke, R.B., Gill, I.P., Ramirez, W.R., Sherman, C., 2008. In: Riegl, B.M., Dodge, R.E. (Eds.), Coral-reef geology: Puerto Rico and the US Virgin Islands, in Coral Reefs of the USA. Springer, Dordrecht, Netherlands, 263–302. http://dx.doi.org/10.1007/978-1-4020-6847-8_7.
James, N.P., Bone, Y., 2011. Neritic Carbonate Sediments in a Temperate Realm: southern Australia. Springer, Dordrecht, 254.
James, N.P., Collins, L.B., Bone, Y., Hallock, P., 1999. Carbonates in a temperate realm: modern sediments on the Southwest Australian shelf. J. Sediment. Res. 69, 1297–1321.
James, N.P., Bone, Y., Kyser, T.K., Dix, G.R., Collins, L.B., 2004. The importance of changing oceanography in controlling late Quaternary carbonate sedimentation on a high-energy, tropical, oceanic ramp: north-western Australia. Sedimentology 51, 1179–1205. http://dx.doi.org/10.1111/j.1365-3091.2004.00666.x.
Jarrett, B.D., Hine, A.C., Halley, R.B., Naar, D.F., Locker, S.D., Neumann, A.C., Twichell, D., Hu, C., Donahue, B.T., Jaap, W.C., Palandro, D., Ciembronowicz, K., 2005. Strange bedfellows - a deep-water hermatypic coral reef superimposed on a drowned barrier island; southern Pulley Ridge, SW Florida platform margin. Mar. Geol. 214, 295–307.
Jordan, A., Davies, P., Ingleton, T., Foulsham, E., Neilson, J., Pritchard, T., 2010. Seabed habitat mapping of the continental shelf of NSW. New South Wales Department of Environment. Climate Change and Water, Sydney, 206.
Ke, X., Collins, M.B., Poulos, S.E., 1994. Velocity structure and sea bed roughness associated with intertidal (sand and mud) flats and saltmarshes of the wash. UK J. Coast. Res. 10, 702–715.
Kindler, P., Hearty, P.J., 1997. Geology of the Bahamas: architecture of Bahamian Islands. In: Vacher, H.L., Quinn, T. (Eds.), Geology and Hydrogeology of Carbonate Islands, Developments in Sedimentology 54. Elsevier, Amsterdam, 141–160.
Kindler, P., Mazzolini, D., 2001. Sedimentology and petrography of dredged carbonate sands from Stocking Island (Bahamas). Implications for meteoric diagenesis and aeolianite formation. Palaeogeogr., Palaeoclimatol., Palaeoecol. 175, 369–379.
Kostylev, V.E., Courtney, R.C., Robert, G., Todd, B.J., 2003. Stock evaluation of giant

scallop (Placopecten magellanicus) using high-resolution acoustics for seabed mapping. Fish. Res. 60 (2–3), 479–492.
Kracker, L., Kendall, M., McFall, G., 2008. Benthic features as a determinant for fish biomass in Gray's reef national marine sanctuary. Mar. Geod. 31, (267–28).
Lambeck, K., Nakada, M., 1990. Late Pleistocene and Holocene sea-level change along the Australian coast. Palaeogeogr., Palaeoclimatol., Palaeoecol. 89, 143–176.
Lambeck, K., Rouby, H., Purcell, A., Sun, Y., Sambridge, M., 2014. Sea level and global ice volumes from the Last Glacial Maximum to the Holocene PNAS 111 (43), 15296–15303.
Linklater, M., Brooke, B.P., Hamylton, S.M., Nichol, S.L., Woodroffe, C.D., 2015. Submerged fossil reefs discovered beyond the limit of modern reef growth in the Pacific Ocean. Geomorphology 246, 579–588.
Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic δ18O records. Paleoceanography 20, PA1003. http://dx.doi.org/10.1029/2004PA001071.
Lyne, V.D., White, W.T., Gledhill, D.C., Last, P.R., Rees, T., Porter-Smith, R., 2009. Analysis of Australian Continental Shelf Provinces and Biomes Based on Fish Data. CSIRO Marine and Atmospheric, Hobart.
Macintyre, I.G., 1988. Modern coral reefs of Western Atlantic: new geological perspective. Am. Assoc. Pet. Geol. Bull. 72, 1360–1369.
Macintyre, I.G., Rutzler, K., Norris, J.N., Smith, K.P., Cairns, S.D., Bucher, K.E., Steneck, R.S., 1991. An early Holocene reef in the western Atlantic: submersible investigations of a deep relict reef off the west coast of Barbados. W. I. Coral Reefs 10, 167–174.
Martin, A.K., Flemming, B.W., 1986. The Holocene shelf sediment wedge off the south and east coast of South Africa. In: Knight, R.J., McLean, J.R. (Eds.), Shelf Sands and Sandstones. Canadian Society of Petroleum Geologists Memoir II, 27–44.
McArthur, M.A., Brooke, B., Przeslawski, R., Ryan, D.A., Lucieer, V.L., Nichol, S., McCallum, A.W., Mellin, C., Cresswell, I.D., Radke, L.C., 2009. A review of abiotic surrogates for marine benthic biodiversity. Geoscience Australia, Canberra, 61, Geoscience Australia Record 2009/42.
McArthur, M.A., Brooke, B.P., Przeslawski, R., Ryan, D.A., Lucieer, V.L., Nichol, S., McCallum, A.W., Mellin, C., Cresswell, I.D., Radke, L.C., 2010. On the use of abiotic surrogates to describe marine benthic biodiversity. Estuar. Coast. Shelf Sci. 88, 21–32.
McMahon, T.A., Finlayson, B.L., 2003. Droughts and anti-droughts: the low flow hydrology of Australian rivers. Freshw. Biol. 48, 1147–1160.
Monk, J., Barrett, N.S., Hill, N.A., Lucieer, V.L., Nichol, S.L., Siwabessy, P.J.W., Williams, S.B., 2016. Outcropping reef ledges drive patterns of epibenthic assemblage diversity on cross-shelf habitats. Biodivers. Conserv. 25, 485–502. http://dx.doi.org/10.1007/s10531-016-1058-1.
Moriarty, J.M., Harris, C.K., Hadfield, M.G., 2014. A hydrodynamic and sediment transport model for the Waipaoa shelf, New Zealand: sensitivity of fluxes to spatially-varying erodibility and model nesting. J. Mar. Sci. Eng. 2, 336–369. http://dx.doi.org/10.3390/jmse2020336.
Murray-Wallace, C.V., Woodroffe, C.D., 2014. Quaternary Sea-level Changes – A Global Perspective. Cambridge University Press, 484.
Murray-Wallace, C.V., Brooke, B.P., Cann, J., Belperio, A., Bourman, R., 2001. Whole-rock aminostratigraphy of the Coorong Coastal Plain, South Australia: towards a 1 million year record of sea-level highstands. J. Geol. Soc., Lond. 158, 111–124.
Nakamura, Y., Sano, M., 2005. Comparison of invertebrate abundance in a seagrass bed and adjacent coral and sand areas at Amitori Bay, Iriomote Island, Japan. Fish. Sci. 71 (3), 543–550.
Nichol, S., Anderson, T.J., McArthur, M., Barrett, N., Heap, A.D., Siwabessy, J., Brooke, B., 2009. Southeast Tasmania temperate reef survey: post survey report. Geoscience Australia record 2009/43. Geoscience Australia. Canberra, 89.
Nichol, S.L., Brooke, B.P., 2011. Shelf habitat distribution as a legacy of Late Quaternary marine transgressions: a case study from a tropical carbonate province. Cont. Shelf Res. 31, 1845–1857.
Nichol, S.L., Anderson, T.J., Battershill, C., Brooke, B.P., 2012. Submerged reefs and aeolian dunes as inherited habitats, Point Cloates, Carnarvon Shelf, Western Australia. In: Harris, P.T., Baker, E. (Eds.), Atlas of Seafloor Geomorphology as Habitat. Elsevier Insights.
Nichol, S.L., Howard, F.J.F., Kool, J., Stowar, M., Bouchet, P., Radke, L., Siwabessy, J., Przeslawski, R., Picard, K., Alvarez de Glasby, B., Colquhoun, J., Letessier, T., Heyward, A., 2013. Oceanic Shoals Commonwealth Marine Reserve (Timor Sea) Biodiversity Survey: ga0339/sol5650 – Post Survey Report (Record 2013/38). Geoscience Australia, Canberra.
Nicholas, W.A., Howard, F.J.F., Carroll, A.G., Siwabessy, P.J.W., Tran, M., Radke, L., Picard, K., Przeslawski, R., 2014. Seabed environments and shallow sub-surface geology of the Vlaming Sub-basin, offshore Perth Basin: Summary results from marine survey GA0334 (Record 2014/49). Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2014.049.
Nielsen, O., Roberts, S., Gray, D., McPherson, A., Hitchman, A., 2005. Hydrodynamic modelling of coastal inundation. In: Zerger, A., Argent, R.M. (Eds.), MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, (December 2005).
Nutley, D., 2014. Inundated sites in Australia. In: Evans, A., Flatman, J., Flemming, N. (Eds.), Prehistoric Archaeology on the Continental Shelf, A Global Review. Springer, 307.
Pain, C.F., Pillans, B.J., Roach, I.C., Worrall, L., Wilford, J.R., 2012b. Old, flat and red – Australia's distinctive landscape. In: Blewett, R. (Ed.), Shaping a Continent, Building A Nation: A Geology of Australia. Geoscience Australia and ANU E Press, Canberra, 225–275.
Peterson, G., Allen, C.R., Holling, C.S., 1998. Ecological resilience, biodiversity and scale. Ecosystems 1, 6–18.
Picard, K., Nichol, S.L., Hashimoto, R., Carroll, A.G., Bernardel, G., Jones, L.E.A., Siwabessy, P.J.W., Radke, L.C., Nicholas, W.A., Carey, M.C., Stowar, M., Howard, F.J.F., Tran, M., Potter, A., 2014. Seabed Environments and Shallow Geology of the Leveque Shelf, Browse Basin, Western Australia; GA0340/SOL5754 – Post-survey report (Geoscience Australia Record 2014/10). Geoscience Australia, Canberra.
Post, A.L., Wassenberg, T.J., Passlow, V., 2006. Physical surrogates for macrofaunal distributions and abundance in a tropical gulf. Mar. Freshw. Res. 57, 469–483.
Przeslawski, R., Daniell, J., Anderson, T., Barrie, J.V., Battershill, C., Heap, A., Hughes, M., Li, J., Potter, A., Radke, R., Siwabessy, J., Tran, M., Whiteway, T., Nichol, S., 2011. Seabed Habitats and Hazards of the Joseph Bonaparte Gulf and Timor Sea, Northern Australia (Geoscience Australia Record 2011/40). Geoscience Australia, Canberra, 156.
Przeslawski, R., Alvarez, B., Kool, J., Bridge, T., Caley, M.J., Nichol, S., 2015. Implications of sponge biodiversity patterns for the management of a marine reserve in northern Australia. PLoS ONE 10 (11), e0141813. http://dx.doi.org/10.1371/journal.pone.0141813.
Ramsay, P.J., 1994. Marine geology of the Sodwana Bay shelf, Southeast Africa. Mar. Geol. 120, 225–247.
Reise, K., 1981. Gnathostomulida abundant alongside polychaete burrows. Mar. Ecol. Prog. Ser. 6 (3), 329–333.
Riegl, B., Piller, W.E., 2003. Possible refugia for reefs in times of environmental stress, Int. J. Earth Sci. 92, 520–531. http://dx.doi.org/10.1007/s00531-003-0328-9.
Roy, P.S., 1998. Cainozoic geology of the coast and shelf. In: Scheibner, E., Basden, H. (Eds.), Geology of New South Wales - Synthesis, Volume 2: Geological Evolution. Memoir 13. Geological Survey of New South Wales, Sydney, 361–385.
Ryan, D.A., Bostock, H.C., Brooke, B.P., Marshall, J.F., 2007. Bathymetric expression of the Fitzroy River palaeochannel, northeast Australia: response of a major River to sea-level change on a semi-rimmed, mixed siliciclastic-carbonate shelf. Sediment. Geol. 201, 196–211.
Ryan, D.A., Brooke, B.P., Collins, L.B., Spooner, M., Siwabessy, P.J.W., 2008. Formation, morphology and preservation of high-energy carbonate lithofacies: Evolution of the cool-water Recherche Archipelago inner shelf 207. Sedimentary Geology, south-western Australia, 41–55.
Snelgrove, P.V.R., 2001. Diversity of Marine Species. Encyclopedia of Ocean Sciences. Academic Press, Oxford, 748–757.
Sprigg, R.C., 1979. Stranded and submerged sea-beach systems of southeast South Australia and the aeolian desert cycle. Sediment. Geol. 22, 53–96.
Toscano, M.A., Lundberg, J., 1998. Early Holocene sea-level record from submerged fossil reefs on the southeast Florida margin. Geology 26, 255–258. http://dx.doi.org/10.1130/0091-7613(1998)026 < 0255:EHSLRF > 2.3.CO;2.
Tsuchiya, M., Nishihira, M., 1986. Islands of Mytilus edulis as a habitat for small intertidal animals - effect of Mytilus age structure on the species composition of the associated fauna and community organization. Mar. Ecol.-Prog. Ser. 31 (2), 171–178.
Ward, I., Veth, P., Manne, T., 2014. To the islands borne: the research potential of submerged landscapes and human habitations sites from the islands of NW Australia. In: Harff, J., Bailey, G., Lüth, F. (Eds.), Geology and Archaeology: Submerged Landscapes of the Continental Shelf.. Geological Society, London, 411. http://dx.doi.org/10.1144/SP411.4.
Wedding, L.M., Friedlander, A.M., McGranaghan, M., Yost, R.S., Monaco, M.E., 2008. Using bathymetric lidar to define nearshore benthic habitat complexity: implications for management of reef fish assemblages in Hawaii. Remote Sens. Environ. 112, 4159–4165.
Whitehouse, J., 2007. Evaluation of mineral resources of the continental shelf, new South Wales. Q. Notes 124, Geol. Surv. New South Wales, 23.
Wiedicke, M., Kudrass, H.-R., Hübscher, C., 1999. Oolitic beach barriers of the last Glacial sea-level lowstand at the outer Bengal shelf. Mar. Geol. 157, 7–18.
Williams, A., Bax, N.J., 2001. Delineating fish-habitat associations for spatially based management: an example from the south-eastern Australian continental shelf. Mar. Freshw. Res. 52, 513–536.
Williams, A., Althaus, F., Dunstan, P.K., Poore, G.C.B., Bax, N.J., Kloser, R.J., McEnnulty, F.R., 2010. Scales of habitat heterogeneity and megabenthos biodiversity on an extensive Australian continental margin (100–1100 m depths). Mar. Ecol. 31, 222–236.
Woodroffe, C.D., 2002. Coasts: form, process and evolution. Cambridge University Press, Cambridge, 623.
Woodroffe, C.D., Brooke, B.P., Linklater, M., Kennedy, D.M., Jones, B.G., Buchanan, C., Mleczko, R., Hua, Q., Zhao, J., 2010. Response of coral reefs to climate change: expansion and demise of the southernmost Pacific coral reef. Geophys. Res. Lett. 37, 15.
Yokoyama, Y., Webster, J.M., Cotterill, C., Braga, J.C., Jovane, L., Mills, H., Morgan, S., Suzuki, A., 2011. IODP Expedition 325: Great barrier reefs reveals Past Sea-level, climate and environmental changes Since the last ice age. (and the IODP Expedition 325 Scientists)Sci. Drill. 12, 32–45. http://dx.doi.org/10.2204/iodp.sd.12.04.2011.