EOS

Research in Great Australian Bight Yields Exciting Early Results

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Confirmation that Pleistocene mound features underlying the outer shelf and shelf edge are bryozoan buildups—effectively cool-water reefs—was one of several exciting discoveries during recent research earlier this year on the Great Australian Bight. Also found on Ocean Drilling Program (ODP) Leg 182 was startling evidence of high salinity fluid circulation within the shelf substrate, producing extremely high methane and hydrogen sulfide gas levels and accelerated diagenesis.

In addition, an expanded middle Eocene to early Oligocene record of Southern Ocean initiation was recovered by the shipboard scientific party, aboard the *JOIDES Resolution*. The group also calculated unexpectedly high rates of shelf edge cool-water carbonate accumulation (up to 40 cm/kyr).

Leg 182 drilling (see Figure 1) of the Cenozoic cool-water carbonate platforms of the Great Australian Bight sought to answer fundamental questions about development of the circum-Antarctic Current (CAC) and evolution of the Southern Ocean during the opening of the Tasman Gateway and about Southern Ocean sea level fluctuations and their effect on stratigraphic packaging and early diagenesis of cool-water carbonates. Other issues pursued were cool-water carbonate platform facies distributions and accumulation dynamics; fluid circulation, fluid geochemistry, and diagenetic processes in the platforms; and patterns and modes of speciation and diversification of Cenozoic cool-water calcareous biota.

The research is one of the few ODP legs dedicated to understanding continental margin sedimentary geology and should provide an important contrast to the terrigenous-dominated New Jersey margin (Legs 150, 174A). It is also one of the few legs dedicated to drilling in a pure carbonate depositional system and should invite interesting comparisons to the northeast Australian margin-Great Barrier Reef (Leg 133), the western Bahama Banks (Leg 166), and the atolls and guyots drilling (Legs 143, 144). The work should provide new

insights into the depositional dynamics controlling cool-water and nontropical carbonate sedimentation and may reveal how important and common such depositional systems were in the geologic past.

The Great Australian Bight is a carbonate-dominated, passive continental margin that formed during the protracted period of extension and rifting that led to the separation of Australia and Antarctica in the Cretaceous and evolved during the subsequent northwards drift of the Australian continent. The onset of faster spreading in the middle Eocene corresponded with establishment of fully marine conditions and initiation of carbonate sedimentation in the widening "gulf" between Australia and Antarctica. Carbonate sedimentation continued throughout the remainder

of the Cenozoic, as the gulf evolved first into a broad, open seaway and then into the modern Southern Ocean.

With a long-term, persistent arid climate in central Australia and a topographically low-lying hinterland, few rivers existed capable of discharging terrigenous sediments onto the margin. Instead, a relatively thin (~1 km) succession of six Eocene to Quaternary sequences consisting of cool-water carbonate sedimentary facies were deposited (Figure 2), overlying a basal siliciclastic sequence. The present margin supports the Eucla Shelf, a 2500-km-long, 150-200-km-wide depositional system, on top of which exists the world's largest province of modern cool-water carbonate sediments, dominated by a mixture of bryozoa, foraminifer, mollusc, and tunicate material [*James*, 1997].

Paleoceanography a Beneficiary

The Leg 182 sites are the only ODP drillholes in the Southern Ocean between Australia and Antarctica—the Australian-
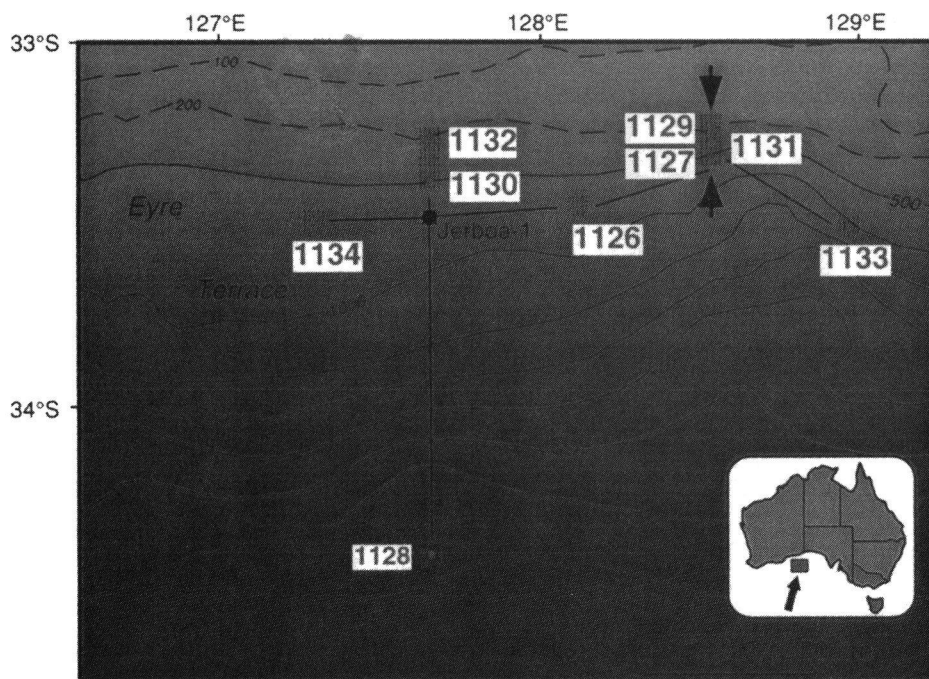

Fig. 1. Location map of the Eucla Shelf, Great Australian Bight, showing Leg 182 drill sites in relation to the seismic site survey grids. Jerboa-1 is a 1980-vintage hydrocarbon exploration drill hole. Location of the seismic transect shown in Figure 3 is marked by arrows. Original color image appears at the back of this volume.
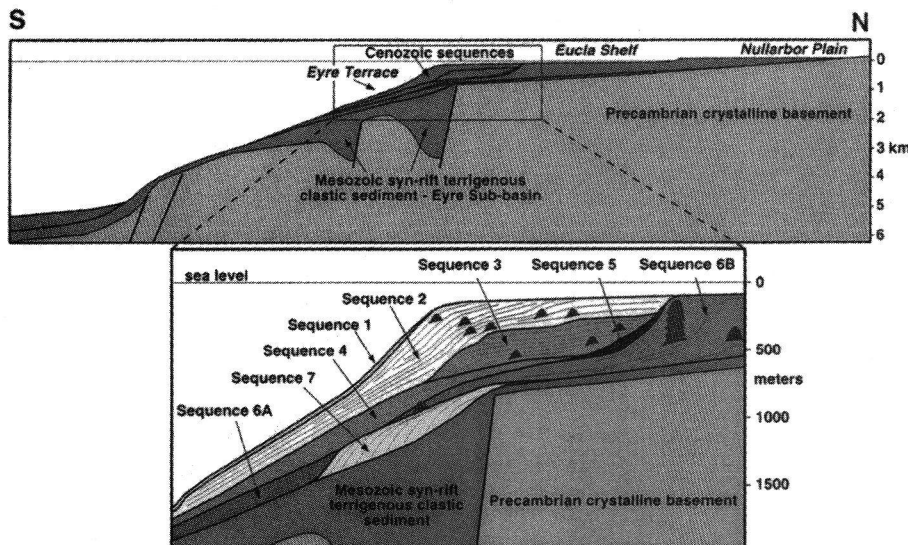
Fig. 2. Schematic cross section across the Great Australian Bight margin showing the distribution of Cenozoic seismic sequences. All but Sequence 7 are cool-water carbonates. Original color image appears at the back of this volume.

Antarctic Seaway. A beneficiary is paleoceanography. Sediments recovered during this leg provide an excellent opportunity to understand the record of Southern Ocean widening in this area, and the progression and timing of events associated with the establishment of through-flowing surface and deep waters. Although post-cruise research remains, several scientific results were clear from initial shipboard analysis.

Establishment of surface and deep-water circulation in the seaway were important events that contributed to the isolation and cooling of Antarctica and provided the setting for Antarctic continental glaciation and the Eocene-Oligocene climate transition [*Kennett*, 1977]. The opening of the seaway and establishment of the CAC resulted in the initial formation of sea-ice surrounding Antarctica, ventilation of the global deep ocean, and a dramatic deepening of the carbonate compensation depth (CCD) during the late Eocene to early Oligocene.

At Site 1128, a deepwater site 3874 m below sea level, lower Paleogene siliciclastic-dominated sediments (green, sandy siltstones to claystones) are overlain by upper Paleogene and Neogene carbonate-dominated sediments (nannofossil-foraminiferal oozes). Low carbonate concentrations (0.1 to 12.6 wt.% $CaCO_3$) suggest that the lower Paleogene sediments were deposited below a fluctuating CCD.

The transition from dominantly siliciclastic to constant and significant carbonate accumulation (>20 wt.% $CaCO_3$) occurred during the late Eocene (ca. 36 Ma) at Site 1128. Intermediate-water sites illustrate the transition from early postrift marine sandstones to carbonates deposited during the middle Eocene. The late Eocene increase in deep-sea carbonate sedimentation is evidence for an increase in bottom-water ventilation, perhaps as a result of the establishment of surface-water

connections across the South Tasman Rise producing high-latitude cooling and sea ice formation.

A 20-m-thick nannofossil chalk bed is found in the lowermost Oligocene. Based on magnetostratigraphic data, the chalk bed coincides with Chron C13n (33.058-33.545 Ma) and may reflect temporary deepening of the lysocline in this area, perhaps in response to deepwater ventilation and Antarctic glaciation coinciding with a positive $\delta^{18}O$ shift designated Oi1 [*Miller et al.*, 1991; *Zachos et al.*, 1996].

The transition back to calcareous clays at the top of C13n suggests a return to more sluggish deepwater circulation until Chron C10n2n (28.745 Ma), when carbonate became dominant again. This final transition occurs at ~90 m below the seafloor (mbsf) and may reflect increased ventilation associated with the establishment of the CAC as the Tasman Gateway continued to widen and deepen.

Quaternary Sediment Wedge

The shelf edge to upper slope in the Great Australian Bight is distinguished by a spectacular succession of prograding clinoforms forming an unusually thick sediment wedge of mostly Quaternary age (Figure 3) overlying a pronounced sequence boundary. Sites 1127, 1129, and 1131 (Figure 1) form a closely spaced depth transect across the wedge.

Biostratigraphic analyses indicate that the hiatus represented by the basal sequence boundary lasted from 7 to 12 million years extending back to the middle Miocene. More astonishing, the Pleistocene thickness exceeds 550 m, indicating average accumulation rates of over 300 m/Myr through this time period. For shorter periods of time, accumulation rates exceeded 40 cm/kyr, which rival the fastest rates known in shallow-water tropical carbonate depositional

systems [*James*, 1997] and are twice the rates of modern Bahamian slope sedimentation. Sediments constituting this slope wedge are bioturbated muds and very fine, sand-sized skeletal grains produced on the adjacent shelf. Seismic, downhole logging, and mineralogic data suggest that the wedge is packaged in cycles most likely responding to astronomically forced sea level fluctuations.

These data and observations invite a number of questions. Why is the Pleistocene so productive compared to other periods of time? What is the method and timing of such efficient offshelf sediment transport? How are the cycles packaged lithologically and what role did sea level fluctuations play in packaging them? How is the extensive erosion of the upper slope turned on and off?

Bryozoan Mounds

The transition zone from proximal, coarse-grained, bryozoan-rich shelf sediments [*James et al.*, 1994] to distal, fine-grained, biofragmental muds of the prograding Neogene wedge is marked by the presence of biogenic mounds. The mounds, observed on seismic images (Figure 3) [*Feary and James*, 1998] in water depths of ~200-350 m across the western Great Australian Bight, are oval- to ridge-shaped in plan view and have depositional relief of ~20 m. They range from isolated buildups in deep water to mound complexes stratigraphically separated by intervals of evenly bedded sediment in shallow water.

Coring of these unlithified structures confirms that they are constructed primarily by a diverse suite of bryozoans, mostly delicate branching, flat robust branching, fenestrate, and arborescent growth forms [see *Bone and James*, 1993]. The sediment has a floatstone to rudstone depositional texture with a burrowed, fine-grained, muddy matrix rich in benthic and planktonic foraminifers, fecal pellets, bioclasts, bryozoan fragments, echinoid spines, tunicate spicules, sponge spicules, and calcareous nannofossils.

None of the mounds is currently growing, and the most recent are veneered with an ~7-m-thick layer of muddy skeletal sand. The stratigraphically youngest mounds are inferred to have grown during isotope stage 2 (~17-22 ka) when the Leeuwin Current (a warm-water current that flows southward along the western Australian coast during interglacials) was not flowing, and upwelling was prevalent along the southern continental margin.

It seems that upwelling during this glacial period resulted in increased nutrient supply and proliferation of bryozoans and reef-mound building. Such an explanation is supported by the presence, within the mounds, of benthic foraminifers that characterize such nutrient-rich environments. If this interpretation is correct, then the series of stacked mound complexes and intervening units of evenly bedded sediment at the shallowest
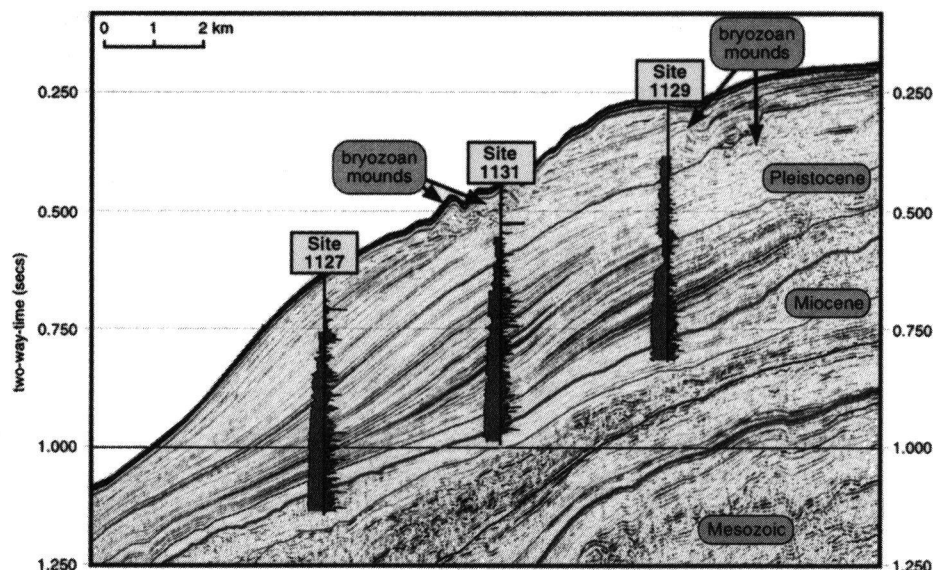
Fig. 3. Seismic line illustrating the spectacular prograding clinoforms and bryozoan mounds comprising Sequence 2, entirely of Pleistocene age indicating very high accumulation rates. Sites 1129, 1127, 1131 are shown with sonic (red) and gamma (green) downhole logs. Original color image appears at the back of this volume.

sites represent a superb record of the interaction between oceanographic changes and reef-mound growth.

The significance of these features also lies in their connection to the older rock record. Subphotic biogenic reefs and mounds rich in bryozoans are common features of Mesozoic and especially Paleozoic carbonate facies, especially within slope paleoenvironments [*James and Bourque*, 1992; *Monty et al.*, 1995]. The features cored in the Great Australian Bight are similar in geometry, scale, and general composition to these older structures known from the rock record, with the main difference being that the modern examples lack intensive synsedimentary lithification. Although bryozoan-rich mounds have been recorded from rocks as young as early Paleocene [*Surlyk*, 1997], such structures were previously unknown from the "modern" ocean. Thus these late Quaternary buildups are the first examples of these long-lived reef types to be found in their original depositional setting.

Presence of Brine

Another significant discovery during Great Australian Bight drilling was the presence of a brine, varying in salinity between 80 and 105, at seven sites (the exceptions being Sites 1128 and 1133). The brine occurred at relatively shallow depths in the deeper water sites (1134 and 1126), while at the shallow water sites (1127, 1129, 1130, 1131, and 1132) maximum salinity was not encountered until below 400 mbsf. A contour map of the distribution of Cl at three sites (1127, 1131, and 1129), which form a transect from deep to shallow water, is shown in Figure 4. This salinity distribution indicates that there is a broadly flat-lying fluid body underlying the outer shelf and upper slope.

Pore fluids in the Pleistocene portion of the sediments from these sites possess a Na^+/Cl^- ratio in excess of that of seawater, suggesting that these fluids had been involved in the dissolution of NaCl. Although the origin of the saline fluids has not yet been established, a probable explanation is that they formed during Pleistocene lowstands within extensive evaporative ponds on the broad Eucla Shelf.

Our speculation is that such evaporative basins must have been periodically recharged by seawater to produce the high salinity observed. If this explanation is correct, the

substrate of the Eucla Shelf represents a superb example of a fluid circulation system driven by sea level fluctuations.

High concentrations of hydrogen sulfide (H_2S), methane, and high values of alkalinity are also a result of the saline pore fluids. The high concentrations of H_2S and alkalinity are derived from the oxidation of organic material by sulfate-reducing bacteria. The absence of terrigenous sediment input along this margin has resulted in low iron concentrations within the carbonate sediments, with the result that H_2S is not sequestered as iron sulfides. Consequently, H_2S concentrations are able to reach very high levels, in excess of 150,000 ppm at Site 1129—the highest measured on any ODP leg.

As a result of the high rate of sedimentation being located close to the continental shelf edge, these sites contained an initial high concentration of organic material. Under normal conditions, the organic material would be oxidized first by oxygen and then by sulfate-utilizing bacteria, thereby creating alkalinity and H_2S. Although this process also takes place on the Eucla margin, the high salinity brines underlying and within the Pleistocene succession provide up to three times the normal sulfate concentrations, so that the abundant organic material is able to produce large amounts of H_2S.

One of the consequences of the high concentrations of H_2S and alkalinity is the accelerated rate of diagenesis observed. Extremely high concentrations of CH_4 also were observed for shallow-water carbonates (~730,000 ppm), but overall this is probably not globally significant with respect to potential greenhouse gas contributions to the atmosphere.
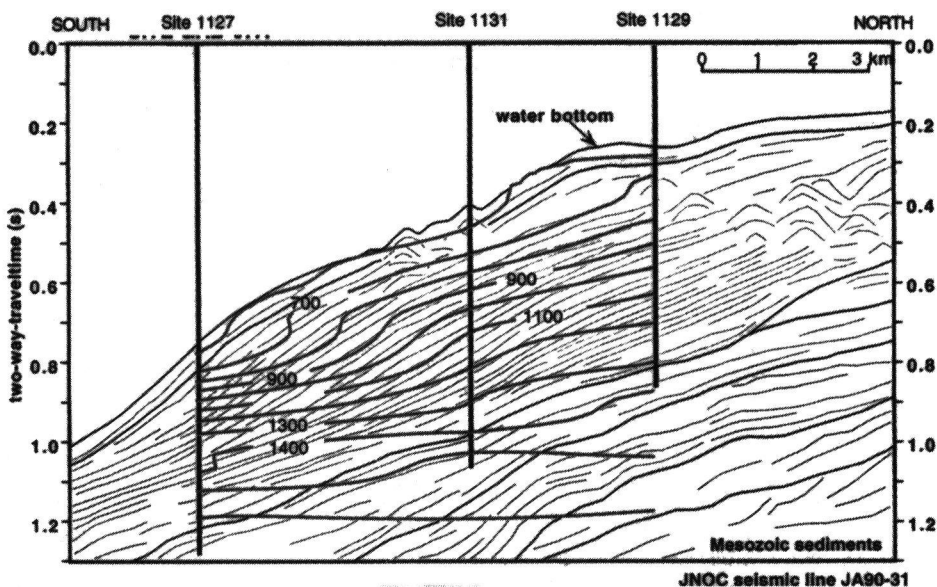

Fig. 4. Contour map of Cl concentration at Sites 1127, 1131, and 1129 depth transect overlying the interpretation of the seismic line. Note that the concentrations of equal Cl concentration cross cut the seismic sequences and appear to originate from a subhorizontal brine. Original color image appears at the back of this volume.

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References

Bone, Y., and N. P. James, Bryozoans as carbonate sediment producers on the cool-water Lacepede Shelf, southern Australia, *Sediment. Geol., 86*, 247-271, 1993.

Feary, D. A., and N. P. James, Seismic stratigraphy and geological evolution of the Cenozoic, cool-water Eucla Platform, Great Australia Bight, *AAPG Bull., 23*, 427-430, 1998.

James, N. P., The cool-water carbonate depositional realm, in *Cool-water carbonates*, SEPM Spec. Pub. No. 56, edited by N. P. James and A. D. Clarke, pp. 1-20, Society for Sedimentary Geology, Tulsa, Okla., 1997.

James, N. P., and P.-A. Bourque, Reefs and mounds, in *Facies models: response to sea level change*, edited by R. G. Walker and N. P. James, pp. 323-347, Geological Association of Canada, St. John's, Newfoundland, 1992.

James, N. P., T. D. Boreen, Y. Bone, and D. A. Feary, Holocene carbonate sedimentation on the west Eucla shelf, Great Australian Bight: a shaved shelf, *Sedimentology, 90*, 161-178, 1994.

Kennett, J. P., Cenozoic evolution of Antarctic glaciation, the circum-Antarctic Ocean, and their impact on global paleoceanography, *J. Geophys. Res., 82*, 3843-3859, 1977.

Miller, K., J. D. Wright, and R. G. Fairbanks, Unlocking the ice house: Oligocene-Miocene oxygen isotopes, eustacy, and margin erosion, *J. Geophys. Res., 96*, 6829-6848, 1991.

Monty, C. L. V., D. W. J. Bosence, P. H. Bridges, and B. R. Pratt (Eds.), *Carbonate mud-mounds: Their origin and evolution*, International Association of Sedimentologists Spec. Pub No. 23, 537 pp., Blackwell Sci., Cambridge, Mass., 1995.

Surlyk, F., A cool-water carbonate ramp with bryozoan mounds: Late Cretaceous-Danian of the Danish basin, in *Cool-water carbonates*, SEPM Spec. Pub. No. 56, edited by N. P. James and A. D. Clarke, pp. 293-308, Society for Sedimentary Geology, Tulsa, Okla., 1997.

Zachos, J. C., T. M. Quinn, and K. A. Salamy, High-resolution (104 years) deep-sea foraminiferal stable isotope records of the Eocene-Oligocene climate transition, *Paleoceanography, 11*, 251-266, 1996.

U.S. State Department Urged to Beef Up Science Component

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The U.S. State Department often comes under pressure to respond to a variety of international emergencies one after another, from the U.S. embassy bombings in Kenya and Tanzania to Hurricane Mitch in Central America to the crisis in Kosovo.

Many of the department's priorities include significant science, technology, and health (STH) components: nuclear nonproliferation, global climate change, protecting scientific databases, and international food and water supply safety, including arsenic in drinking water wells in Bangladesh, among other varied issues.

The department, however, provides inadequate attention and resources to STH issues at a time when these concerns are becoming ever more significant in foreign policy, according to a new report by the U.S. National Research Council (NRC) of the National Academy of Sciences (NAS).

The department is not taking advantage of the nation's strength in STH and is late to the bargaining table on some issues, such as intellectual property rights, according to "The Pervasive Role of Science, Technology, and Health in Foreign Policy: Imperatives for the Department of State," a report by the NRC Committee on Science, Technology, and Health Aspects of the Foreign Policy Agenda of the United States.

The report, which the State Department requested and has indicated it will study, urges the department to continuously integrate STH into the nation's foreign policy agenda, and provides specific recommendations for increasing an STH presence within the department.

"It has been observed for some time that STH competence in the department has been going down, despite the fact that the world has become more STH-intensive," said committee chair Robert Frosch, at an October 7 briefing in Washington, D.C. Frosch is a former NASA administrator and current associate in science and international affairs at Harvard University's John F. Kennedy School of Government.

"Greater attention should be paid to STH because it is a major [national] asset, and more competence is required to do that," he said. "This is a STH strong and concentrated country. We are working these issues globally both individually, privately, and as a nation, and we are not using that capability enough in foreign policy. The goal should be to have the State Department aware of this at all levels and posts, and staffed and working on the problem continuously. The outside STH community in and out of government would like to help the department do this."

To underscore the pervasiveness of STH issues within the State Department, the committee examined the department's 1999 document, "U.S. Strategic Plan for International Affairs," and found that 13 of 16 objectives listed there include significant STH content. The committee also found 56 examples of country or region-specific STH-related issues, including use of water resources in the Middle East, oil exploration in Nigeria, and waste disposal in Mexico.

While the State Department has been able to produce major efforts in technical areas such as nonproliferation and a number of environmental issues, the report found that insufficient attention is given to other issues such as health, non-nuclear energy, and globalization of industrial technologies.

"These issues are forcing their way for attention not only in the executive branch, but in the legislative branch. Every day, the news brings some new headline of a science or health issue that requires national attention," said NRC Committee Member David Newsom, former undersecretary for political affairs at the State Department. "If the State Department can structure itself so it is competent to report and anticipate STH positions that are going to be problems for the U.S., Congress is going to be responsive and interested as well," he said.

Among the recommendations the committee calls for the State Department to act upon:

• Designate an undersecretary of state to provide leadership and coordination for STH-related issues.

• Establish an external science and technology advisory committee.

• Encourage U.S. Secretary of State Madeleine Albright to establish a policy that gives greater attention to STH dimensions of foreign policy.

• Make better use of the capability of other technically competent U.S. departments and agencies some maintain international relationships and mission responsibilities in global issues such as the oceans, or in specific issues such as regional geology, water, or health—and encourage the State Department to transfer responsibility for some international STH activities to other federal agencies. The report suggests, for example, that the National Oceanic and Atmospheric Administration could manage the preparation of paperwork for research ship clearance requests, and that the National Science Foundation could expand its role in managing activities of bilateral U.S.-Israeli foundations.

"The practice has been for State to take total policy responsibility for these areas, even though other departments frequently are on the ground and carrying it out," said Frosch. "This has become a significant burden on the department."

• Allocate adequate resources to support the report's recommendations. An advisory committee could cost $500,000 per year, according to the report. Other costs could include staffing and upgrading science positions—including assigning 25 STH-competent
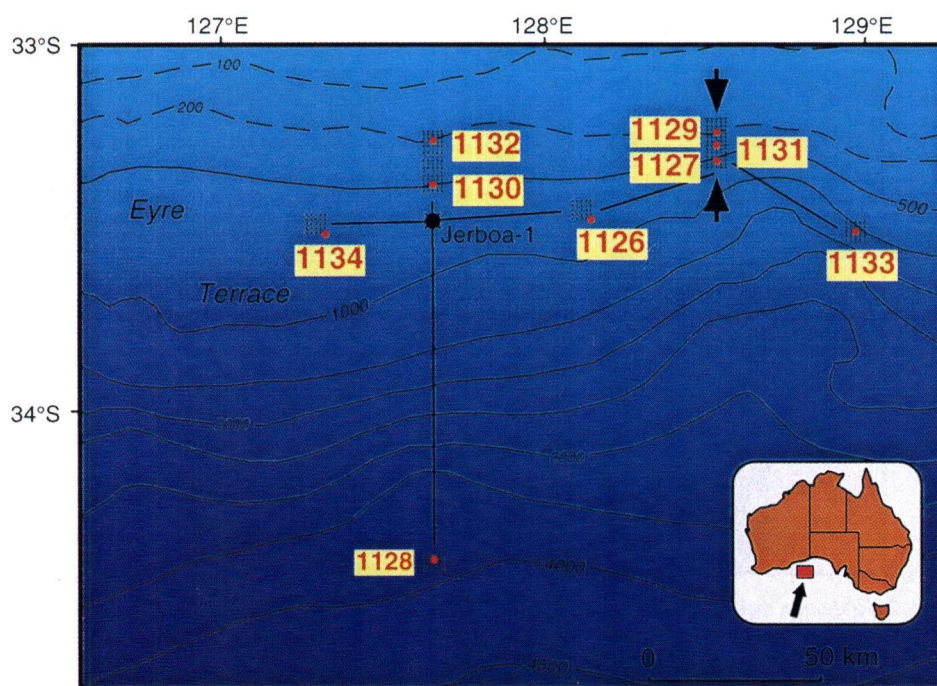
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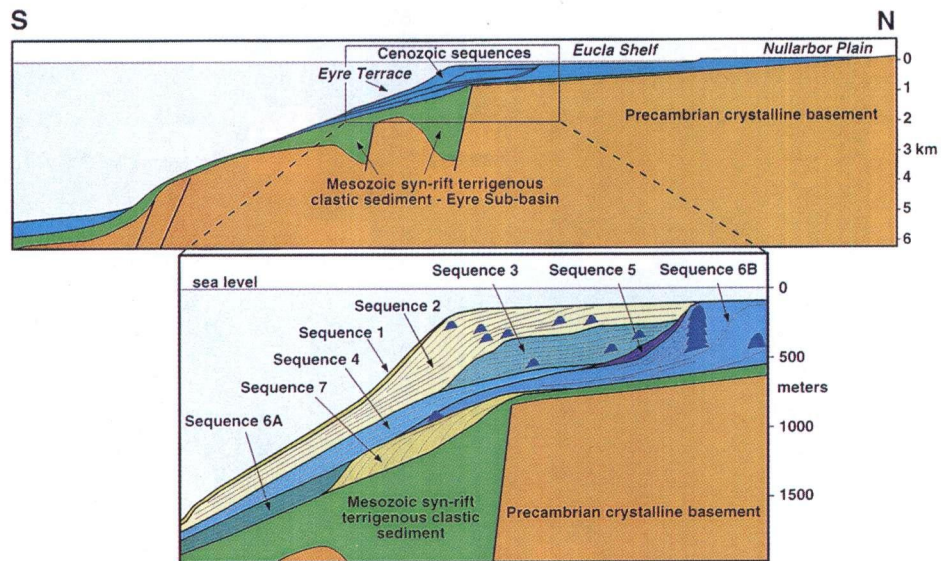
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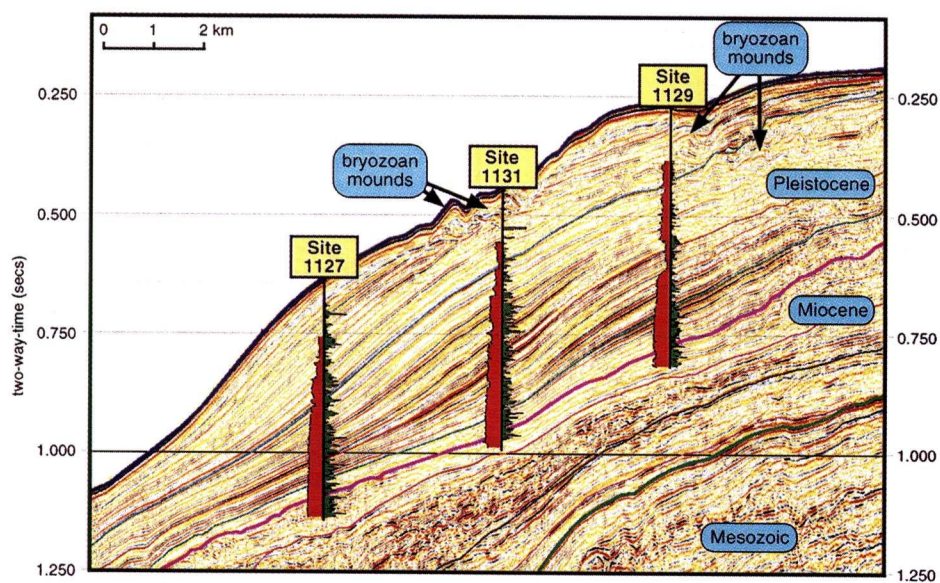
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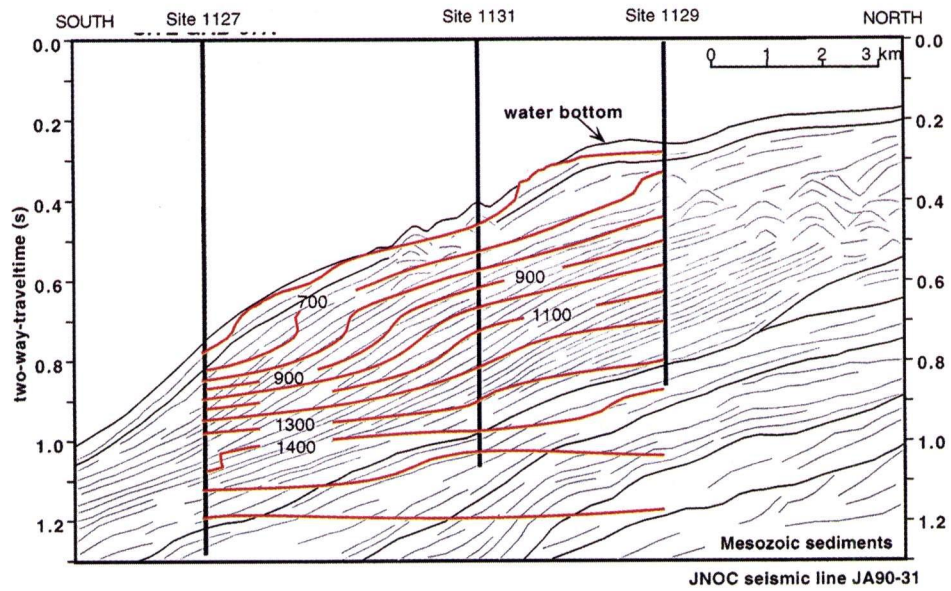
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