

ODP Leg 194: Sea Level Magnitudes Recorded by Continental Margin Sequences on the Marion Plateau, Northeast Australia

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INTRODUCTION

Carbonate platforms are large geologic structures composed of the remains of calcium carbonate-secreting organisms that can be found in environments ranging from tropical to temperate, and in locations that are free of siliceous sediment to those with significant amounts of terrigenous sediment. Because these platforms are composed of biogenic remains they are sensitive to changes in environmental conditions such as sea level, wind or currents, nutrient content, and water temperature. Thus, the study of carbonate

platforms provides fundamental information regarding environmental change in a range of environments. In addition to their high-quality environmental record, carbonate platforms are often important petroleum reservoirs. Therefore, much effort has been expended in both industry and academia to understand the growth, development, and associated diagenetic alteration of carbonate platforms.

From January to March 2001, Leg 194 drilled a series of eight sites through Oligocene-Pliocene carbonate platforms on the Marion Plateau and adjacent slope sediments, located seaward of the south central Great Barrier Reef off northeast Australia (Fig. 1). Primary goals of this drilling were to calibrate an important interval of the global sea level curve and to investigate the influence of paleoceanographic changes on carbonate platform development in a cool sub-tropical environment. Results from Leg 194 provided an accurate estimate of the magnitude of middle Miocene sea level fall,

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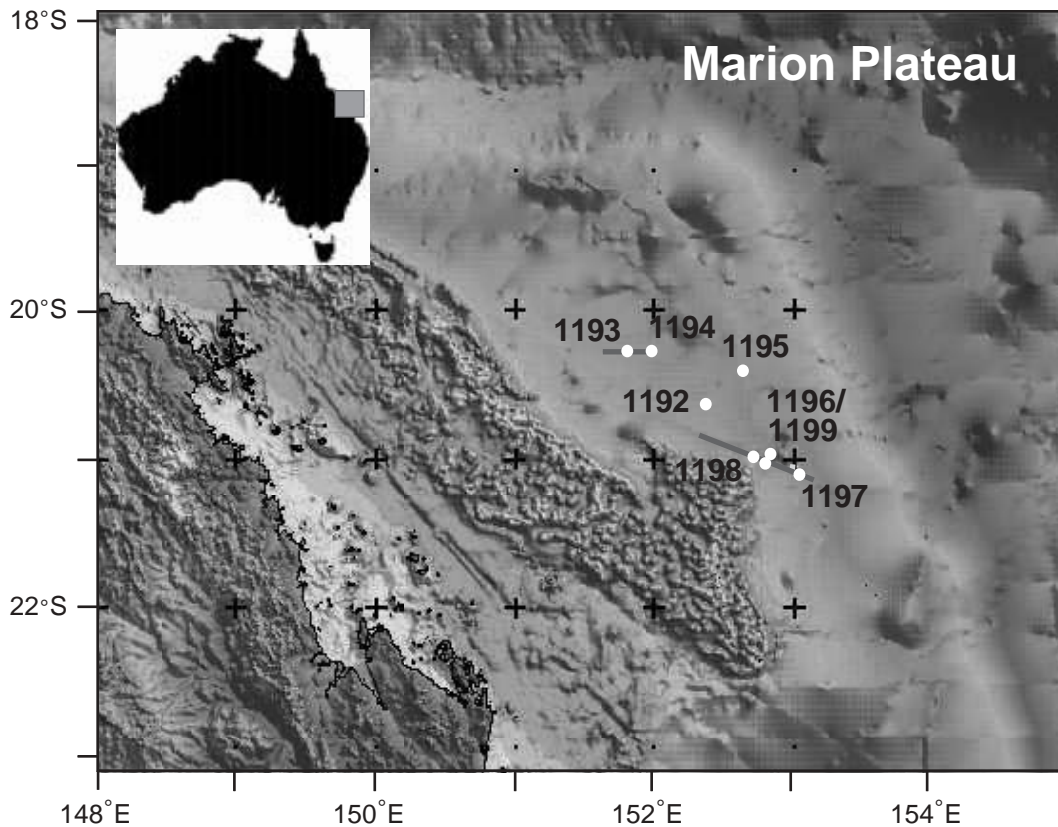


Figure 1. Bathymetric map of ODP Leg 194 drillsites (circles) off northeastern Australia. The location of these sites relative to the Australian continental margin is indicated in the box at upper left. Lines indicate the locations of seismic sections shown in Figures 2 and 3. Bathymetry provided by the Australian Geological Survey Organization.

and indicated that sub-tropical faunal assemblages are capable of building tropical platform geometries. Additional work on recovered sediments will provide important information for constraining paleo-currents in the western South Pacific.

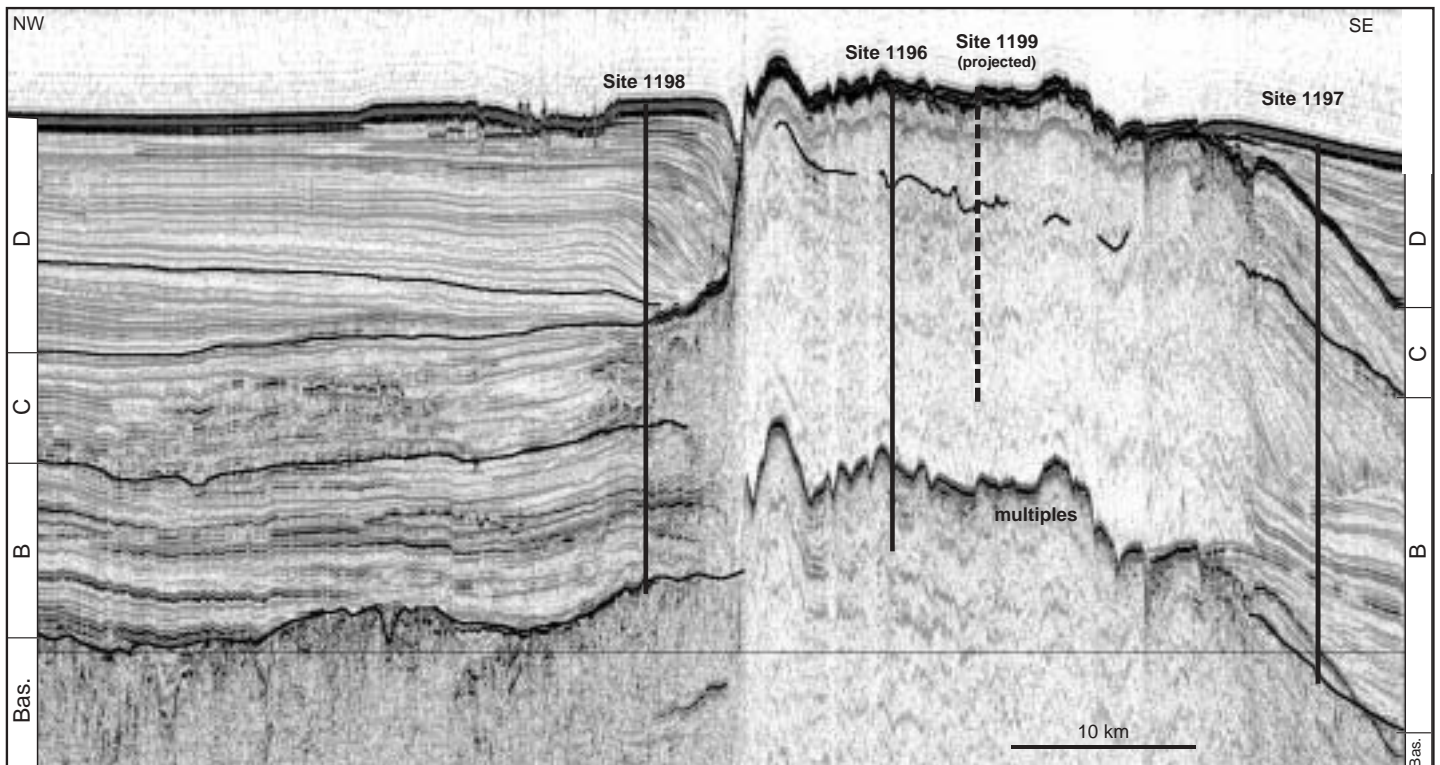
PRINCIPAL SCIENTIFIC RESULTS

Timing of Carbonate Platform Development

The northeast Australian margin is characterized by many carbonate platforms, the most notable and youngest being the Great Barrier Reef (International Consortium for Great Barrier Reef Drilling, 2001). The older Queensland and northern Marion Plateaus were drilled during Leg 133 (Davies et al., 1991). The Marion Plateau (Fig. 1) was selected for Leg 194 drilling as it provided

ideal targets for addressing the magnitude of sea level change and evolution of the platform. Seismic profiles and sediments recovered during Leg 194 indicate that the Marion Plateau experienced extensive sub-tropical/cool sub-tropical carbonate platform development over much of the plateau from the early to middle Miocene (Fig. 2; color plate inside the back cover, and Fig. 3).

In the late middle Miocene (~11 Ma), carbonate bank productivity rapidly diminished due to exposure after the major sea level fall from ~11-7 Ma. Platform growth did not reinitiate over most of the area after re-flooding. This is surprising because growth rates of the organisms that construct carbonate platform edifices are high enough to outpace potentially destructive sea-level rises. The death of carbonate platforms and reefs has been termed



Line MAR07

Figure 3. Seismic section along the southern drilling transect; extents of boreholes at Sites 1198, 1196, 1999, and 1197 are shown by vertical lines (see Fig. 1 for locations). Site 1199 is located approximately 5 km northeast of this seismic line and was projected onto the line perpendicularly. Seismic mega-sequences that can be correlated throughout the study area are labeled on both sides of the figure. The seismically transparent, southern carbonate platform can be seen at the center of the figure. This platform is made up of multiple growth phases throughout the Miocene. The platform drowned in the late Miocene to early Pliocene, and current-induced non-deposition has kept its surface nearly free of sediment. This carbonate platform nucleated in a topographic depression or on a carbonate ramp and its subsequent growth was strongly controlled by current flow. The platform architecture is asymmetric, with the upcurrent (left) side being relatively sediment-starved as compared to the downcurrent (right) side.

the “paradox of drowning” (Schlager, 1981). The cause for the demise of the Marion Plateau carbonate platforms remains unclear, but may be due to environmental stress caused by sea level variations in conjunction with reduced sea-surface temperatures (Isern et al., 1996), greatly increased rates of subsidence for the Marion Plateau (Mueller et al., 2000), increased river discharge (Pigram et al., 1992), and increased current activity across the drowning platforms.

Given the progression of the early shallow-water reef systems to the present water depths of the drilling sites (304-420 m), it is clear that postrift thermal subsidence is a controlling factor on long-term accommodation space for platform growth. The postrift subsidence of the region occurs even though unambiguous rift structures are not observed across the plateau.

Calibration of the Global Sea Level Curve

Measuring the magnitude of eustatic sea level fluctuations is a difficult problem whose resolution is essential both for the establishment of an accurate eustatic sea level curve for the Phanerozoic and for the accurate interpretation of sediment sequences on continental margins. Several attempts have been made to determine the amplitude of glacioeustatic fluctuations, including passive-margin sequence stratigraphy (Haq et al., 1987), modeling of sedimentary depositional regimes (Watts and Thorne, 1984), calibration of the oxygen isotope curve (Miller et al., 1987), and analysis of the depositional history of carbonate sediments on atolls (Schlanger and Premoli-Silva, 1986). These analyses often agree on the timing of sea-level changes, but significant differences exist between estimates of the magnitude of these events. A primary goal of Leg 194 drilling was to calibrate an important part of the global eustatic sea-level curve by estimating the magnitude of the major late middle Miocene (N12-N14) sea-level fall using sequence geometries and sedimentary facies from Sites 1193 and 1194 on the northern drilling transect (Figs. 1 and 2).

Drilling at Site 1194 penetrated a lowstand shallow water carbonate ramp of late middle

Miocene age that interrupts intervals of deeper water sediments. This sequence was deposited ~12 km from an early-middle Miocene carbonate platform drilled at Site 1193 (Fig. 2). Sequence relationships show that this ramp was deposited subsequent to the top of the platform at Site 1193. In addition, sediments recovered from this ramp at Site 1194 show no evidence of reworking, such as abrasion, and consist of distinctly different faunal assemblages as compared to the adjacent carbonate platform. This evidence rules out the possibility that sediments of the lowstand ramp were derived from the adjacent carbonate platform.

The present-day relief between the top of the platform at Site 1193 and the base of the lowstand system at Site 1194 is 145 m. Shipboard porosity data were used to correct for sediment decompaction resulting from the unloading of post-middle Miocene sediment. Corrections of 7 m at Site 1193 and 56 m at Site 1194 reduced the relief to 96 m. Consideration of paleo-water depths of 30 ± 20 m during the highstand at Site 1193 and 40 ± 10 m during the subsequent lowstand at Site 1194, derived from larger benthic foraminifer assemblages, requires a eustatic fall of 86 ± 30 m. This reconstruction assumes infinite flexural strength of the basement between the two sites (i.e., no differential subsidence). This assumption is supported by the presence of undisturbed sediment characterized by constant dip angles, the short distance and horizontal basement geometry between the sites, and the absence of major faults. The estimated magnitude for the late middle Miocene eustatic fall derived here is agrees with estimates derived from other proxies, but is less than the value of 185 m initially proposed using seismic geometry from this area uncalibrated by drilling data. The estimated magnitude also is greater than estimates from the New Jersey margin. Platform erosion at Site 1193 and overall tectonic subsidence during sea level lowering were not considered. Both effects are likely to be smaller than the error margin of the above estimates and would increase the sea level fall. It is also possible that a record of the lowest sea level was not preserved, cored, or observed at Site 1194. This also would increase the magnitude of the eustatic fall described here.

Strong Seafloor Currents Control Carbonate Platform Development

Most well-studied examples of carbonate platforms in modern environments, such as the Bahamas, have sedimentation patterns that reflect prevailing wind directions. Winds are the dominant energy source, forcing sediment off the platform on the leeward side and leaving the windward side relatively sediment-starved. These wind patterns produce a platform asymmetry with steep windward and gentler leeward slopes (e.g., Eberli and Ginsburg, 1987). This model is commonly used to interpret carbonate platforms observed in the geologic record.

The carbonate platforms off northeast Australia, though morphologically similar to the Bahamas platform, have a different developmental history. Interpretations of high-resolution seismic data and cores from Leg 194, along with modern oceanographic data from northeast Australia, show that sedimentation on the Marion Plateau is dominated by oceanographic currents. The influence of these currents, the primary energy source along the platform, on carbonate growth creates an asymmetrical platform geometry where the upcurrent side of the platform is relatively sediment starved and most sediments are deposited in the downcurrent direction (Fig. 3). Furthermore, the dominant sediment shedding direction is opposite that of the prevailing winds but parallel to the principal direction of current flow. These currents likely determine not only the morphology and amount of sediment transported from the platform top, but also the growth potential of the platforms.

The influence of currents is observed today as large sediment drifts on the Marion Plateau surface. A significant benefit of Leg 194 drilling is that continued study of recovered cores will provide a history of the currents off northeast Australia, including changes in strength and flow pattern. These currents are dominated by the East Australian Current, the primary western boundary current in the South Pacific whose development is strongly linked to changes in current flow resulting from the Miocene closure of the low-latitude gateway north of New Guinea. Thus, a better understanding of current flow off northeast Australia

will provide additional information to better constrain the closing of this important gateway.

Influence on Platform Architecture of Physical Parameters and Biofacies

The recognition that currents control carbonate platform sedimentation along the Marion Plateau has important implications for the interpretation of carbonate platforms imaged on seismic data. Prior to Leg 194 drilling, seismic data interpretation suggested that the organisms that constructed the platforms of the Marion Plateau were dominated by tropical, warm-water species, including corals. The remains of these warm-water organisms generally form flat-topped platforms with steep sides, as they are dominated by unstable aragonite and high magnesium calcite mineralogy that becomes cemented as it undergoes alteration to more stable calcite mineralogy.

Seismic data show that the platforms on the Marion Plateau are similarly characterized by massive, table-like structures, and yet the recovered sediments from Leg 194 are almost entirely composed of the remains of cool, sub-tropical organisms such as red algae, bryozoans, and larger benthic foraminifers. These calcite-dominated organic remains have a lower diagenetic potential than their aragonite-dominated counterparts in the tropical realm. Despite the reduced cementation potential, the drilled platforms are well cemented. On the slopes, however, reduced cementation resulted in poor recovery. The observation that cool sub-tropical faunal assemblages produce platform geometries that are similar to tropical carbonates suggests that physical parameters, such as current flow and sea level change, may be more important in the establishment of platform architectures than the dominant biofacies.

Fluid Flow

Porewaters from Leg 194 sediments provide clear evidence that seawater is circulating through the carbonate platforms and proximal sediments on the Marion Plateau. Sampling of fluids within the carbonate platforms was not possible due to low core recovery. Water samples taken from sites adjacent to the carbonate platforms show that seawater is being fed through the platform edifices into

high-permeability, late Miocene sediments that form an aquifer overlain by ~200 m of low-permeability sediments of Pliocene age. Furthermore, the dolomitization observed in both drilled platforms is in itself indirect evidence for past fluid circulation through these platforms. Dolomite formation on a large scale requires fluid flow to deliver the required magnesium to the precursor calcium carbonate sediments. The timing and mechanisms of this flow and the nature of the fluids, whether normal seawater or hypo- or hyper-saline fluids, are unresolved questions.

Acoustic Basement

Prior to Leg 194, no direct information existed concerning the basement composition of the Marion Plateau. The highly altered volcanic flows and volcanoclastic basement rocks recovered during Leg 194 differ greatly from the metasedimentary rocks drilled on the Queensland Plateau during Leg 133 (Davies et al., 1991). The lack of deformation suggests that these volcanics may have been emplaced during the Late Cretaceous-Paleocene rifting of northeastern Australia from the Papuan Plateau and the Lord Howe Rise. The high intensity and consistent paleomagnetic response of the basement may provide age estimates for both the emplacement of the basalts and the timing of low-temperature alteration. This new information, supplemented with post-cruise analyses, will have important implications for understanding regional tectonics and also for understanding the subsidence history of the Marian Plateau.

LEG 194 SCIENTIFIC PARTY

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REFERENCES

- Davies, P.J., McKenzie, J.A., Palmer-Julson, A., et al., 1991. *Proc. ODP, Init. Repts.*, 133 (Pts. 1, 2): College Station, TX (Ocean Drilling Program).
- Eberli, G. P., and Ginsburg, R., 1987. Segmentation and coalescence of platforms, Tertiary, NW Great Bahama Bank. *Geology*, 15:75-79.
- Haq, B. U., Hardenbol, J., and Vail, P. R., 1987. Chronology of fluctuating sea-levels since the Triassic. *Science*, 235:1156-1167.
- International Consortium for Great Barrier Reef Drilling, 2001. New constraints on the origin of the Australian Great Barrier Reef: Results from an international project of deep coring. *Geology*, 29:483-486.
- Isern, A. R., McKenzie, J. A., and Feary, D. A., 1996. The role of sea surface temperature as a control on carbonate platform development in the western Coral Sea. *Paleo. Paleo. Paleo.*, 124:247-272.
- Miller, K. G., Fairbanks, R. G., and Mountain, G. S., 1987. Tertiary oxygen isotope synthesis, sea-level history, and continental margin erosion. *Paleoceanogr.*, 2:1-19.
- Mueller, R. D., Lim, V. S. L., and Isern, A. R., 2000. Late tertiary tectonic subsidence on the northeast Australian passive margin: response to dynamic topography? *Mar. Geol.*, 162:337-352.
- Pigram, C. J., Davies, P. J., Feary, D. A., and Symonds, P. A., 1992. Absolute magnitude of the second-order middle to late Miocene sea-level fall, Marion Plateau, northeast Australia. *Geology*, 20:858-862.
- Schlager, W., 1981. The paradox of drowned reefs and carbonate platforms. *Geol. Soc. Am. Bull.*, 92:197-211.
- Schlanger, S. O., and I. Premoli-Silva, 1986. Oligocene sea-level falls recorded in the mid-Pacific atoll and archipelagic apron settings. *Geology*, 14:392-395.
- Watts, A. B., and J. Thorne, 1984. Tectonics, Global changes in sea-level and their relationship to stratigraphic sequences at the U. S. Atlantic continental margin. *Mar. Petrol. Geol.*, 1:319-339.