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Thinned Crust in Southwest Pacific May Harbor Gas Hydrate

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The Lord Howe Rise (LHR) is a large, complex, and poorly studied fragment of thinned continental crust submerged 750–3000 m beneath the oligotrophic waters of the central Tasman Sea (Figure 1). Deep seismic profiles taken during recent cruises in the region have revealed an intriguing phenomenon: the eastern slope of the LHR has a prominent and extensive bottom simulating reflector (BSR) that cross-cuts lithology at 0.65–0.75 s two-way travel time (twt) [*Exon et al.*, 1998; *Lafoy et al.*, 1998]. Given best estimates for sonic velocity (1600 m/s) and thermal gradients (0.9 + 0.04°C/m) in sediment on the LHR, predicted temperatures and pressures at the depth of the BSR lie on the CH_4-CH_4 hydrate-seawater equilibrium curve. Thus, the BSR on the LHR most likely represents an interface between gas hydrate and free gas [e.g., *Dickens et al.*, 1997]. Although BSRs and gas hydrates are increasingly found in the marine realm, the LHR discovery has raised an interesting conceptual problem concerning the origin of gas hydrates.

For gas hydrate or free gas to form in deep-sea sediment, sufficient quantities of gas are needed to saturate pore water [*Dickens et al.*, 1997]. Such conditions are satisfied by processes in two general ocean areas [*Kvenvolden*, 1993]. The first, extreme methanogenesis, occurs in regions of high organic matter input. The second, gas transport, occurs in sediment columns along continental margins with significant upward fluid flow. Gornitz and Fung [1994] have considered these factors and used best estimate values for productivity and fluid flow to model global gas hydrate distribution. Although this exercise remains speculative, all known occurrences of marine gas hydrate except those on the LHR exist in predicted areas [*cf. Kvenvolden*, 1993]. The BSR and apparent gas hydrates on the LHR are of special interest to the geophysical community because they challenge current thinking. How can abundant gas occur in an open-ocean location beneath low surface water productivity? Alternatively, how can we confidently detect gas hydrate if BSRs at appropriate pressure/temperature conditions represent phenomena other than hydrate?

New results from the LHR suggest a plausible answer for the BSR that involves an unusual tectonic history for the region.

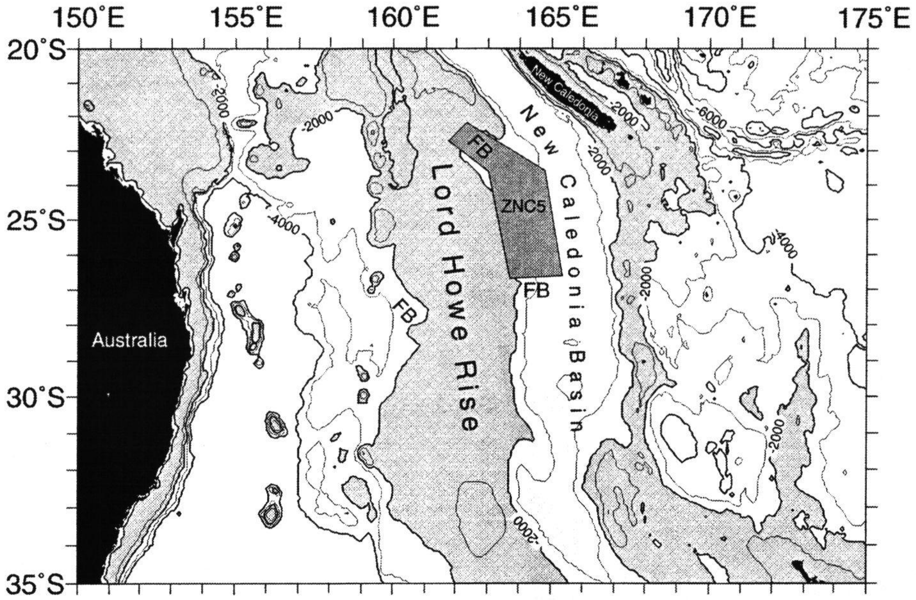

Fig. 1. The southwest Pacific showing the area of the Lord Howe Rise mapped by the ZoNéCo 5 (ZNC5) cruise (gray). FB: Fairway Basin.

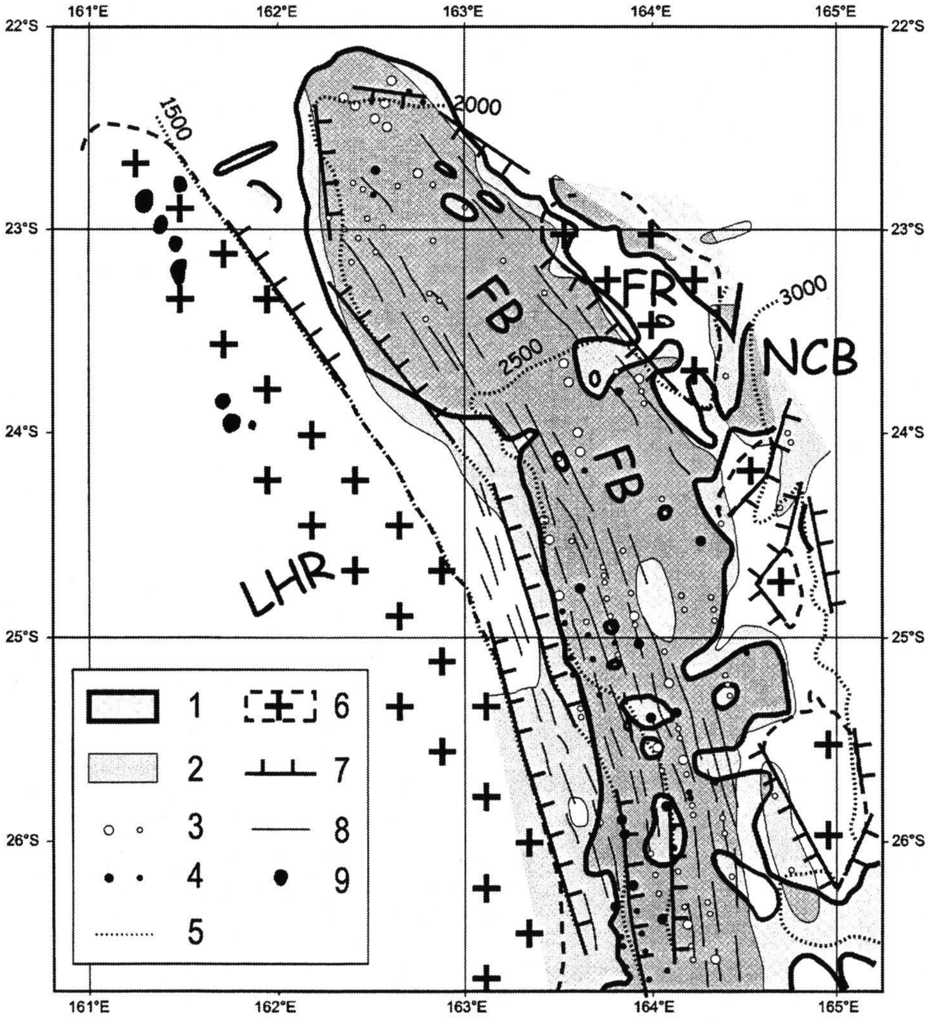

Fig. 2. Map showing spatial relationships between structure, salt/mud diapirs, and the BSR. 1) Area with BSR; 2) Area with salt/mud layers; 3) Large and narrow buried domes; 4) large and narrow shallow domes; 5) bathymetrical contours (interval, 500 m); 6) basement; 7) fault affecting the basement; 8) fault within the sedimentary cover and reaching the surface; 9) volcanic domes. LHR: Lord Howe Rise; FB: Fairway Basin; FR: Fairway Ridge; NCB: New Caledonia Basin.

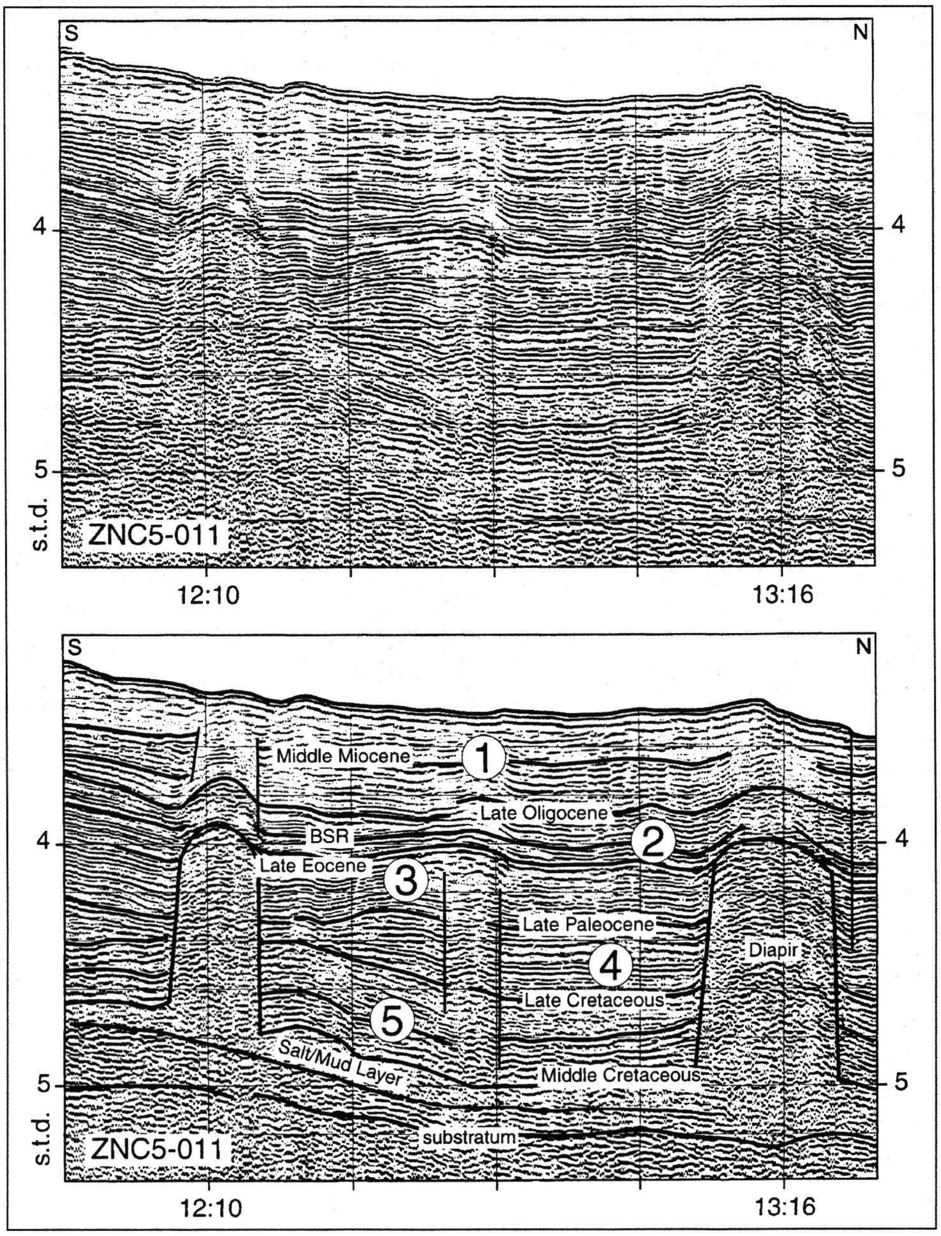

Fig. 3. Seismic profile across the Fairway Basin showing relationships between diapirs and BSR. On the basis of seismic characteristics and sediment at DSDP Site 208, the sedimentary sequence is probably: 1) Late Oligocene to present day; 2) Late Eocene to Late Oligocene; 3) Late Paleocene to Late Eocene; 4) Late Cretaceous to Late Paleocene; 5) Lower to Late Cretaceous.

Within the framework of the ZoNéCo program devoted to studying marine resources in the New Caledonia Exclusive Economic Zone (EEZ), French and Australian scientists recently carried out an extensive bathymetric and geophysical survey of the northeast Lord Howe Rise on the Ifremer research vessel *L'Atalante* (October 14–November 7, 1999). The approximately 100,000 km^2 covered by the survey lies between 22°S and 27°S and 162°30E and 165°30E, and in the Fairway Basin region between the New Caledonia Basin to the east and the Lord Howe Rise summit to the west (Figure 1). Because previously collected seismic profiles provided limited constraints on BSR dimensions or possible explanations for gas accumulation, a significant portion of the ZoNéCo 5 cruise was dedicated to mapping the BSR and searching for unusual tectonic or sedimentary features. The combined use of multibeam echosounding (swath mapping), side-scan imaging, six-channel seismic reflection profiling, and 3.5 kHz subbottom profiling allowed the first detailed investigation of this vast but largely unexplored region.

Results from ZoNéCo 5 highlight the intriguing nature of the eastern LHR as a geophysical oddity and possible frontier hydrocarbon province with gas hydrate. Seismic profiles show a large north-south basin, the southern extension of the Fairway Basin, filled with several seconds of sediment (perhaps to 5 km in places) and separated from the New Caledonia Basin by a discontinuous series of steeply rising basement massifs (Figure 2). Although available evidence suggests much of the region is extremely thin continental crust detached from Australia during Mesozoic rifting [*Hayes and Ringis*, 1973; *Gaina et al.*, 1998], the composition of basement in this region is unclear. The tectonic evolution of the Fairway Basin is further complicated because the crest of the eastern LHR has been truncated. Seismic ties to the stratigraphic section at DSDP Sites 208 and 588 (albeit not straightforward) indicate Oligocene to present-day sediment overlying basement on the crest of the LHR. Thus, early Paleogene sediment on the LHR was removed, perhaps through Eocene uplift and subaerial exposure [*Van de Beuque et al.*, 1998], or was never deposited at deep depth. Eocene compression undoubtedly occurred north and east of the region [*Lafoy et al.*, 1994].

ZoNéCo 5 discovered nearly 100 large (5–15 km across) diapirs in the north-central part of the Fairway Basin (Figure 2). The diapirs are sourced from a homogeneous sediment layer at about 2–2.5 s twt below seafloor and rise vertically through overlying sediment (Figure 3). Individual domes often rise to within 0.5 s twt of the seafloor, and, in a few cases, coalesce into elongated ridges (up to 50 km). Some diapirs are associated with deep faults affecting basement. On the basis of seismic characterization [*Van de Beuque et al.*, 1998], general regional history, and information from Site 208, sediment began filling the Fairway Basin in the Middle Cretaceous. Deep diapirs of salt have been described in margin settings, such as the north Atlantic rim and Mediterranean [*Pautot et al.*, 1970]. The diapirs of the Fairway Basin may come from Middle Cretaceous salt deposited during early stages of rifting along the eastern Australian margin. However, with available information, the diapirs could be composed of mud.

ZoNéCo 5 mapped the BSR over about 70,000 km^2 within French marine jurisdiction, making it one of the most extensive BSRs known [*cf. Kvenvolden*, 1993]. In broad terms, the BSR is restricted to the Fairway Basin in areas with diapirs. Over several diapirs, there is a complex relationship between the BSR and seafloor structure, where the BSR shoals and the seafloor have a pockmark (Figure 3). Where this relationship has been observed elsewhere, it signifies upward movement of warm CH_4-charged water through gas hydrate layers along faults and subsequent gas venting on the seafloor. Indeed, a surprising find by ZoNéCo 5 was the rough topography and extensive faulting in the Fairway Basin (Figure 3), a supposedly inactive region of the ocean.

The faults sometimes extend to the seafloor with scarps exceeding 5 m of relief. The area of diapirs and faulting in the Fairway Basin generally coincides with the region of BSRs (Figure 2), suggesting a connection between the phenomena. On the basis of the ZoNéCo 5 data, a plausible explanation for the BSR is: 1) thermogenic gas is generated in the basin with burial of Cretaceous shallow marine (or terrestrial) sediment followed by Eocene compression; 2) gas hydrate forms at shallow depth through upward flow of hydrocarbons along diapirs; and 3) some gas escapes to the seafloor in areas with faulting and pockmarks. Thus, the emplacement and evolution of gas hydrates in the Fairway Basin would be analogous to that in other regions with significant thermogenic gas, diapir-related flow, and hydrocarbon seepage, notably the Gulf of Mexico [e.g., *Kennecutt and Brooks*, 1990]. Current thinking on gas hydrate and petroleum resource distribution will have to consider large continental rift basins in open-ocean locations.

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Coastal Sedimentary Research Examines Critical Issues of National and Global Priority

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An international conference was held recently in Honolulu, Hawaii, to examine and plan for coastal sedimentary research in the United States and globally. Participants agreed that sedimentary coastal environments constitute a critical national and global resource that suffers widespread degradation due to human impacts. Moreover, human population growth and inappropriate development in the coastal zone are escalating public asset losses due to coastal hazards and placing large numbers of communities at growing risk (Figure 1).

Consensus was reached on a number of specific scientific priorities, which include better correlation of local relative Holocene sea-level histories, identifying mass balance in littoral sediments, extending the instrumental record with sedimentary archives, understanding the "biolithology" of carbonate reefs on the meter scale, tracking geochemical flux through coastal waters and substrates, and placing more emphasis on why coastal variability exists rather than simply characterizing it. With the understanding that coastal environmental change is a critical national and international research priority, the participants agreed that an international workshop on coastal forecasting should be convened to define a vision for the future of coastal sedimentary research and identify critical areas of enhanced investigation within a research framework.

The Crowded Coast

The U.S. coastal zone is one of the nation's greatest environmental and economic assets [*Ocean Studies Board*, 1999]. A national migration toward coastal towns and villages occurred in the last half of the 20th century and continues today, and now over 80% of the American population lives within 50 miles of the coast. By 2010 population density along ocean shores will be 400 people per square mile compared to less than 100 per square mile for the rest of the nation. Fourteen of the country's 20 largest urban corridors are along the nation's coast and a major portion of U.S. economic infrastructure is near or on the ocean. Globally, the figures in these categories are similar. Over 50%—some 3.2 billion people—live along a coastline today, but this figure is expected to rise to 75% by 2025 [*Hinrichsen*, 1999].

This burgeoning population depends on limited natural resources. Overfishing, mineral depletion, sewage disposal, aquifer deficiencies, vulnerability to coastal hazards, and beach and wetland loss are critical issues throughout the nation and the world. The natural health of the coastal environment is endangered and is a focal point for federal and local policy development. In truth, however, many management policies do not provide adequate solutions, often because they lack a scientific basis.

We live in a time of sea-level highstand with accelerated rises projected ahead. Environmental change—gradual, rapid, and catastrophic—is an integral feature of high sea levels. To understand the history and processes driving coastal environmental changes, research on a range of spatial and temporal scales is needed. High-resolution geologic records of coastal change can extend the instrumental record to the recent past, and former intervals of sea-level highstand can help us understand the present.

Coastal sedimentary research is highly relevant to understanding coastal environments. Most coastal ecosystems depend upon sedimentary substrates and sedimentary transport processes for critical nutrient flux and trophic energy. Sedimentary processes are typically non-linear and highly complex, and hence they are easily disrupted. Our understanding of the structure and function of sediment-dependent environments (that is, reefs, wetlands, estuaries, beaches, etc.) is improving but remains inadequate. The ability to forecast coastal environmental change can be improved with focused research.

No Sponsor for the Academic Community

The academic core of the U.S. coastal sedimentary research community has suffered from a lack of planning for its scientific future. The field has long been characterized by individual research efforts, but there are few unified and system-level research products that cross disciplinary lines. Major aspects of how and why coastal sedimentary processes interact across spatial and temporal scales remain unknown. With the exception of a small number of research efforts (e.g., the National Science Foundation's [NSF] Land Margin Ecosystem Research Program), there is a lack of significant progress in understanding the linkages and interrelationships among and between shoreline environments.

This situation is now hindering research funding. For instance, within NSF, coastal sedimentary research is left without a clear proponent in either the Earth or Oceans directorates [*FUMAGES*, 1998]. Within the National Oceanic and Atmospheric Administration, the Federal Emergency Management Administration and, to some extent, the Environmental Protection Agency and NASA, funding is available for spatial and temporal analysis of coastal trends, but these efforts typically focus on what environmental tendencies occur and often do not answer why or how coastal change happens.