

# Broad region of no sediment in the southwest Pacific Basin

David K. Rea\*<sup>†</sup> Department of Geological Sciences, University of Michigan, Ann Arbor, Michigan 48109-1005, USA  
Mitchell W. Lyle<sup>†</sup> } Center for the Geophysical Investigation of the Shallow Subsurface, Boise State University, Boise, Idaho  
Lee M. Liberty<sup>†</sup> } 83725-1536, USA  
Steven A. Hovan<sup>†</sup> } Department of Geoscience, Indiana University of Pennsylvania, Indiana, Pennsylvania 15705-1087,  
Matthew P. Boly<sup>†</sup> } USA  
James D. Gleason<sup>†</sup> } Department of Geological Sciences, University of Michigan, Ann Arbor, Michigan 48109-1005, USA  
Ingrid L. Hendy<sup>†</sup> }  
Jennifer C. Latimer<sup>†</sup> }  
Brandi M. Murphy<sup>†</sup> } Center for the Geophysical Investigation of the Shallow Subsurface, Boise State University, Boise, Idaho  
83725-1536, USA  
Robert M. Owen<sup>†</sup> Department of Geological Sciences, University of Michigan, Ann Arbor, Michigan 48109-1005, USA  
Christopher F. Paul<sup>†</sup> Center for the Geophysical Investigation of the Shallow Subsurface, Boise State University, Boise, Idaho  
83725-1536, USA  
Thomas H.C. Rea<sup>†</sup> 1756 South Chestnut St., Casper, Wyoming 82601, USA  
Andrea M. Stancin<sup>†</sup> Department of Geological Sciences, University of Michigan, Ann Arbor, Michigan 48109-1005, USA  
Deborah J. Thomas<sup>†</sup> Department of Oceanography, Texas A&M University, College Station, Texas 77843-3146, USA

## ABSTRACT

A broad region, nearly the size of the Mediterranean Sea, exists in the central South Pacific Ocean that is devoid of sediment and has been so since the Late Cretaceous. The requirements for remaining sediment free are very low biological productivity, a shallow calcite compensation depth, essentially no dust input, and no deposition of hydrothermal oxides and hydroxides. One or two of these conditions are common, but nowhere else do all four occur. The combined effect of these sediment-inhibiting factors is a consequence of crustal age, seawater chemistry, and atmospheric, oceanographic, and physiographic isolation. Furthermore, this unique combination of conditions has prevailed for more than 80 million years.

**Keywords:** South Pacific Ocean, deep-sea sedimentation, paleoceanography, Late Cretaceous, Paleogene.

## INTRODUCTION

In February and March of 2005 the R/V *Melville* surveyed and cored a number of sites in the southwest Pacific Basin (Figs. 1 and 2), as a prelude to presenting a full drilling proposal to the Integrated Ocean Drilling Program on the subject of Paleogene paleoceanography and paleoclimatology. The region is, in general, poorly surveyed, and useful track lines are spaced two or more degrees apart over much of the region. Some specific features are well surveyed, like parts of the Heezen-Tharp fracture zone system or the Louisville Seamount chain. Our several piston and gravity cores were raised from depths ranging from 4000 m to 5300 m and sampled the upper part of the sedimentary section; none encountered volcanic basement. They and the seismic-reflection profiles collected during the transits and surveys provide new insights to the sedimentary geology of the southwestern and sub-Antarctic Pacific.

Our cores and western profile indicate that the central part of the basin is characterized

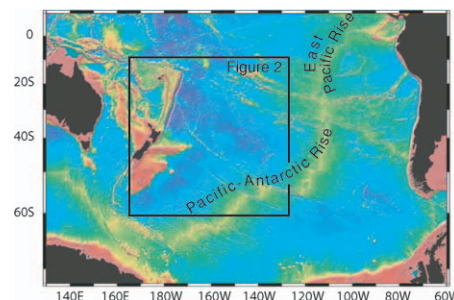
by a thin layer of pelagic clay extending south from  $\sim 30^{\circ}\text{S}$ . The southern part of our cruise track (Fig. 2), along  $\sim 50^{\circ}\text{S}$ , is characterized by siliceous sediment at depths greater than 4750 m, and carbonate-bearing siliceous oozes at depths shallower than 4750 m. Cores raised from these different regions and facies will go far to advance our understanding of the paleoceanography and paleoclimatology of this remote part of the world. These results were anticipated on the basis of the regional oceanography.

The new and surprising result is the discovery of a broad region in the central South Pacific where the seafloor is essentially devoid of sediment. The region, termed here the South Pacific bare zone, is bound approximately by the northern limits of siliceous biogenic sediment, which extend east-west along  $42.5^{\circ}\text{S}$ , and the lower southwestern slope of the Austral Islands at  $\sim 28^{\circ}\text{S}$  to the north. The western extent lies generally east of our track line from Tahiti south to the Marlin Rise. To the east, the boundary is somewhere east of our track line; an estimation of its location follows. These boundaries comprise a genuinely vast area of the central South Pacific,  $\sim 2 \times 10^6 \text{ km}^2$  (Fig. 2).

## CRUISE RESULTS

The R/V *Melville* operated three seismic systems during our site-survey cruise, the 12 kHz echo sounder, 3.5 kHz seismic profiler, and a 150 in<sup>3</sup> GI air-gun system, which used either a 4 channel (under way) or a 24 channel (site-survey) hydrophone streamer. Late in the cruise, the 4 channel streamer was reduced to  $\sim 3.75$  channels by a shark.

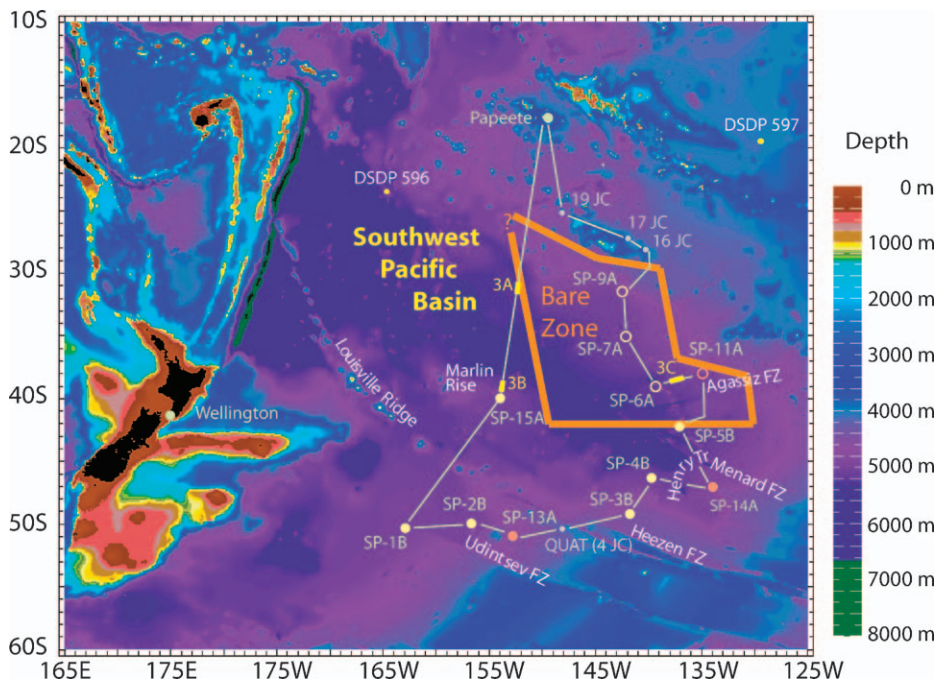
Vertical resolution is a function of seismic velocity and frequency. Reflections from water bottom and subbottom boundaries have frequencies centered at 300 Hz for the GI gun source. Using a 1500 m/s water velocity and 1/4 wavelength limit for vertical resolution (Sheriff, 1980; Sheriff and Geldart, 1995), beds as thin as 1.25 m can be resolved. Similarly, the theoretical seismic resolution of the chirp subbottom profile system is  $\sim 15$  cm. However, at the seafloor on bare crust, the minimum thickness of sediment that can be measured is limited by scattering off the rough basalt surface, not the 1/4 wavelength criterion. In basins, that scattering is related to volcanic flow roughness; on abyssal hills, a larger roughness scale is superimposed associated with faulting and volcanic edifice building.



**Figure 1.** Index map of South Pacific Ocean showing location of Figure 2 and of Pacific-Antarctic Rise and East Pacific Rise.

\*Email: davidrea@umich.edu.

<sup>†</sup>The South Pacific Latitudinal Transect (SPLAT) Survey and Coring Team.



**Figure 2.** Bathymetric map of southwest Pacific Basin, showing *Melville* cruise track line, survey locations (filled circles indicate full or partial sediment cover; open circles indicate bare seafloor), Deep Sea Drilling Project (DSDP) Sites 596 and 597, and outline of South Pacific bare zone. Locations of seismic-reflection profile segments shown on Figure 3 are indicated as heavier lines. FZ—fracture zone; Tr—trough.

This seafloor acoustic scattering hides sediment until a sufficient amount is deposited to smooth the surface roughness. Given the scales of flow roughness (roughly meter-scale variations in topography), a smooth sediment surface should be created in basins with 1–2 m of sediment deposition. On abyssal hills and other topography with greater vertical relief, more sediment must be deposited to smooth the seafloor. In our western track line, heading south from Tahiti to Marlin Rise, we passed from “acoustically bare” to clearly distinguishable sediment when the sediment thickness was ~7 m thick (Fig. 3A). Based on that empirical criterion, the threshold for undeniably detecting sediments is between 2 and 7 m.

Our seismic-profile coverage included the 2300-km-long western under-way track on Late Cretaceous crust, eight survey areas of 1000–1500 km<sup>2</sup> each that were positioned atop magnetic anomaly 25n, with a latest Paleocene age of 56 Ma, and three others on middle Eocene crust. All survey areas are linked with seismic-reflection profiles. The western track line showed that discontinuous to absent sediment characterizes the part of the southwest Pacific Basin north of 30.5°S. To the south, a thin pelagic drape characterizes the seafloor and thickens southward (Figs. 2 and 3). Coring this horizon at 40°S revealed it to be zeolitic clay—the typical red clay of the deep oceans (Fig. 2, survey location SP-15A). Sediment thickness along the southern

part of our survey region between 50.5°S and 46.5°S is as much as 250 m, and averages ~150 m thick.

At our survey set on 56 Ma crust at 42.5°S (Fig. 2, survey location SP-5B), we found a gravity core taken from a flatter spot recovered only 56 cm of pelagic clay with manganese nodules on top. We attempted another gravity core following our survey at 39°S (Fig. 2, survey location SP-6A) and found only 15 cm of zeolitic clay and a dozen or so small manganese nodules on top. At 31.6°S (Fig. 2, survey location SP-9A), a survey of 1100 km<sup>2</sup> revealed a single patch of sediment of 1 km<sup>2</sup> at the bottom of a narrow valley, which turned out to be hydrothermal-hydrogenous oxides and clay. Other coring attempts in the region of the bare zone were hindered by bad weather and waves washing over the deck.

We made a careful examination of our processed air-gun and 3.5 kHz profiles along our eastern track line from 47°S (Fig. 2, survey location SP-14A) north to our survey site at 31.6°S (Fig. 2, survey location SP-9A) and noted where sediment cover was either continuous, apparently discontinuous, or certainly discontinuous or absent (Fig. 4). The region of clearly discontinuous to absent sediment extends to the north from ~42.5°S to somewhere north of the 31.6°S survey area. One of the important features to note is that no sediment could be found either on the flat areas

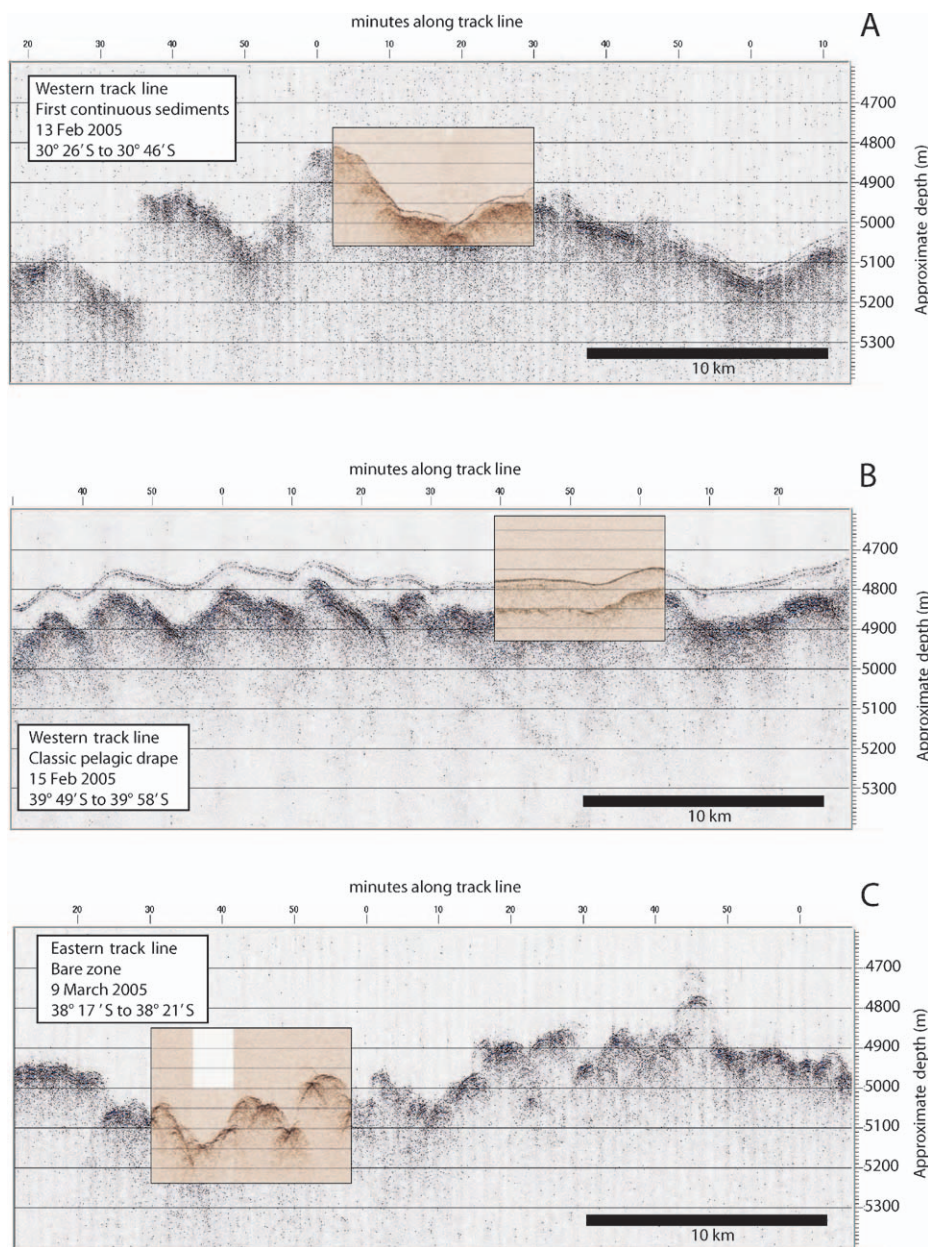
of the seafloor or in the small basins between the abyssal hills, as would be expected if winnowing had been an important process. Where we could easily image the seafloor, it was clearly devoid of sediment.

### IMPLICATIONS OF THE BARE ZONE

Crust in the bare zone region was generated between 85 Ma (seafloor magnetic anomaly 34) and 34 Ma (anomaly 13, see following) along the forerunner of the present Pacific–Antarctic Rise (Fig. 1) at slow to moderate spreading rates of 18–44 km/m.y. (based on the magnetic anomaly maps of Cande et al., 1989). Our finding over broad regions of the ocean floor that less than five meters of sediment accumulated in more than 80 million years requires that four separate conditions be met. Many regions of thin sediment cover fulfill one or two of these circumstances, but perhaps only the South Pacific bare zone meets all four. The conditions are: (1) very low biological productivity in the overlying surface waters; (2) a shallow calcite compensation depth (CCD) and/or relatively deep crustal subsidence pathway; (3) essentially no dust or other terrigenous input; and (4) very low input of hydrogenous and hydrothermal oxides. We will consider each of these in turn.

The bare zone underlies presently low biological-productivity waters of the South Pacific gyre, and the lack of sediment cover since crustal formation means it has always underlain a low-productivity region. The region with thin to no sediment presently lies at 28° to 42.5°S. The latitude of 42.5°S marks the northern extent of biogenic, usually siliceous, sedimentation. We assume this boundary trends east-west, parallel to modern oceanographic current patterns (Fig. 2).

The location history of any region of the seafloor is determined by the process of backtracking, which in turn depends on knowing the plate tectonic history of a region. In the South Pacific, this history is becoming reasonably well understood (Cande et al., 1995; Tebbens and Cande, 1997; Jordahl et al., 1998). The recent reevaluation of the “fixed” nature of hotspots (Tarduno et al., 2003) is less of a concern when backtracking across a single spreading center to a continental plate, Antarctica, which has moved very little throughout the Cenozoic. Here we refer to the paleogeographic maps generated by the Ocean Drilling Stratigraphic Network ([www.odsnet.org/odsnet/index.html](http://www.odsnet.org/odsnet/index.html)) and note that the bare zone, now at 28° to 42°S, backtracks to a roughly 15-degree-wide latitudinal band between 50° and 65°S at ca. 65 Ma. In this location, it retains the same geographic relation with Australia, mostly east and slightly south. Implications are that this region of the South Pacific has always lain below a low-productivity sub-

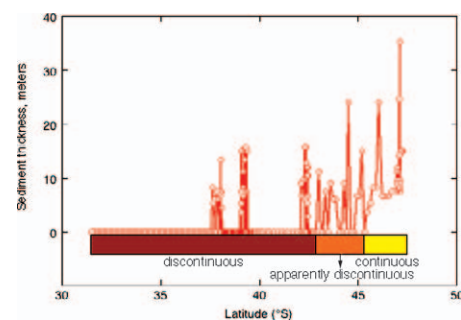


**Figure 3. Examples of sediment coverage in southwest Pacific Basin. Profiles are taken from air-gun seismic-reflection data; insets are from 3.5 kHz profiler, which provides a higher-resolution image of thin to absent sediment cover. A: Very thin but apparently continuous sediments. B: Continuous pelagic clays at Marlin Rise. C: Bare seafloor.**

tropical gyre, as far back in time as the end of the Cretaceous.

The calcite compensation depth is that depth where the productivity-related remains of carbonate-secreting plankton are completely consumed (compensated for) by dissolution. At depths greater than the calcite compensation depth, no  $\text{CaCO}_3$  accumulates on the seafloor. We have already noted that productivity has been low in the central-gyre region represented by our surveys; hence, the calcite compensation depth is likely rather shallow, reflecting the low supply of  $\text{CaCO}_3$ . Our *Melville* core raised from 4042 m at 28°S (Fig. 2, location 16JC) came from quite close

to the depth of the calcite compensation depth, which lies at ~4100 m at 19°S (Fig. 2, Deep Sea Drilling Project [DSDP] Site 597; Rea and Leinen, 1985). We assume that the calcite compensation depth history developed for the low-productivity waters at 19°S (Rea and Leinen, 1985) mimics that found in the low-productivity region further south, and that the calcite compensation depth in the region of the bare zone has never been deeper than ~4100 m in Oligocene to Holocene times. Observations in the eastern Equatorial Pacific (van Andel et al., 1975; Rea and Lyle, 2005) and elsewhere (van Andel et al., 1977) have demonstrated that the pre-Oligocene calcite

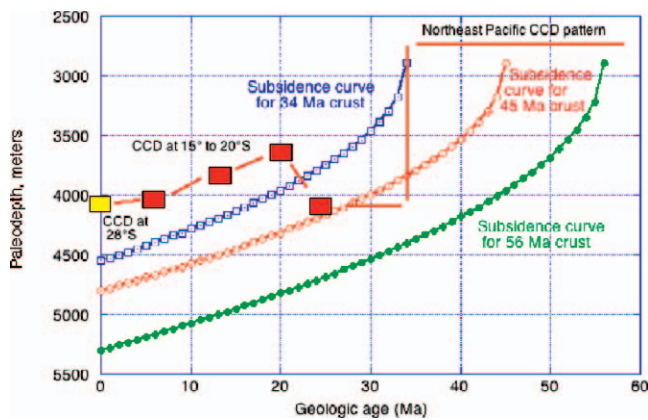


**Figure 4. Extent of sediment coverage between 48° and 31.5°S.**

compensation depth was perhaps 1400 m shallower than the present 4100 m, and most of this depth change occurred rapidly at the Eocene-Oligocene boundary. For the region of the bare zone, then, the calcite compensation depth may have been as shallow as 2700 m or less in pre-Oligocene time (Fig. 5). Crustal subsidence has been rather regular for the Pacific–Antarctic Rise since the Oligocene (Calcagno and Cazenave, 1994). It is, therefore, possible to describe a reasonable crustal subsidence pathway for these conditions that never intersects the calcite compensation depth for 56 Ma crust, and intersects it only briefly for 45 Ma crust (Fig. 5). Furthermore, the calcite compensation depth history for the Pacific (van Andel et al., 1975; Rea and Lyle, 2005) implies that crust younger than the Eocene-Oligocene boundary (anomaly 13) will have at least a thin  $\text{CaCO}_3$  layer lower in the sedimentary section (Fig. 5), as is found at DSDP Site 597 at 19°S (Fig. 2; Leinen et al., 1986a). For these reasons, we place the eastern boundary of the bare zone at the location of anomaly 13 as mapped by Cande et al. (1989).

Maps showing the input of dust to the global ocean show that the central South Pacific and the Southern Ocean are the most dust-free regions in the world, with broad regions characterized by dust input rates of 1 or 2  $\text{mg}/\text{cm}^2/\text{k.y.}$  or even less (Leinen et al., 1986b; Rea, 1994). DSDP coring at Site 597 revealed 1.5 m of middle Miocene and younger pelagic clay atop the 45 m of Oligocene to middle Miocene carbonate sediment that overlies basalt there (Leinen et al., 1986a). The clay sedimentation rate in the bare zone would have to be even less than this 0.1  $\text{m}/\text{m.y.}$  rate. The dry regions of Australia appear to provide little dust to the South Pacific, and the modest Australian dust input plume that does exist may trend southwest of the region of the bare zone (Leinen et al., 1986b), from DSDP Site 596 crossing site SP-15A on Marlin Rise (Fig. 2) and extending southeast from there. Eventual analyses of the 14 m of pelagic clay we recovered from coring on Marlin Rise, espe-

**Figure 5. Subsidence and calcite compensation depth (CCD) scenarios for seafloor of South Pacific bare zone. CCD information is taken from our *Melville* cruise results for modern value, Rea and Leinen (1985) for Neogene values, and the Rea and Lyle (2005) study in the Northeast Pacific for Paleogene values. When seafloor is deeper than CCD, no carbonate sediment accumulates. In this scenario, 34-m.y.-old crust will have some Oligocene carbonate, 45-m.y.-old crust will have very little carbonate, and 56-m.y.-old crust will have no carbonate sediment on it.**



cially any age control, will help place further constraints on these issues.

Many of the cores described as pelagic clays contain up to 50% iron and manganese oxides. These materials are precipitated from seawater and, depending on their trace-element geochemical makeup, are considered to be either hydrogenous or hydrothermal in origin. Their accumulation rate is not well known, but it is on the same order of magnitude as the red clays. The lack of aluminosilicate detritus may be explained by wind patterns and continental aridity history, but one might still expect several meters of hydrothermal sediment to have been deposited from the plume of marine hydrothermal systems generated at the Pacific–Antarctic Rise seafloor spreading center (Fig. 1). DSDP Site 597, well west of the rise axis (Figs. 1 and 2), has on the order of 5 m of hydrothermally derived sediment directly overlying basement in the lower part of the section there (Leinen et al., 1986a). However, farther south it is likely that persistent current patterns may have caused the hydrothermal plume to drift east rather than west over the bare zone. The modern distribution of He-3 in the water column above the East Pacific Rise shows a westward-moving plume between ~5 and 20°S (Lupton, 1998) and a symmetrical distribution of He-3 at 25°S (Takahata et al., 2005). Dymond (1981) noted that sediment derived from hydrothermal plumes is displaced to the west of the East Pacific Rise crest between 10° and ~30°S, and is displaced east of the rise crest to the south of 30°S. These observations suggest that deep currents south of 30°S would carry hydrothermal sediment preferentially to the east of the rise crest, away from the bare zone region, and that they have been doing so for much of the Cenozoic.

The South Pacific bare zone may be the only place in the world's ocean where basalt has been exposed to seawater for up to 80 million years. It is likely that the lack of sediment

sealing would allow low-temperature alteration to continue there for a much longer time than in a more typical setting where the seafloor is sediment-covered after a few million years. This extended period of low-temperature alteration apparently did not result in undue heat loss, as no unusual depth anomaly is associated with this region.

#### SUMMARY

We have discovered and partially mapped a  $2 \times 10^6$  km<sup>2</sup> region of Late Cretaceous and Paleogene crust that has virtually no sediment and is unique in all the ocean basins. Such a region can only exist if it has been overlain by low-productivity waters, always has been deeper than the calcite compensation depth, and remained far from continents and spreading centers. These conditions have persisted since latest Cretaceous time, a testimony to the constancy of oceanographic phenomena in this part of the South Pacific Ocean.

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