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J. E. N. Veron

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Evolution of the far northern barrier reefs

By J. E. N. Veron†
Department of Biological Sciences, James Cook University of North Queensland, P.O. Box 999, *Townsville, Queensland, Australia* 4810

The basement and much of the volume of the northern barrier reefs are Miocene in age. Formation of the ancestral northern barrier reefs was greatly affected by late Miocene crustal instability associated with formation of the Papuan Basin. Present physiographic features are primarily the product of Quaternary eustatic changes. Present morphologies of the deltaic and far northern dissected reefs are discussed in relation to what is known of the geological history of the area.

Introduction

In this paper, morphologic features of the northern barrier reefs are combined with geological data to suggest principal developments in the evolutionary history of the reef.

The inevitable complexity of this subject, combined with lack of information on almost all its aspects, has prevented, until recently, the proposal of any well substantiated model of reef development within the Great Barrier Reef (G.B.R.) Province. Early writers (Gardiner 1898; Hedley 1926; Hedley & Taylor 1908; Davis 1917; Andrews 1922; Richards 1922; Bryan 1928) mostly commented on or discussed various aspects of Darwin's model of reef evolution, or (Crossland 1931; Gardiner 1932) discussed Stephenson, Stephenson, Tandy & Spender's (1931) description of the surface features of Yonge Reef.

Fairbridge (1950) was the first to give an integrated account of the principal problems involved in the understanding of the evolution of the G.B.R. The subject was briefly reviewed by Jones (1966) and Jones & Endean (1967), then discussed in depth by Maxwell (1968, 1969). Recent reviews of the geology and geomorphology of Queensland's continental shelf (Bird 1971; Maxwell 1973; Heidecker 1973) provide a broad background for the interpretation of more detailed, localized studies and for comparisons between the G.B.R. and reef systems of other parts of the world.

The subject of this paper is restricted to the far northern barrier reefs as described in earlier papers (Veron & Hudson 1978; Veron 1978; both in this volume), to which studies the reader is directed without further reference.

Early geological history

Recent petroleum exploration in the Gulf of Papua has given some insight into the nature of the reef basement and into its early geological history (Tanner 1969; unpublished well reports of Pasca No. 1 (Phillips Australia Oil Co.) and Anchor Cay No. 1 (Tenneco–Signal Oil Co.)).

The basement of the northern Great Barrier Reef and the associated open-sea platform reefs is lower Miocene in age and is underlain by Mesozoic sedimentary rocks (e.g. Anchor Cay) and highly deformed Palaeozoic metamorphics such as are exposed along much of the Queensland coast.

† Present address: Australian Institute of Marine Science, P.O. Box 1104, Townsville, Australia 4810.

The substructure of the modern reef is Miocene in age and probably much of the reef volume is Miocene (Tanner 1969). During the early Miocene, much of the Papuan Basin appears to have been divided into basins and shelf areas by a system of more or less continuous barrier or elongate reef zones. Those areas behind each barrier were built up by carbonate sedimentation with intermittent patch reefs developing in preferential bathymetric positions in similar manner to the reefs of today.

During late Miocene there began a period of crustal instability and emergence of the fringes of the Papuan Basin. The rapidly rising Niugini Highlands overwhelmed the rapidly sinking Papuan Basin with a flood of clastics. This was accompanied by volcanism, most common in the eastern portion of the basin near the deepest downwarp; but is evidenced in the southwestern portion of the basin where several present-day islands are composed of Recent basalts. Anchor Cay No. 1 well shows that there was more than a single out-pouring, as in places reef corals are interspersed between successive flows.

The ancestral G.B.R. extended northward across the Gulf of Papua and for an unknown distance across the present location of the island of Niugini. However, the above-mentioned late Miocene lowering of the Papuan Basin floor terminated reef growth at approximately 9° S lat. Northward of this line there developed a sharply defined eastward dipping flexure from a 'hinge line'. Stratigraphic intervals increase eastward (basinward) from the hinge line. Some ancestral reefs, e.g. the 'Pasca No. 1 reef', were overwhelmed during the late Miocene; others further to the south were able to keep pace with the sinking basement and appear today as the open-sea lagoonal platform reefs (Portlock Reef, Eastern Fields and Boot Reef) which in places rise abruptly from depths of 1000 m or more.

Barrier reef development continued through Pliocene time to the present. Thus, Anchor Cay well penetrated a reef section of Pliocene age and the reef's continuance is locally evident on seismic sections.

Quaternary geological history

By the close of the Tertiary, major physiographic zones of the northern G.B.R. were probably similar to those of today. The Queensland Trench was separate from the Southern Shelf Embayment, the Southern Marginal Shelf had been linked with that of the Northern Region and the Coral Sea Platform had been isolated (Maxwell 1969). Present surface features are primarily a consequence of Pleistocene and Holocene sea level fluctuations.

Although reliable interpretation of the eustatic record during the Tertiary is difficult, Maxwell (1969) concluded that there is substantial evidence to indicate sea levels that were much higher than the present. The lower sea levels of the Quaternary have led to the planation and erosion of older reefs and to the formation of the strand-lines primarily apparent in the Central and Southern Regions.

The important consequence of these fluctuations for reefs is that periods of prolific reef growth during transgressions alternate with periods of severe erosion and consequent sedimentation during regressions.

Whatever the effects of early Quaternary sea level fluctuation, it is clear that sea levels of the past 120000 years are largely responsible for the present reef morphologies. It is widely agreed that during this period, eustatic changes oscillated between −100 m and +10 m. There appears to have been a major still-stand of about −50 m centred about 40000 a B.P., after which the sea level decreased to approximately −100 m, 20000 a B.P. However, the all-important detail of subsequent (Holocene) eustatic changes remains obscured behind a series of conflicting studies, both 'local' and world-wide.

During the last major (Wisconsin) glaciation, the sea must have withdrawn from most of the G.B.R. province, certainly from the Northern Region. The present northern barrier reefs would have formed a high limestone wall separating the ocean from the continental shelf, now an emerged lagoon-floor plain traversed by rivers and covered with steep-sided, flat-topped limestone hills in the positions of modern reefs as well as the continental emergences that now form the continental islands. The seaward face of the outer limestone wall would have been subject to rapid subaerial erosion and would probably have eroded into a line of karstic ridges, such as Chevalier (1973) envisaged for barrier reefs of New Caledonia.

Subsequent to the Wisconsin glaciation the sea rose to its present level – either at a more or less uniform rate as suggested by several authors (see Hopley 1974) or more rapidly to above present levels followed by fluctuations of various descriptions as suggested by others, including Fairbridge (1961) and Mörner (1969, 1971).

Discussion

The lack of information on the age and nature of the surface and subsurface (presumably Quaternary) layers of the reef, combined with the lack of an adequate picture of Holocene sea levels, makes any further account of the reef's history extremely speculative. However, this study does indicate some of the factors which have led to the differentiation of the present barrier reef morphologies. Two aspects are considered.

1. *Evolution of present morphologies*

(*a*) *The northern limit of the G.B.R. and the northern dissected barrier reefs*

This study indicates that the northern limits of the barrier reefs at about $9\frac{1}{2}°$ S as well as the morphology of the reefs between $9\frac{1}{2}$ and 10° S have been determined by tectonic subsidences as described by Tanner (1969) rather than by sedimentation and/or low salinity from the rivers of the Gulf of Papua as suggested by Fairbridge (1973*b*).

Present evidence for this view is as follows: (1) Coral cover of the far northern barrier reef is as great or is greater than that observed in the deltaic reefs and most of the ribbon reefs studied. (2) Coral abundance of the Murray Islands 28 km SW of the northern reef limit compares favourably with those of more easterly and southerly islands, and shows no evidence of adverse environmental conditions (Mayer 1918; Vaughan 1918; Veron, personal observations). (3) Freshwater from the Fly river has a strong easterly set and would be more likely to affect the barrier reefs of southern Niugini (Whitehouse 1973) than barrier reefs 110 km to the south. (4) Aerial photographs indicate increasing depth of water cover northward from the northernmost reef studied. (5) The two reefs studied mostly had steep sides to depths of 17–37 m and were surrounded by sand and rubble; there was no encroaching silt layer.

(*b*) *Deltaic reefs*

Although aerial photographs of the deltaic reefs and the more northern dissected reefs indicate that those two types have little or nothing in common, Veron has shown that they occupy similar bathymetric situations and have similar seaward faces with subcontinuous ridges crossing the mouths of their channels. Principal differences are (1) the nature of the channels, and (2) the formation of the deltaic complex at the back of the deltaic reefs.

Clearly the seaward channels of the deltaic reefs are a product of the flood tide (when water can only cross the reef line via the channels). Their steep sides are poorly illuminated and have little coral cover except near the surface and consequently would appear to be in the process of erosion. The whole of the reef back of the deltaic reefs, especially the westward projecting 'arms' of the channels, appear to be in the process of rapid development, no doubt as a result of the twice daily injection of oceanic water.

The deltaic system therefore appears to be in the process of change and development. The ancestral reef of the dissected and deltaic types was perhaps similar, with the present morphologies being associated with different changes in relative sea levels, the former from tectonic subsidence as indicated above, the latter from a relative decrease in sea level of primarily eustatic origin occurring during much more recent times (see §2 below).

(*c*) *Ribbon reefs*

Such a diversity of form is included in the 536 km length of ribbon reefs that few generalizations can be made about them here. However, it should be noted that (1) they are all situated at the very edge of the Queensland Trench and have very steep sloping outer faces descending to great depth and (2) that the reefs are separated by channels and passes of irregular depth and size which indicate a substantial structural separation between one reef and the next.

The origin of the ribbon reefs is probably closely associated with the origins of the Queensland Trench. Gardner (1970) has proposed that the Tasman geosyncline from Niugini (including the east Australian continental shelf) and the Papuan geosyncline (from Niugini and including New Caledonia and New Zealand) (David 1950) were a single feature with Niugini lying adjacent to northern Queensland. He proposed that, between late Eocene and late Oligocene, Niugini rotated anticlockwise to its present position, forming as it did so many of the physiographic features of the Coral Sea, including the Queensland Trench.

Whatever its origin, the absence of any continental slope between the Queensland Trench and the ribbon reefs suggests that some form of reef system has always lined its western rim. Otherwise a continental slope and a narrower shelf would surely have developed.

The detached reefs, including the Great Detached Reef, were probably once part of the main line of barrier reef. Likewise the present main reef line is probably situated westward of earlier lines.

2. *Effects of Holocene sea levels on barrier reef outer reef flats*

One of the most distinctive aspects of the ribbon and deltaic reefs is the outer reef flat which mostly consists of hard, very flat limestone devoid of any coral cover and, for extensive areas, having little or no cover of larger algae. Reef flats of this nature are not found with inner reefs; they are clearly associated with exposure to strong wave action. This study tentatively suggests that they are the wave-resistant result of planation by fall in relative sea level occurring after the last (Holocene?) emergence. This suggestion is not original; both Newell (1961) and Fairbridge (1973*a*) have made similar observations on other reefs.

Alternative explanations include: (*a*) that sufficient unobserved calcifying organisms are present in the rock matrix to balance erosion forces, (*b*) that the reef flats formed during the present sea level still-stand but that the calcifying organisms involved are no longer present, and (*c*) that the reef flats formed during some pre-Holocene still-stand at present sea level and are sufficiently resistant to wave and aerial erosion to have maintained their present form during Holocene sea level fluctuations.

A study of the age and nature of the surface few metres of reef flat should readily clarify the above speculation. At present it is only possible to note that there is no evidence of subaerial erosion on the reef flats. This indicates that their present surfaces were not exposed during the last major regression and have only been exposed during present or above-present sea levels.

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