The Abrolhos carbonate platforms: geological evolution and Leeuwin Current activity

L B Collins,[1] K-H Wyrwoll,[2] & R E France[3]

[1]School of Applied Geology, Curtin University of Technology, Bentley, WA 6102, Australia
[2]Department of Geography, The University of Western Australia, Nedlands, WA 6009, Australia
[3]Western Mining Corporation (Petroleum Division), West Perth, WA 6005, Australia

Abstract

The Houtman Abrolhos reefs comprise three carbonate platforms situated between latitudes 28° and 29.5°S on the western continental margin of Australia, close to the present southerly limit for coral growth. The geomorphology of the platforms and their low islands varies from atoll-like in the south to less regular forms in the north. "Blue-hole" terrains are conspicuous elements of the eastern parts of the platforms. Lagoon sand sheets are dominated by corals and calcareous red algae, in contrast to shelf sediments which are composed of bryozoans, calcareous red algae, molluscs and foraminifers. The coral reefs of the Abrolhos platforms have a probable maximum thickness of 130m, and postdate open carbonate shelves of Paleocene to Upper Eocene age. The growth history of the Abrolhos over the last few hundred thousand years is closely linked to global sealevel fluctuations. Late Quaternary stratigraphy exposed in platform islands is dominated by coral-algal framestone/bindstone and rudstone, for which preliminary dates suggest a Last Interglacial age (*ca* 125 ka BP). Late Holocene coral reef development is largely restricted to leeward reef slopes, walls of "blue-holes", and leeward, more easterly surfaces of platforms. The persistence of reef growth during the Quaternary is linked to the presence of the Leeuwin Current, which probably only came into existence during the Early to Middle Pleistocene. The widespread development of Last Interglacial coral reefs at the Abrolhos and along the western continental margin to latitudes as far south as 34.5°S, and faunal data, support a period of vigorous Leeuwin Current activity. The known distribution of Holocene coral reefs is far more limited, both in areal extent at the Abrolhos, and latitudinally. These differences are probably largely due to fluctuations in Leeuwin Current activity.

Introduction

The Houtman Abrolhos (Fig. 1) are a series of shelf-edge coral reefs which form the southernmost coral reef complex in the Indian Ocean. The Abrolhos reef complex is unique in its location off a western continental margin. It is well known that a general explanation for global reef distribution is sea surface temperature (*eg* Stoddart 1969, Levinton 1982). The limits to normal coral growth are 17-18°C and 33-34°C. Coral growth along west coasts of continents is generally limited by the presence of a cold boundary current which lowers sea surface temperatures, for at least part of the year, below the limit of coral growth; examples of these are the California, Humboldt and Benguela Currents. The presence of the Leeuwin Current along the western margin of Australia results in sea surface temperatures which allow the development of major reef complexes as far south as 29.5°S, the southern limit of the Abrolhos.

This paper describes the geomorphology, geology and Late Quaternary history of the Abrolhos coral reefs and carbonate platforms, and, as far as this is possible with present knowledge, examines the influence of the Leeuwin Current on the growth history of the reefs.

Geomorphological and geological characteristics and sediments

The Abrolhos carbonate platforms are at the northern end of the Rottnest Shelf, a narrow, open carbonate shelf which lies along the quiescent rifted margin of southwest Australia (Veevers 1974, Smith & Cowley 1987, Collins 1988). The Abrolhos are located within the Abrolhos Sub-basin, a part of the Perth Basin. Little previous work has been undertaken on the geology of the reef complex. Teichert (1947) and Fairbridge (1948) have provided important introductions to the geology and geomorphology of the reef complex. More recently France (1985) studied the Holocene geology of the Pelsaert Group.

The Abrolhos reef complex is located at the margin of the shelf and water depth increases steeply to the west (Fig.1). A number of terraces are evident along the shelf edge extending to a depth of 115 m (Harris 1989 unpublished data). The emergent parts of the reef are in three island groups (Fig. 1). Deep channels reaching depths of *ca* 40 m separate the central Easter Group

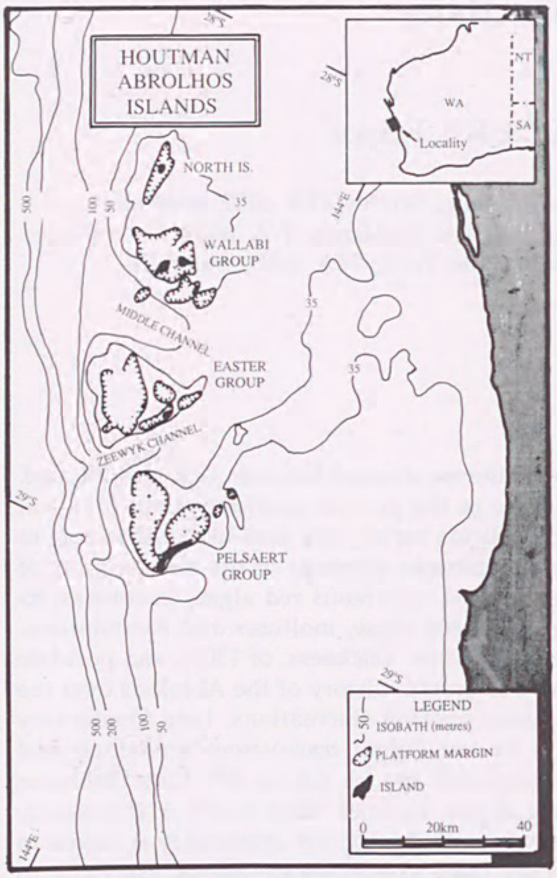

Figure 1 Location map of Houtman Abrolhos Islands and carbonate platforms.

from the adjacent northern and southern island groups. The islands are generally low in elevation, and often amount to little more than small tabular platforms, rising some 3 - 5 m above present sealevel. The exception is provided by the Wallabi Group and North Island where Late Quaternary dune units result in elevations of up to 15 m.

The three island groups differ significantly in their overall geomorphological expression. The Pelsaert Group is approximately triangular in shape, with a strongly defined bounding reef margin rimming the lagoon, except along the poorly defined northern rim (Fig. 1). The Easter Group has a more complex and less "enclosed" geomorphological expression. It consists of a series of arcuate island chains, separated by deep channels ("passages", *eg* Easter Passage) and located leeward of the western reef margin and associated lagoon. The Wallabi Group is dominated by the two large islands, West and East Wallabi, and generally lacks the geomorphological organization of the other island groups. Well developed lagoon sandsheets are prominent elements of the Pelsaert and Easter Groups. "Blue-hole" terrains are a conspicuous element of the geomorphology of the eastern parts of the island groups, but are absent from the western parts. In other parts of the world "blue-holes" have been interpreted as having a solutional karst - doline origin (see the summary discussion of Purdy 1974). However, in the Abrolhos the precise origin of "blue-hole" terrain is unknown, and depositional and lithofacies factors may have controlled "blue-hole" development. There is a marked contrast between western and eastern substrates of the platforms. Well lithified coralline algal-coral lithofacies of the west differ sharply from poorly lithified branching-coral framestones and rudstones of the east. The latter are at least 25 m thick beneath "blue-hole" terrain in the Easter Group, and these low-strength, vuggy limestones are potentially far more vulnerable to collapse and/or solution processes.

Lithofacies characteristics and distribution

Quaternary sediments of the Abrolhos platforms and adjacent shelf are both reef framework and bindstone facies, generated by corals and encrusting coralline algae, and fragmental facies, which comprise shelf and platform sand sheets and rudstone accumulations. Coral growth is generally poor on the windward reef slopes where bindstone lithofacies dominate. Lagoon patch reefs are prominent elements and are especially evident in the Pelsaert Group. The leeward reef slopes and associated deep channels support an extensive coral cover.

Holocene bindstones generated by encrusting red algae form veneers over intertidal substrates along reef crests, overlying rocky substrates, and in shallow lagoon areas, encrusting either rock substrates or coral framestones. These veneers are usually <20 cm thick. Holocene coral framestones are present as thin veneers or reef accumulations. Lagoon substrates and walls of "blue-holes" have well developed framework communities. France (1985) has suggested a potential maximum thickness of 5 m for framework facies, but no subsurface data are yet available to substantiate this claim. Emergent rudstone facies, forming storm-beach ridge sequences, are prominent elements of the geomorphology of the islands of the leeward regions of the reefs.

The spatial distribution and character of these lithofacies is well reflected in the make-up and stratigraphy of the islands (Fig. 2). In general, the central portions of the platforms are dominated by "high" rock islands, and additionally in the Wallabi Group, eolianite islands. The eastern margins of the platforms have composite islands as the most abundant type. "High" rock islands typically have coastal exposures of reef and reef flat facies (bindstone with some framestone), occasionally overlain by erosional remnants, 1-2 m thick, of a basal, well bedded skeletal grainstone. The eolianite islands consist of reef facies overlain by bedded grainstone and well developed Pleistocene eolianites which, in places, are mantled by Holocene dunes. Composite islands, which overlie submerged platforms with well developed "blue-holes", consist of limited framestone, overlain by intertidal and storm ridge rudstone facies. Composite

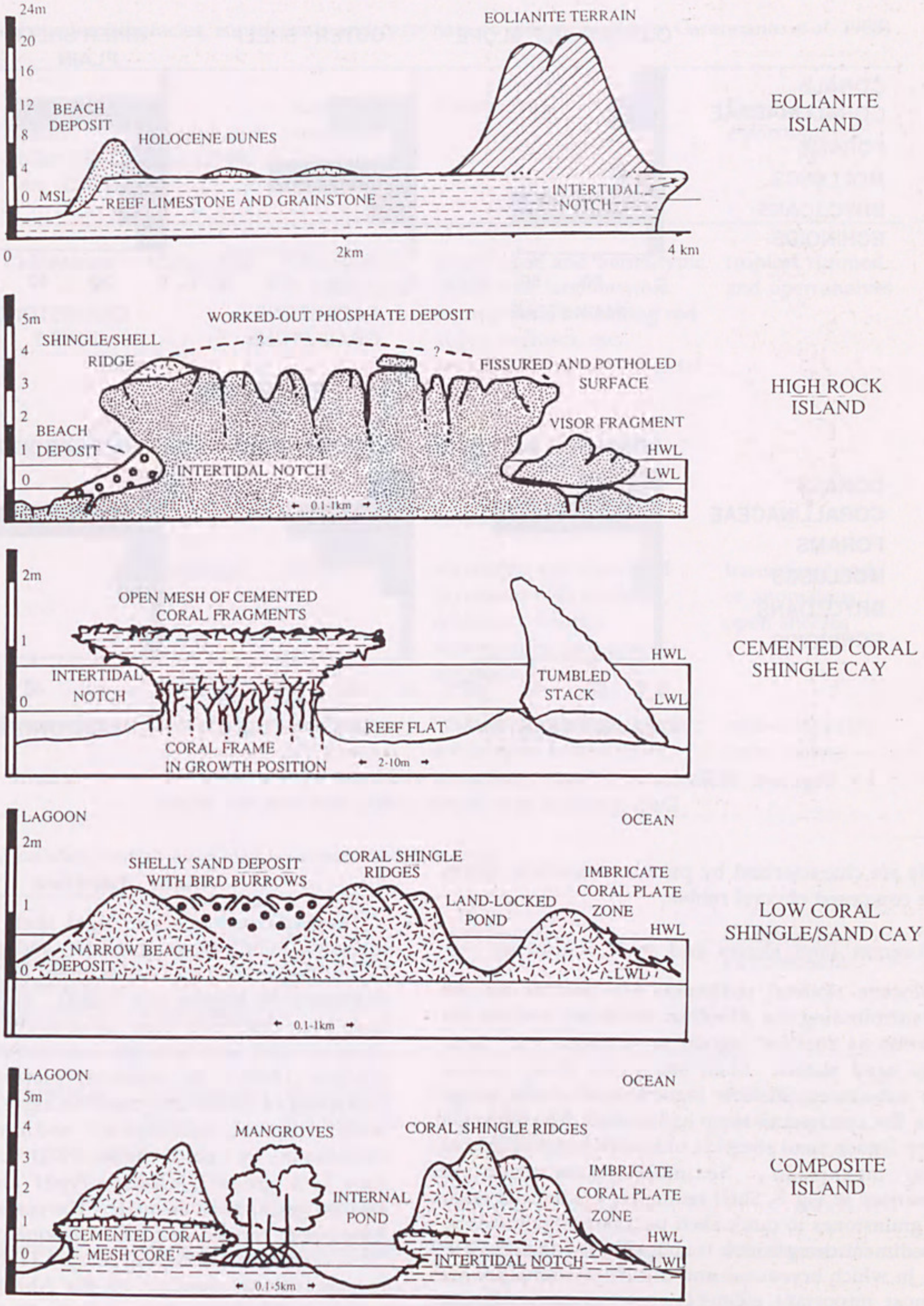

Figure 2 The morphostratigraphic characteristics of the islands in the Abrolhos platforms. Modified after France (1985).

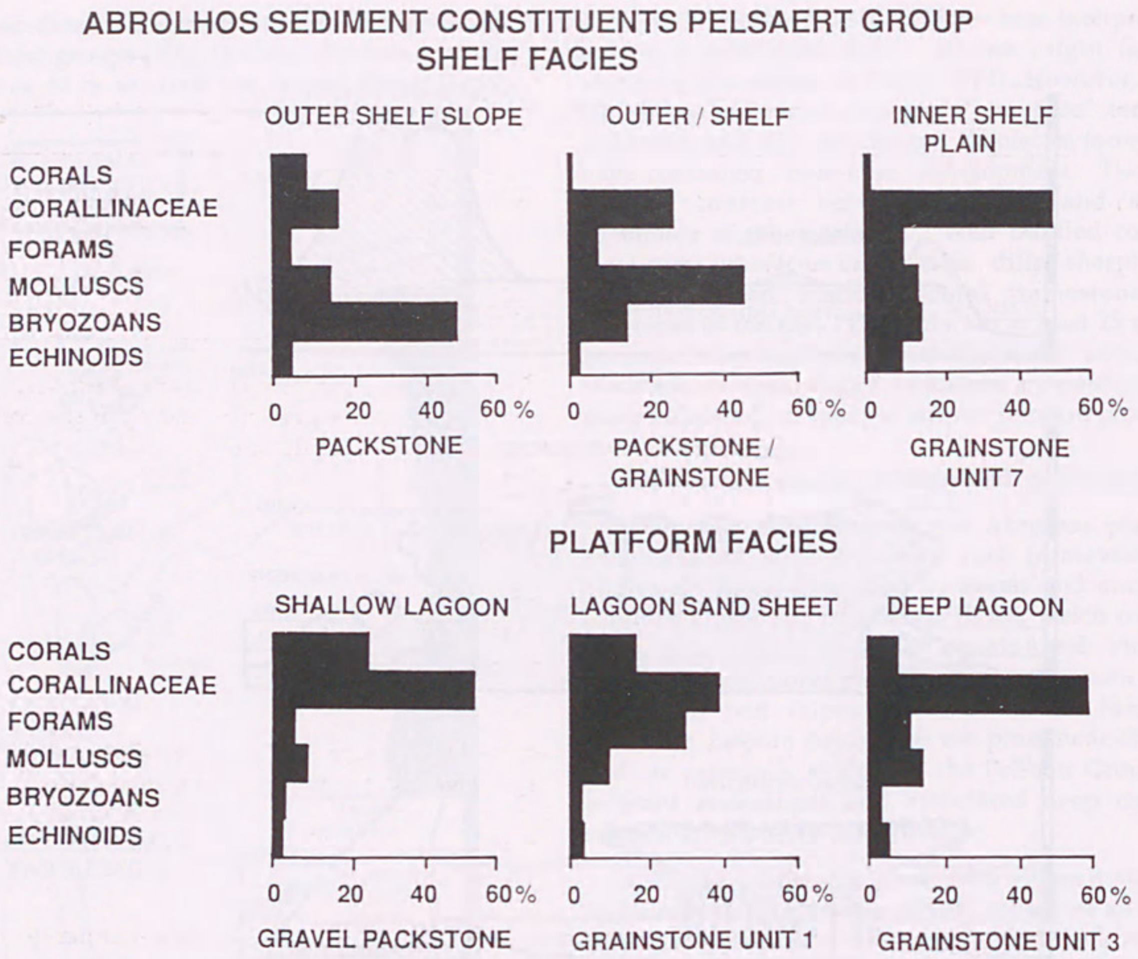

Figure 3 Holocene sediment constituents of the Abrolhos shelf and Pelsaert platform. Data modified after France (1985), and from this study.

islands are characterized by prominent surficial storm ridges composed of coral rubble.

Lagoon sand sheets and shelf sediments

Holocene skeletal sediments are present on the shelf surrounding the Abrolhos platforms, and on the platforms as shallow lagoon sand sheets and deep lagoon sand sheets. Shelf sediments thinly veneer rocky substrates. Shallow lagoon sand sheets range from a few centimetres to up to 3 m thick. The thickness of deep lagoon sand sheets is unknown but probably of similar magnitude. Sediment constituents are summarised in Fig. 3. Shelf sediments grade from inner shelf grainstones to outer shelf packstones/bindstones, and sediment composition is controlled by the resident biota, in which bryozoans and calcareous red algae are the most important elements, with minor molluscs, foraminifers and echinoids. Much of the sediment of lagoon sand sheets is generated by reef-crest communities of corals and coralline red algae (both encrusting forms and rhodolites) and is swept lagoonwards by wave- and wind-generated currents. Coralline algae and corals are volumetrically most important, with minor molluscs, foraminifers, bryozoans and echinoids.

Biotic transition

The bryozoan-coralline algal shelf sediments are distinctly temperate in character, and are regarded as foramol sediments by Lees & Buller (1972), or bryomol sediments by Nelson *et al.* (1988). Similar sediments have been described from the southern Rottnest Shelf, south of 32°S, and from the southern Australian shelf (Collins 1988). In contrast, platform sediments, composed of corals and coralline algae, have affinities with tropical/subtropical sediments (termed chlorozoan by Lees & Buller 1972) but differ in that they lack green (*Halimeda*-type) algae and non-skeletal grains such as ooids. The correlation between lithofacies, constituents and carbonate environments for a carbonate continental margin (Table 1) illustrates the transitional position of the Abrolhos platforms, which at 28°-29.5°S, form a discontinuously rimmed shelf which lies between tropical rimmed shelves to the north, and open shelves to the south. In contrast, the biotic transition between chlorozoan and foramol assemblages on the eastern Australian shelf is recorded at 24°S by Marshall & Davies (1978). There are several recorded modern examples of transition

TABLE 1

A. Correlation between lithofacies, constituents and carbonate environments (after Carannante *et al.* 1988)

Lithofacies: Lees & Buller (1972) Lees (1975)	Lithofacies: Carannante *et al.* (1988)	Key elements	Constituents	Commoner environments
Chlorozoan	Chlorozoan	Chlorophyta + Zoantharia	green algae and hermatypic corals with large benthic foraminifers, branching red algae, molluscs, etc. associated with non-skeletal grains.	tropical rimmed and open shelves
Chloralgal	Chloralgal	Chlorophyta	green algae with large benthic foraminifers, branching red algae molluscs, etc.,	
	Rhodalgal	Rhodophyta	encrusting red algae and bryozoans with molluscs, echinoids, benthic foraminifers, barnacles, serpulids, etc	transitional and/ or anomalous open shelves
Foramol	Molechfor	Molluscs + Echinoids + Foraminifers	molluscs, echinoids, benthic arenaceous foraminifers, barnacles, serpulids, etc.	cold-temperate open shelves

B. Abrolhos lithofacies, constituents and carbonate environments

Lithofacies: Lees & Buller (1972) Lees (1975)	Lithofacies: This paper	Key elements	Constituents	Commoner environments
Chlorozoan	Chlorozoan type	Zoantharia Rhodophyta	Hermatypic corals and encrusting and, branching red algae; also molluscs, foraminifers; nonskeletal grains absent	Abrolhos platforms
Foramol	Rhodalgal	Rhodophyta	Encrusting red algae and bryozoans; with molluscs, echinoids, foraminifers, etc.	Abrolhos shelf

from chlorozoan to rhodalgal lithofacies. Carannante *et al.* (1988) consider that lithofacies distribution is subject to complex environmental factors that seem related primarily to water temperature, controlled by latitude and depth.

Skeletal grain associations in warm tropical and temperate waters may be contrasted using salinity-temperature annual range diagram pairs. In Fig. 4, salinity and temperature data have been plotted for the southern Rottnest Shelf, the Abrolhos Shelf, and the

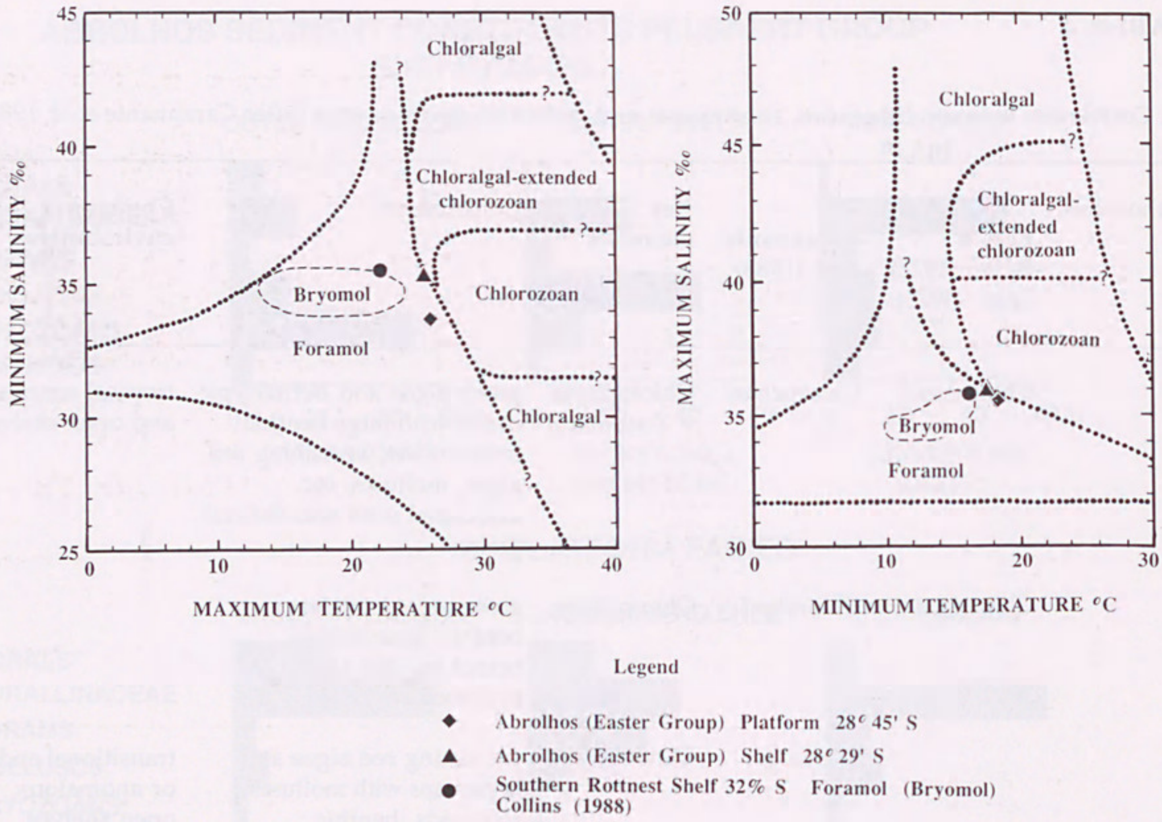

Figure 4 Salinity - temperature annual range diagram pair for southern Rottnest shelf, Abrolhos shelf and Abrolhos platform.

Abrolhos platforms (Easter Group). In contrast to the southern Rottnest Shelf, the Abrolhos data plot in a transitional position between temperate (foramol) grain assemblages and tropical/subtropical (chlorozoan) assemblages. The transitional nature of the Abrolhos platforms, as indicated by the salinity and temperature data, is supported by the data on sediment composition and biotic communities (Fig. 3, Table 1).

The Leeuwin Current clearly influences the biotic transition zone in the Abrolhos and the resultant sedimentation. Firstly, the presence of the west coast transition zone at 28 - 29.5°S, compared to the east coast transition at 24°S, is probably a direct result of the Leeuwin Current. Secondly, the presence of platform sediment with chlorozoan affinities, surrounded by shelf sediment of rhodalgal type, is a transition zone relationship for which the Leeuwin Current is probably the driving mechanism.

Initiation of reef complexes

From our present understanding of the geological history of the Abrolhos region it is clear that during the Tertiary the region saw the development of a seaward thickening carbonate wedge, dominated by bryozoan-mollusc-echinoid skeletal calcarenites and calcilutites, and lacking reef-building corals (Fig. 5). Post-Eocene carbonates were deposited as a thin sheet on a stable shelf (France 1985) and are restricted to the top 130 m of Gun Island No 1 well in the Pelsaert Group. Coral-reef-related sediments appear to be confined to the post-Eocene sequence, and the deepest coral recognised in cuttings is from - 67 m (France 1985). The shallowest of the known Tertiary sediments (Upper Eocene at 130 m) are non-reef calcarenites dominated by foraminifers, bryozoans and molluscs (Hawkins 1969).

These limited data suggest that the maximum possible thickness of the reef complex is 130 m, and that the reefs postdate open carbonate shelves of Paleocene to Upper Eocene age. There are no data to suggest that reef localisation and initiation were directly controlled by underlying geologic features. But if this is so, then it needs to be asked, why are there no prominent reef complexes between those of the Abrolhos and Ningaloo Reef to the north? The answer may after all relate to some geological substrate control, which in the case of the Abrolhos, provided a location suitable for reef development. France (1985) suggested that coralline algal biostromes similar to those of the southern Rottnest Shelf (see Collins 1988) may have provided suitable substrates for the initiation of the Abrolhos reefs. Cores up to 3 m thick have been recovered from these biostromes, which probably developed on drowned eolianite ridges (Collins 1983 Fig. 13). At the Abrolhos, there is one recorded occurrence of pre-existing eolianite topography

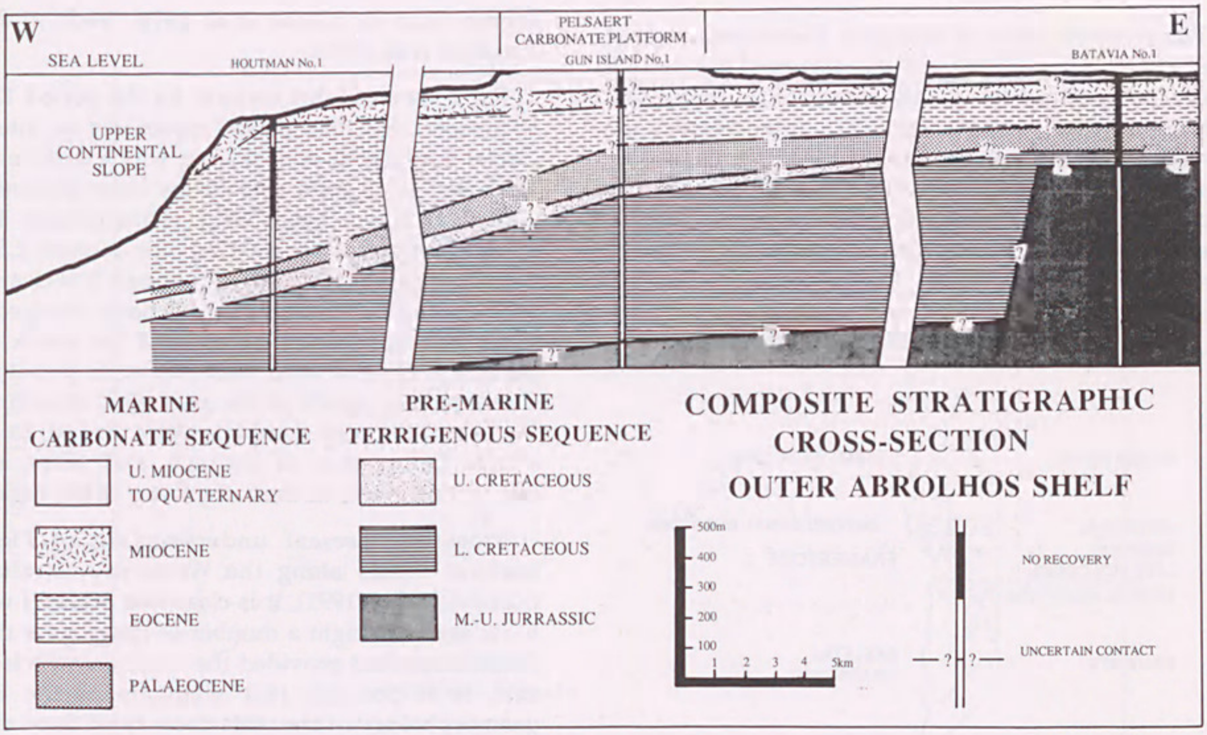

Figure 5 Diagrammatic cross-section of the Abrolhos shelf at 29.5°S. After France (1985).

underlying reef limestones of probable Last Interglacial age, at Gun Island in the Pelsaert Group.

In terms of sea surface temperature control it is not possible to ascertain whether the original development of the coral reef complex was directly due to the presence of the Leeuwin Current or whether this was linked to wider ocean-scale palaeoceanographic conditions suitable for coral reef development. However, it is clear that the persistence of the reef growth during the Quaternary must be linked to the presence of the Leeuwin Current.

There are indications in the geological record that the Leeuwin Current only came into existence during the Early to Middle Pleistocene (Kendrick *et al.* 1991). In the Perth Basin there was a conspicuous change in sedimentation from a Pliocene - Early Pleistocene, essentially siliciclastic suite of sediments, to a later Quaternary, strongly carbonate style of sedimentation.

The shift to a predominantly carbonate environment of deposition was accompanied by higher sea surface temperatures than those which prevailed during the Early Pleistocene. Evidence is found in the Middle Pleistocene mollusc fauna, which indicates greater tropical and subtropical affinities. The details of this are discussed by Kendrick *et al.* (1991). There is only a weak representation of such elements in the mollusc fauna of the older Plio-Pleistocene units, which suggests that the Leeuwin Current was then either of lesser importance than during the Middle Pleistocene, or not active.

Late Quaternary stratigraphy, reefs and geological evolution

The stratigraphy of the Abrolhos platforms is well exposed in coastal sections of the platform islands (Fig. 2) and a composite summary of the lithostratigraphy is given in Fig. 6. Four unconformity-bounded sequences have been identified, three of probable Late Pleistocene and one of Late Holocene age. At present our chronostratigraphic control on the stratigraphy is limited. A number of U-series dates are available for the lower bindstone / framestone/ rudstone unit of Fig. 6. These dates give a Last Interglacial age (*ca* 125 ka BP - Veeh & France 1988 and our preliminary dates) for this unit. This Last Interglacial unit appears to be widespread and dominates much of the geomorphology of the island groups. This conclusion was anticipated by Teichert (1967) who noted that the 100 ka BP data on the coral reef at Rottnest (subsequently revised to *ca* 125 ka BP - see below), implies that the fossil reefs of the Abrolhos will prove to be of the same order of age. However, we stress the preliminary nature of our results and would not be surprised if our stratigraphic inferences need to be revised once more numerical dates become available. The only other numerical dates that are available at present are for Holocene storm ridge units in the Pelsaert Group which show that these are Late Holocene in age. In addition, an emergent coral-frame fringe present along some islands in the Easter and Pelsaert Groups was dated at Pelsaert Island by U-series to 4.8 ka BP (Veeh & France 1988) and ^{14}C to 4.2 ka BP.

The predominance of emergent Pleistocene reefs at the Abrolhos, and thin, discontinuous veneers of Holocene reef overlying this substrate, is in marked contrast to the Great Barrier Reef. Intensive drilling investigations have shown that though Holocene reefs of the GBR are of variable thickness (4-20 m), there is usually a significant buildup of Holocene reef which overlies a buried Pleistocene substrate (Marshall & Davies 1978).

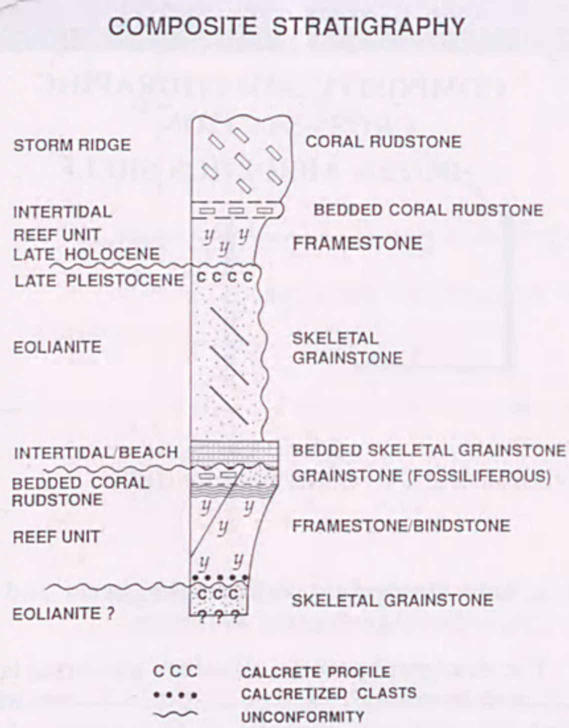

Figure 6 Late Quaternary composite stratigraphy of islands in the Abrolhos platforms.

Late Quaternary sea levels

Over the duration of the Quaternary, global sealevels have fluctuated from around their present height to more than *ca* 150 m below present sealevel (Shackleton 1987). The details of these fluctuations are complex and regionally variable. A summary of our present understanding of the Pleistocene sealevel history of the Western Australian margin is given by Kendrick *et al.* (1991), and mechanisms of Late Quaternary sealevel change are discussed by Lambeck (1987) and Lambeck & Nakada (1990). Clearly the growth history of the Abrolhos over the last few hundred thousand years is closely linked to these sealevel fluctuations.

Evidence for sealevel changes is widespread and coral reefs have proven to be especially informative, the most spectacular of these being the coral staircase of the Huon Peninsula of Papua New Guinea (Bloom *et al.* 1974, Chappell 1974). In Western Australia the reef complexes fringing the western flank of the Cape Range are also striking indicators of former sealevel events (Van de Graaf *et al.* 1976, Veeh *et al.* 1979, Kendrick *et al.* 1991).

Fig. 7 shows global sealevel for the period 135 ka BP to present; this time period represents an interglacial-glacial-interglacial cycle during which sealevels for the most part have been well below their present height. Global climates have been characterized by such glacial-interglacial fluctuations for at least 2.5 million years (Berggren *et al.* 1980). Although it is clear that the periodicity of these events will have changed in that time, it is apparent that sealevel for much of these periods will have been well below its present height. Consequently, much of the geological development of the Abrolhos reef complex was linked to sealevel stands below that of present, and there are clear indications of this in the bathymetry of the region.

From our present understanding of Pleistocene sealevel events along the Western Australian coast (Kendrick *et al.* 1991), it is clear that sealevel was close to its present height a number of times since the Early Pleistocene. And provided the tectonic controls allowed this, it is possible that elements of the emerged geomorphology of the reefs dates from these events, of which the Last Interglacial (*ca* 125 ka BP) was the most recent Pleistocene highstand. The Last Interglacial saw global sealevels probably some 5 m higher than present (*eg* Bloom *et al.* 1974, Chappell 1974, Ku *et al.* 1974, Szabo 1979). Along the coast of Western Australia the Last Interglacial dominates much of the coastal geomorphology. Consequently, it is not surprising that morphostratigraphic units of this age dominate the geomorphology of the Abrolhos reef complex.

Coral growth fluctuations

There appears to be a sharp contrast between the pattern of development of Last Interglacial and Late Holocene reefs. Coral framestone to rudstone and coralline algal bindstone facies of probable Last Interglacial age are widespread over the three platforms, as tabular developments of reef complex in excess of 10 m thick. Late Holocene coral reef development is largely restricted to leeward reef slopes, walls of "blue-holes", and leeward, more easterly surfaces of platforms, where emergent reef facies underlie prograding storm ridges, composed of coral rubble, as part of elongate, composite islands. Whilst it is tempting to suggest that the thicker and more widespread Last Interglacial reef facies indicate stronger Leeuwin Current activity and reef growth, the contrasting pattern of Last Interglacial/Late Holocene reef development may also be a function of substrate factors. The importance of antecedent topography in controlling subsequent coral reef growth is a classic theme in studies of reef geomorphology (*eg* Bloom 1974, Guilcher 1988), and in the case of the Abrolhos, the significantly higher Last Interglacial sealevels were a major determinant of Holocene reef growth patterns. However, there are also clear regional-scale data which point to stronger Leeuwin Current activity during the Last Interglacial.

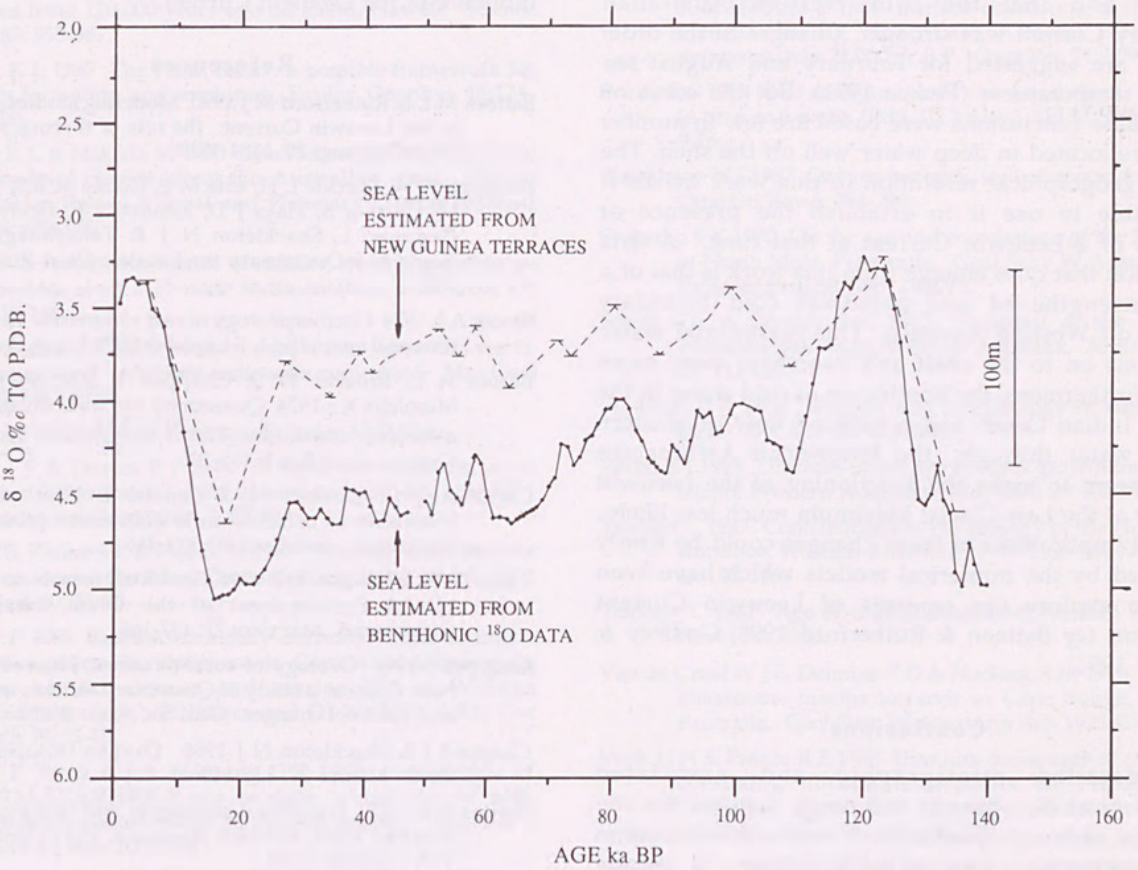

Figure 7 Benthonic oxygen isotope record of East Pacific core V19-30 for the past 140 ka and the sealevel record from the Huon Peninsular, New Guinea (after Chappell & Shackleton 1986).

The Last Interglacial was a time of widespread coral reef development along the coastal margin of much of the Perth Basin. The best known example of this is the *Acropora*-rich Rottnest Limestone (Teichert 1967, Szabo 1979, Playford 1988), 20 km offshore. This has a counterpart on the adjacent mainland in an extensive coralline - algal reef limestone with *Acropora* spp, and other warm water corals, located at the entrance to Fremantle Harbour (Skwarko 1990). These corals occur some 400 km south of their effective modern range limit at the Houtman Abrolhos. Other occurrences of *Acropora* spp. from that time extend to Augusta and eastwards to about latitude 119 °E (Kendrick *et al.* 1991). There are also clear indications in the mollusc assemblages of that time of distributional shifts, with the assemblages showing a greater tropical affinity; Kendrick *et al.* (1991) discuss this at some length.

From the southward extension of temperature-sensitive coral growth, Kendrick *et al.* (1991) argue that during the Last Interglacial sea surface temperatures along the inner shelf were higher than today, to the extent that in the Perth region inshore surface temperatures were at least 2°C higher than the 16.5°C minimum of today (Pearce *et al.* 1989).

From available evidence (discussed by Kendrick *et al.* 1991) it would seem that after the Last Interglacial highstand, sealevels along the coast of Western Australia did not again attain their present height until the Holocene. This conclusion corresponds with the generally accepted view of global sealevel in that time (Fig. 7). It is likely that the linear-ridge structures of the Abrolhos fore-reef may represent drowned reefs corresponding in age to relatively high sealevel during the last 120 ka (Fig. 7). Drowned reefs have been widely recognized in the tropical oceans (see Carter & Johnson 1986), and invariably have proven difficult to date.

The most recent work shows that at the height of the Last Glacial Maximum (*ca* 18 ka BP) global sealevel was some 130 m below present (Fairbanks 1989). Whilst the presence of linear ridge - drowned reef forms west of the Abrolhos at depths of up to 115 m (Harris 1989) implies that at the time of their formation, reef development and coral growth were still possible, the age and composition of the structures is unknown, and it is likely that sea surface temperatures were too cold for coral growth during lowstand conditions. From Indian ocean-scale paleoceanographic reconstructions (Prell *et al.* 1980) it is thought that at the Last Glacial Maximum sea surface temperatures along the coast of Western Australia were significantly lower than present and that the cold Western Australian Boundary Current was stronger. Changes of the order of -4°C are suggested for February and August sea surface temperatures (Pearce 1991). But the cores on which these conclusions were based are few in number and were located in deep water well off the shelf. The lack of geographical resolution in this work makes it impossible to use it to establish the presence or absence of a Leeuwin Current at that time. A firm conclusion that does emerge from this work is that of a much strengthened and persistent cold boundary current off Western Australia. This makes cold water incursions on to the shelf and nearshore zone more likely. Furthermore, the dominance of cold water in the eastern Indian Ocean and a reduced flow of Western Pacific water through the Indonesian Archipelago would seem to make the functioning of the Leeuwin Current at the Last Glacial Maximum much less likely. The full implications of these changes could be firmly evaluated by the numerical models which have been used to explore the controls of Leeuwin Current formation (*eg* Batteen & Rutherford 1990, Godfrey & Weaver 1991).

Conclusions

A detailed stratigraphic and associated chronological data base is still being acquired for the Abrolhos carbonate platforms. Despite this limitation some important generalisations can be made concerning the role of the Leeuwin Current in platform and reef development, and the contrasting Late Quaternary stratigraphy of the Abrolhos reefs and eastern Australian reefs.

The widespread development of Last Interglacial coral reefs along the western continental margin to latitudes as far south as 34.5°S, and molluscan faunal data, support a period of vigorous Leeuwin Current activity. The emergent coral-algal reefs of the central and western islands of the Abrolhos have been confirmed as an important part of this system. The distribution of known Holocene reefs is, in contrast, far more limited, both in areal extent and latitudinally; the most southerly significant reefs being at the Abrolhos at latitude 28.5°S. These differences are probably largely due to fluctuations in Leeuwin Current activity. The Abrolhos reefs are characterised by widespread emergent Pleistocene substrate, consisting of Last Interglacial reef facies. Holocene corals are present as thin, discontinuous veneers over this substrate. This is in marked contrast to the Great Barrier Reef, where Holocene reefs have buried the Pleistocene substrate.

Last Interglacial reef substrates, both at the Abrolhos and elsewhere along the Western Australian coast, are frequently well above MSL and therefore could not be colonised by Holocene corals. The lack of significant thicknesses of Holocene reefs, as yet assessed only in very general ways, may also reflect slow growth rates of corals (Crossland 1981) operating at the southerly limits of their environment, under the influence of the Leeuwin Current.

References

Batteen M L & Rutherford M J 1990 Modeling studies of eddies in the Leeuwin Current: the role of thermal forcing. J Phys Oceanogr 20: 1484-1520.

Berggren W A, Burckle L H, Cita M B, Cooke M B S, Funnell B M, Gartner S, Hays J D, Kennett J P, Opdyke N D, Pastouret L, Shackleton N J & Takayanagi Y 1980 Towards a Quaternary time scale. Quat Res 13: 277-302.

Bloom A L 1974 Geomorphology of reef complexes. In : Reefs in time and space (Ed L F Laporte) SEPM Spec Publ 18: 1-8.

Bloom A L, Broeker W S, Chappell J, Matthews R K & Mesolella K J 1974 Quaternary sea level fluctuations on a tectonic coast: new Th^{230}/U^{234} dates from New Guinea. Quat Res 4: 185-205.

Carannante G, Esteban M & Simone L 1988 Carbonate lithofacies as palaeolatitude indicators: problems and limitations. Sed Geol 60: 333-346.

Carter R M & Johnson D P 1986 Sea level controls on the post-glacial development of the Great Barrier Reef, Queensland. Mar Geol 77: 137-164.

Chappell J 1974 Geology of coral terraines, Huon Peninsula, New Guinea: a study of Quaternary tectonic movements and sea level changes. Geol Soc Amer Bull 85: 553-570.

Chappell J & Shackleton N J 1986 Oxygen isotopes and sea level. Nature 27: 137-140.

Collins L B 1983 Postglacial sediments and history, southern Rottnest Shelf, Western Australia. PhD Thesis, Uni of WA (unpublished).

Collins L B 1988 Sediments and history of the Rottnest Shelf, southwest Australia: a swell-dominated, non-tropical carbonate margin. Sed Geol 60: 15-49.

Crossland C J 1981 Seasonal growth of *Acropora* cf. *formosa* and *Pocillopora damicornis* on a high latitude reef (Houtman Abrolhos, Western Australia). Proc Fourth Int Coral Reef Symp Manila 1: 663-667.

Fairbanks R G 1989 A 17,000 year old glacio-eustatic sea level record: influence of glacial melting on the Younger Dryas event and deep ocean circulation. Nature 342: 637-642

Fairbridge R W 1948 Notes on the geomorphology of the Pelsart Group of the Houtman's Abrolhos Islands. J Roy Soc W Aust 33: 1-43.

France R E 1985 The Holocene geology of the Pelsaert reef complex, southern Houtman Abrolhos, Western Australia. PhD Thesis, Uni of WA (unpublished).

Godfrey J S & Weaver A G 1991 Is the Leeuwin Current driven by Pacific heating and winds? Progress in Oceanogr 27:225-272

Guilcher A 1988 Coral Reef Geomorphology. John Wiley & Sons 228pp.

Harris P T 1989 Sidescan sonar study of submerged reefs and terraces on the outer shelf and upper slope adjacent to Houtman Abrolhos reefs, Western Australia (unpublished manuscript).

Hawkins R D 1969 Gun Island No 1 completion report. BMR Aust Rec 1968/205 (unpublished).

Kendrick G W, Wyrwoll K H & Szabo B J 1991 Pliocene-Pleistocene coastal events and history along the western margin of Australia. Quaternary Science Reviews (in press).

Ku T L, Kimmel M A, Easton W H & O'Neil T J 1974 Eustatic sea level 120,000 years ago on Oahu, Hawaii. Science 183: 959-967.

Lambeck K L 1987 The Perth Basin : a possible framework for its formation and evolution. Explor Geophys 18:124-128.

Lambeck K L & Nakada M 1990 Late Pleistocene and Holocene sea-level change along the Australian coast. Palaeo Palaeo Palaeo (Global and Planetary Change Section) 89: 143-176.

Lees A 1975 Possible influence of salinity and temperature on modern shelf carbonate sedimentation. Mar Geol 19: 159-198

Lees A & Buller A T 1972 Modern temperate - water and warm water shelf carbonate sediments contrasted. Mar Geol 13: M67-M73.

Levinton J S 1982 Marine Ecology. Prentice-Hall 526p.

Marshall J F & Davies P J 1978 Skeletal carbonate variation on the continental shelf of eastern Australia. BMR J Aust Geol Geophysics 3: 85-92.

Nelson C S, Keone S L & Head P S 1988 Non-tropical carbonate deposits on the New Zealand continental shelf. Sed Geol 60: 71-94.

Pearce A F 1991 Eastern boundary currents of the southern hemisphere. In: The Leeuwin Current: an influence on the coastal climate and marine life of Western Australia. (eds. AF Pearce and DI Walker) J Roy Soc WA 74:35-45.

Pearce A F, Prata A J & Manning C R 1989 Comparison of NOAA/AVHRR-2 sea surface temperatures with surface measurements in coastal waters. Internat J Remote Sens 10: 37-52.

Playford P E 1988 Guidebook to the geology of Rottnest Island. Geol Soc Aust (Western Australian Division) Excursion Guidebook No. 2:67pp.

Prell W L,Hutson W H, Williams D F, Be A W H, Geitzenauer K & Molfino B 1980 Surface circulation of the Indian Ocean during the Last Glacial Maximum, approximately 78,000 yr B P. Quat Res 74: 309-336.

Purdy E G 1974 Reef configurations : cause and effect. In : Reefs in time and space. (Ed L F Laporte) SEPM Spec Publ 18: 9-76.

Shackleton N J 1987 Oxygen isotopes, ice volume and sea level. Quat Sci Rev 6: 783-790.

Skwarko S K 1990 On the age and correlations of the fossil reef at North Mole, Fremantle. Geol Surv W Aust, Unpubl Palaeontological Rep 1990/2.

Smith G C & Cowley R G 1987 Potential of the northern Abrolhos Sub-Basin, Western Australia. APEA Journal 27: 112-136.

Stoddart P R 1969 Ecology and morphology of recent coral reefs. Biol Rev 44: 433-490.

Szabo B J 1979 Urarium-series age of coral growth on Rottnest Island, Western Australia. Mar Geol 29: M11-M15.

Teichert C 1947 Contributions to the geology of the Houtman's Abrolhos, Western Australia . Proc Linn Soc NSW 71 (3, 4): 145-196.

Teichert C 1967 Age of coastal limestone, Western Australia. Aust J Sci 30:71.

Van de Graaf W J E, Denman P D & Hocking R M 1976 Emerged Pleistocene marine terraces on Cape Range, Western Australia. Geol Surv W Aust Ann Rep 1975:62-69.

Veeh H H & France R E 1988 Uranium-series ages of corals and coexisting phosphate deposits on Pelsaert Reef Complex, Houtman Abrolhos Islands, Western Australia. Quat Res 30:204-209.

Veeh H H, Schwebel D, Van de Graaf W J E & Denman P D 1979 Uranium-series ages of coralline terrace deposits in Western Australia. J Geol Soc Aust 26: 285-292.

Veevers J J 1974 Western continental margin of Australia. In: The Geology of Continental Margins. (Eds C A Burke & C L Drake), Springer-Verlag New York N.Y.: 605-515.