Ocean Drilling Constrains Carbonate Platform Formation and Miocene Sea Level on the Australian Margin

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Carbonate platforms are large geologic structures composed of the remains of formerly living, calcium carbonate-secreting organisms that can develop in environments ranging from tropical to temperate, and in locations that are free of siliceous sediment to those with significant amounts of sediment from land. Because these platforms are composed of biogenic remains sensitive to changes in environmental conditions such as sea level, wind or currents, nutrient content, and water temperature, 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. Thus, much effort has been expended in both the academic and industrial sectors in order to understand the growth, development, and associated diagenetic alteration of carbonate platforms.

From January to March 2001, Ocean Drilling Program (ODP) Leg 194 drilled the Marion Plateau (Figure 1), a carbonate "reef" on the northeast Australia margin, to investigate long-term environmental change. Many prior ODP legs have also drilled carbonate platforms for this purpose, including Legs 101 and 166 adjacent to the Bahamas Platform, Legs 143 and 144 on the Pacific Atrolls, Leg 182 in the temperate carbonates of southern Australia, and Leg 133, which like Leg 194 also took place on the tropical-subtropical platforms of the northeast Australian margin.

The primary goals of ODP Leg 194 were to calibrate an important interval of the global sea-level curve and to investigate the influence of paleoceanographic changes on the development of carbonate platforms in a cool subtropical environment. Leg 194 drilled a series of eight sites (Figure 1) through Oligocene-Pliocene carbonate platforms and their adjacent slope sediments. These sites were located seaward of the south central Great Barrier Reef. A major outcome of Leg 194 is that sub-tropical faunal assemblages are capable of building tropical platform geometries. Furthermore, Leg results have enabled an accurate estimate of the magnitude of middle Miocene sea-level fall. Additional work on recovered sediments will provide important information for constraining paleo-currents in the western South Pacific.

The Carbonate Platforms of Northeastern Australia

The northeast Australian margin is characterized by the presence of many carbonate platforms, the most notable and youngest being the Great Barrier Reef [International Consortium for Great Barrier Reef Drilling, 2001]. Of the older carbonate platforms, the Marion Plateau (Figure 1) was selected for Leg 194 drilling, as it provided ideal targets for addressing evolution of the platform and the magnitude of sea-level change. Seismic profiles and sediments recovered during Leg 194 indicate that the Marion Plateau exhibited extensive sub-tropical/cool sub-tropical carbonate platform development over much of the plateau from the early to middle Miocene (Figures 2–3).

In the late middle Miocene (~11 Ma), carbonate bank productivity rapidly diminished due to exposure resulting from a major sea level fall that occurred between ~11–7 Ma. After re-flooding, carbonate platform growth did not re-initiate over most of the area. The failure to do so 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 the "paradox of drowning" in the literature [Schlager, 1981].

![Fig. 1. This map shows the location of ODP Leg 194 sites in northeastern Australia. The box indicates the location of these sites relative to the Australian continental margin. Lines indicate the locations of seismic sections shown in Figures 2 and 3. Original color image appears at the back of this volume.](image-url)
The cause for the demise of the Marion Plateau carbonate platforms is still not well known despite previous ODP drilling, but it 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 [Miller et al., 2000], increased river discharge [Pigram et al., 1992], and increased current activity across the drowning platforms. Leg 194 drilling should provide fundamental information to help solve this mystery, which is of great importance to understanding similar catastrophes seen in other ancient carbonate platforms.

The Influence of Strong Sea Floor Currents

Most well-studied examples of carbonate platforms in the modern environment, such as the Bahamas, have sedimentation patterns that reflect prevailing wind directions. In these cases, winds act as the dominant energy source, forcing sediment off the platform on the leeward side, leaving the windward side relatively sediment-starved. As a consequence, this wind pattern produces a platform asymmetry with steep windward and gentler leeward slopes [e.g., Eberli and Ginsburg, 1987], and it has been used as the general model for interpreting carbonate platforms observed in the geologic record.

The carbonate platforms off northeast Australia, although similar in morphology to the Bahamas platform in many respects, have a significant difference that influences their development. Interpretations of high-resolution seismic data and cores from Leg 194, along with modern oceanographic data from northeast Australia, have demonstrated that sedimentation on the Marion Plateau is dominated by oceanographic currents. In contrast to the Bahamas, these currents are the primary energy source. The influence of currents 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 (Figure 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 but also the growth potential of the platforms, as well as the location and amount of sediment transported from the platform top.

The influence of currents continues today as large sediment drifts are observed on the Marion Plateau. 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 their 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.

Some Surprises from Drilling

The recognition that currents control Marion Plateau carbonate platform sedimentation has important implications for the interpretation of carbonate platforms imaged on seismic data. Prior to Leg 194 drilling, it was believed 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. The platforms on the Marion Plateau are likewise characterized by massive, table-like structures, and yet the recovered sediments from Leg 194 show that they 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 nevertheless well cemented. On the slopes, however, reduced cementation resulted in extremely poor recovery. The fact that the 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 bioclastics.

Calibrating the Global Sea-level Curve

Measuring the magnitude of eustatic sea-level fluctuations has proved to be 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 there are significant differences between estimates of the magnitude of these events. A primary goal of Leg 194 drilling was to provide an accurate estimate of the magnitude of the major late middle Miocene sea-level fall using sequence geometries and sedimentary facies from the northern drilling transect at Sites 1193 and 1194 (Figure 2). The results of these calculations enable the calibration of an important part of the global eustatic sea-level curve.

Drilling at Site 1194 penetrated shallow water-deposited carbonate ramp or platform
of late middle Miocene age that interrupts intervals of deeper water sediments and represents a lowstand sequence. This sequence was deposited ~12 km from the early-middle Miocene carbonate platform drilled at Site 1193 (Figure 2). Sequence relationships show that this ramp was deposited subsequent to the top of the platform at Site 1193. 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.

Using shipboard porosity measurements to correct for sediment decompaction resulting from unloading post-middle Miocene sediment (7 m at Site 1193; 56 m at Site 1194) reduces that relief to 96 m. Considering the paleowater depth information from larger benthic foraminifer assemblages during the highstand at Site 1193 (30±20 m) and the subsequent lowstand at Site 1194 (40±10 m) requires a eustatic fall of 86±50 m. This reconstruction assumes infinite flexural strength of the basement between the two sites (that is, no differential subsidence), which is supported by the presence of undisturbed and constant-dipping sediments, a small distance and horizontal basement geometry between the sites, and the absence of major faults. This estimated magnitude for the late middle Miocene eustatic fall is in concert with estimates derived from seismic geometry from this area that had not been calibrated by drilling data [Pigram et al., 1992]. Platform erosion at Site 1193 and overall tectonic subsidence during the sea-level lowering were not considered. Both effects are much 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 in Sub-unit IIa at Site 1194, which would also increase the magnitude of the eustatic fall.

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Platform top at 383 mbsl (decompacted at 376 mbsl); Paleowater depth 10 - 50 m

Base lowstand-ramp at 528 mbsl (decompacted at 472 mbsl); Paleowater depth 30-50 m

Fig. 2. This seismic section displays Sites 1193 and 1194 from the northern drilling transect (see Figure 1 for location of the sites). At left, the northern, middle Miocene carbonate platform is imaged. This platform is capped by an exposure surface that developed during the late middle Miocene fall in sea level. In addition, this figure shows the geometric relationship between a low sea-level carbonate ramp complex (between the two white arrows; Site 1194) and the exposed surface of the adjacent carbonate platform (black arrow; Site 1193), which provides an estimate of 86±30 m for the magnitude of the fall in sea level.
Fig. 3. The seismic section shown here displays the southern drilling transect; Sites 1198, 1196, 1999, and 1197 are shown by vertical lines. Site 1199 is located approximately 5 km northeast of this seismic line and was projected onto the line perpendicularly (see Figure 1 for location of the sites). Seismic mega-sequences that can be correlated throughout the study area are labeled on both sides of the figure. At the center of the figure, the seismically transparent, southern carbonate platform can be seen. 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 and its subsequent growth was strongly controlled by current flow; its architecture is asymmetric, with the upcurrent side (left) being relatively sediment-starved as compared to the downcurrent side (right).