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Seismic Stratigraphy and Geological Evolution of the Cenozoic, Cool-Water Eucla Platform, Great Australian Bight[1]

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ABSTRACT

Seismic images of the continental margin in the western Great Australian Bight reveal the internal anatomy of a long-lived Cenozoic cool-water carbonate shelf. The Cenozoic succession is divisible into seven seismic sequences that reflect four depositional phases. Phase A (Paleocene–middle Eocene) is a progradational siliciclastic wedge deposited in a depositional sag, and represents lowstand and transgressive sedimentation. Phase B (middle Eocene–earliest middle Miocene) contains cool-water ramp carbonates with biogenic mounds (Eocene–Oligocene), overlain by a warm-water, flat-topped platform rimmed by the early middle Miocene(?) Little Barrier Reef. Coeval deep-water carbonate deposition formed a multi-lobed sediment apron. This phase was terminated by gentle uplift and tilting throughout southern Australia in the late middle Miocene. Phase C (late Miocene–early Pliocene) represents cool-water lowstand wedge and ramp deposition, and contains numerous biogenic mounds in the youngest sequence. This phase is terminated by an unconformity attributed to marine erosion. Phase D (Pliocene–Quaternary) is a thick succession of cool-water carbonates with spectacular clinoform ramp geometry that forms most of the modern outer shelf, and contains large deep-water biogenic mounds.

This platform, the first large cool-water carbonate shelf imaged by high-quality seismic reflection data, demonstrates the interaction between regional tectonic and local and global paleo-oceanographic processes. As Australia drifted northward during the Cenozoic, the Great Australian Bight moved from high to middle latitudes, and the regional oceanographic regime remained cool water largely because of coeval development of the Antarctic Circumpolar Current in the evolving Southern Ocean. Short episodes of warm-water deposition probably reflect incursions of a proto-Leeuwin current from the Indian Ocean, whereas growth of the Miocene coral-algal "Little Barrier Reef" resulted from a short-term global increase in sea-surface temperatures. This platform, dominated by stacked carbonate ramps, is most similar to the West Florida Shelf, but contains many more biogenic mounds. The western Great Australian Bight carbonate platform is an excellent modern analog for the mesoscale structure of cool-water platforms in the older geologic record.

INTRODUCTION

The geometry of carbonate platforms is determined by the nature and robustness of the carbonate sediment "factory," and by interactions between this factory and relative sea level fluctuations. Traditionally, most researchers have emphasized the response of carbonate platforms to sea level change as the major determinant of platform anatomy (e.g., Kendall and Schlager, 1981; Crevello et al., 1989; Loucks and Sarg, 1993). Researchers have placed considerably less emphasis on the effects of changes in the character of the carbonate production system.

Two major carbonate depositional realms apparently exist in the modern ocean; the warm-water tropical realm and the cool-water (<20°C) temperate realm (Lees and Buller, 1972). Both realms seem to have persisted throughout the Phanerozoic (James and Clarke, 1997). The warm-water realm is typified by carbonate platforms that are characteristically rimmed by reefs or skeletal sand shoals, have considerable relief above surrounding basins, contain extensive low-energy shallow subtidal facies,

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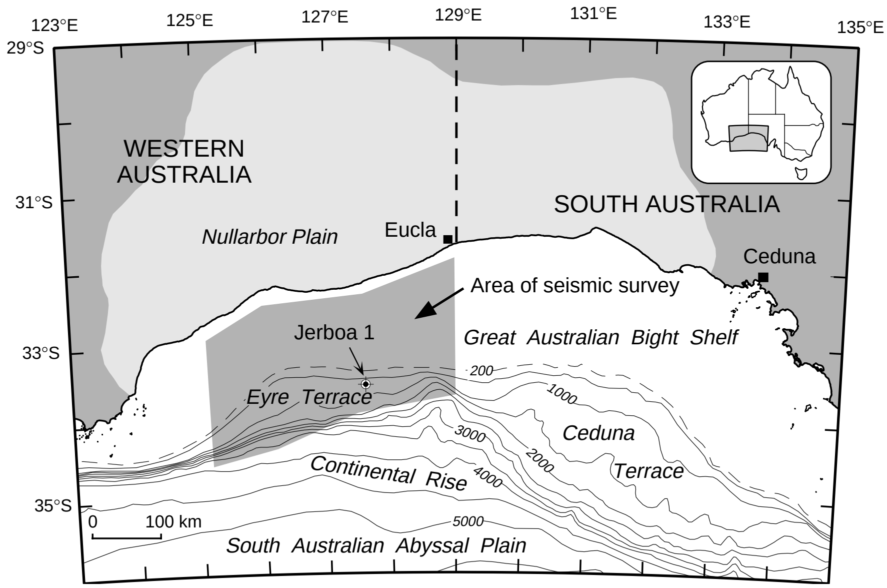


Figure 1—Bathymetric map of the Great Australian Bight (inset map shows location), with the offshore shaded zone showing the area of high-quality seismic data on which this analysis is based. Light shading onshore shows the extent of the Cenozoic Eucla basin, broadly corresponding to the modern Nullarbor Plain. The location of oil exploration drill hole Jerboa 1 is also shown. Bathymetric contours are in meters. Modified from Feary and James (1995).

and are flanked by extensive tidal flats (Wilson, 1975; Tucker and Wright, 1990; James and Kendall, 1992). These warm-water sediments are composed of a photozoan association (James, 1997) of light-dependent organisms and nonskeletal precipitates that have rapid production and accumulation rates. Ramps are present in this realm, but are not as common as rimmed platforms. By contrast, the cool-water realm is typified by open shelves and ramps, with generally high-energy facies in all inner to middle ramp and shelf settings, biogenic mounds only in slope or outer ramp environments, and considerable sediment transport into deep water (James, 1997). Sediments are derived from a heterozoan association of light-independent organisms that have comparatively low production and accumulation rates.

Modern warm-water carbonates have been well studied in the Florida-Bahama Banks, Persian Gulf, and Great Barrier Reef areas. Detailed seismic imagery of the Great Bahama Bank (e.g., Eberli and Ginsburg, 1989), the southwest Florida margin (e.g., Mullins et al., 1986; Brooks and Holmes, 1989), and the northeast Australia margin (e.g., Symonds et al., 1983; P. J. Davies et al., 1988, 1989) has revealed the internal structure of modern tropical platforms. These images are proving useful in interpreting older platforms formed in warm-water situations. By contrast, there are few published high-resolution seismic images of modern cool-water carbonates, and no previously published high-quality seismic reflection data from the largest temperate carbonate shelf in the modern world—the extensive carbonate platforms along the southern margin of Australia. The purpose of this paper is to illustrate the internal geometry of this cool-water shelf in the region of the western Great Australian Bight (GAB), to interpret the seismic stratigraphy in the context of onshore geology, and to compare this platform to other modern carbonate platforms.

There is little direct information about the subsurface of the western GAB shelf and slope. The Jerboa 1 exploration hole on the Eyre Terrace (Figure 1) penetrated a thin Cenozoic succession and recovered a condensed package of Mesozoic synrift rocks (Huebner, 1980). James and von der Borch (1991) used 1979-vintage seismic data to demonstrate that the southern Australian margin is a gentle incline made up of prograding clinoforms, apparently lacking reefal buildups. They inferred that clinoform reflector patterns resulted from off-shelf sediment transport of particulate carbonate sands, together with deep-water carbonate production dominated by bryozoan and sponge growth.

The analysis presented in this paper is based on the detailed seismic stratigraphic interpretation of a 2350 km grid of high-quality, regional two-dimensional (2-D) seismic reflection lines, collected and processed by the Japan National Oil Corporation (JNOC) in 1990 and 1991, over an area of 155,000 km^2 on the continental shelf and upper slope of the western GAB (Figure 2). An additional 1380 km of moderate-quality regional 2-D seismic lines, collected by Esso Australia in 1979 and reprocessed by JNOC, were also used to fill gaps in the JNOC data set (Figure 2). Thickness and depth estimates from two-way traveltime are based on seismic stacking velocities and on proprietary company interval velocity maps (JNOC, 1992).

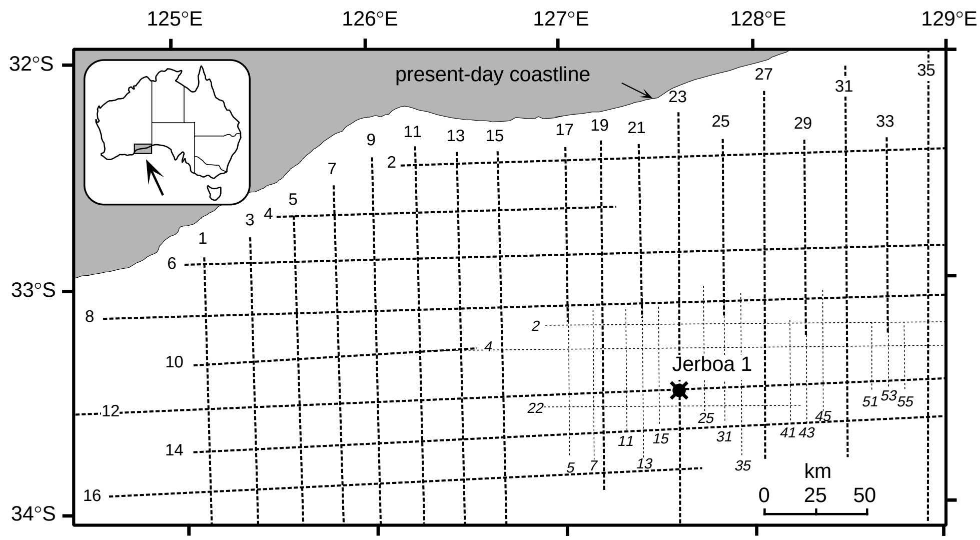


Figure 2—Track map showing the distribution of seismic lines on which this study is based. The heavier dashed lines are JNOC 1990 seismic lines, and the lighter dashed lines are older (1979) Esso seismic lines. The location of oil exploration drill hole Jerboa 1 is also shown.

GEOLOGICAL SETTING

Tectonic Framework

Southern Australia is a divergent, 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 northward drift of the Australian continent. Continental extension began in the Jurassic, followed by breakup in the middle Cretaceous (96 Ma) and slow spreading until the middle Eocene (49 Ma). Spreading accelerated in the middle Eocene (until 44.5 Ma), followed by faster spreading to the present (Veevers et al., 1990).

The initial extension phase prior to breakup, together with the following period of slow spreading, resulted in deep continental margin basins filled with up to 12 km of mainly terrigenous clastic sediment (Willcox et al., 1988; H. L. Davies et al., 1989). These basins broadly correspond to the sites of modern upper slope terraces (e.g., the Eyre Terrace at 400–1600 m depth in the western GAB; Figure 1). Cenozoic sedimentation resulted in an extensive, relatively thin (up to 800 m thick) Eucla basin succession deposited in a predominantly platform-sag to platform-edge tectonic regime (Stagg et al., 1990). Throughout the Cenozoic, the western GAB has been particularly stable, with geohistory analysis of exploration well Jerboa 1 indicating minimal Tertiary subsidence (Hegarty et al., 1988). Slight regional tilting (<1°) in the late middle Miocene resulted in uplift and exposure of the immense, arid, essentially featureless Nullarbor Plain adjacent to the GAB (Figure 1), and restriction of Neogene sedimentation to the modern outer shelf and upper slope.

Oceanographic Setting

Onset of faster sea-floor spreading in the middle Eocene also corresponded to establishment of fully marine conditions and initiation of carbonate sedimentation in the widening gulf between Australia and Antarctica. Carbonate sedimentation continued throughout the Cenozoic as the gulf evolved into a broad, open seaway, and then into the modern Southern Ocean. Oceanographic conditions in the GAB after the middle Eocene are likely to have been similar to modern conditions. The modern shelf is a broad (up to 220 km wide), gently southward-sloping surface continuously swept by long period swells (James et al., 1994). Much of the shallow shelf (<70 m deep) is bare Cenozoic limestone supporting active carbonate production (coralline algae, bryozoans, foraminifers, bivalves), but with minimal sediment accumulation; farther seaward, the outer shelf is mantled by fine, microbioclastic muddy sand (Feary et al., 1993b; James et al., 1994).

The swell- and storm-dominated oceanographic regime is the predominant physical factor presently controlling shelf sedimentation, although episodic influxes of warm, less saline water also affect carbonate production. These incursions reflect activity of the Leeuwin Current, which carries low-latitude, Indian Ocean waters south along the coast of Western Australia and then eastward into the GAB (Cresswell and Golding, 1980; Rochford, 1986). Modern records indicate that these incursions are of variable annual and interannual intensity. Cores from Australia's Northwest Shelf and the GAB indicate that this current was inactive during glacial times (Almond et al., 1993; Wells and Wells, 1994). Warmer water faunas recovered from middle Eocene and middle–late Oligocene samples from the central and eastern GAB have been attributed to activity of a proto-Leeuwin Current (Shafik, 1990). However, the very limited sampling of this succession makes it difficult to reliably differentiate between local current activity and global paleo-oceanographic effects.

Seismic Expression of Reefs and Mounds

One of the most unexpected findings of the seismic stratigraphic analysis of the western Eucla basin Cenozoic succession was the identification of numerous carbonate buildups in the subsurface (Feary and James, 1995). The seismic attributes of these buildups can be used to differentiate between reefs and biogenic mounds (cf. James and Bourque, 1992).

Reefs are coral-algal structures similar to those growing today in warm-water, warm subtropical, or tropical settings. The buildups in the Eucla basin succession that we interpret as reefs have distinctive seismic characteristics: (1) they have a large height:breadth ratio, typically 1:10–1:15, and with one very large example of 1:7 (Figure 3); (2) they are clearly delineated by high-amplitude reflections resulting from high-impedance contrast between the buildup surface and enveloping sediment. In addition, disruption and low amplitude of reflections beneath these buildups and minor velocity pullup indicate that these high-amplitude reflections result in diminished transfer of seismic energy into underlying strata; and (3) on many lines, stacked buildups show that later reefs developed on top of earlier reefs. These stacked reefs merge together vertically and horizontally to form extensive complexes up to 6.5 km across and extending over 200–250 m of section. This seismic pattern is similar to that displayed by Pleistocene stacked reefs within the outer Great Barrier Reef of northeast Australia, where individual reefs represent periods of high sea level, and other phases of the sea level cycle are represented by eroded karst surfaces separating the stacked reefs (Davies, 1983; Symonds et al., 1983).

Biogenic mounds consist of small skeletons and large amounts of fine-grained sediment; these mounds grow in relatively low-energy inner shelf or slope environments, typically forming on ramps, in cooler waters (warm temperate or cool subtropical settings) compared with their reefal equivalents. The attributes of the Eucla basin biogenic mounds are (1) broad, low-relief geometry with characteristic height:breadth ratios ranging from 1:12 to 1:20 (and up to 1:30); (2) slight to moderate impedance contrast between mound margins and surrounding sediment, so that the amplitude of reflections delineating these mounds is low to moderate compared with commonly higher amplitude, continuous or semicontinuous reflections in adjacent sediments (Figure 4); (3) internal reflections within mounds are also of low to moderate amplitude, and generally mimic the mound shape of the upper mound surface, but with lower relief; and (4) although individual, isolated mounds are present in all carbonate sequences, composite mound complexes composed of numerous, apparently coalesced mounds are found in the youngest (late Neogene) sequences. Such mound complexes predominantly occur toward the landward margins of these sequences, and sequence geometry indicates that these complexes formed on the shelf, either at the shelf edge or on the inner shelf.

ONSHORE STRATIGRAPHY

The Eucla basin extends inland up to 350 km from the present coastline and seaward some 200 km to the modern shelf edge and upper slope. Inland, the Eucla basin succession thins and feathers out against Precambrian basement (Figure 1); the succession gradually thickens southward to its thickest beneath the modern shelf edge (Figure 5). Onshore carbonates have been subaerially exposed since the middle Miocene, and the modern surface of the Nullarbor Plain is a vast, flat karst plateau with little vegetation.

Precambrian crystalline basement is overlain by a thin, siliciclastic, Cretaceous cover sequence (of Neocomian–Aptian, Albian–Cenomanian, and Coniacian–Campanian age) that is locally thick where it fills basement depressions (Lowry, 1970). The oldest Cenozoic unit is the thin Hampton Sandstone that is estuarine to fluvial at the base, and contains marine fossils indicating a late middle Eocene age toward the top (Benbow, 1990; Clarke et al., 1996). The Hampton Sandstone is overlain by the thick Wilson Bluff Limestone (Figure 6), a medium- to thick-bedded, white, muddy, burrowed unit of middle and late Eocene age containing abundant bryozoans, scattered echinoid tests and spines, brachiopods, bivalves, sponge spicules, planktonic foraminifers, chert, and minor glauconite (Lowry, 1970). This unit progressively onlapped farther inland, reaching its maximum extent to the margins of the Eucla Platform (Figure 1) in the late Eocene. The maximum thickness onshore is approximately 300 m in the center of the basin at the present shoreline.

The Abrakurrie Limestone (Figure 6) is a coarse-grained bryozoan calcarenite that onlaps the Wilson Bluff Limestone (James and Bone, 1991), is distinctly cyclic, and contains numerous hardgrounds (James and Bone, 1992). The Abrakurrie is up to 100 m thick at the coast, where the area of

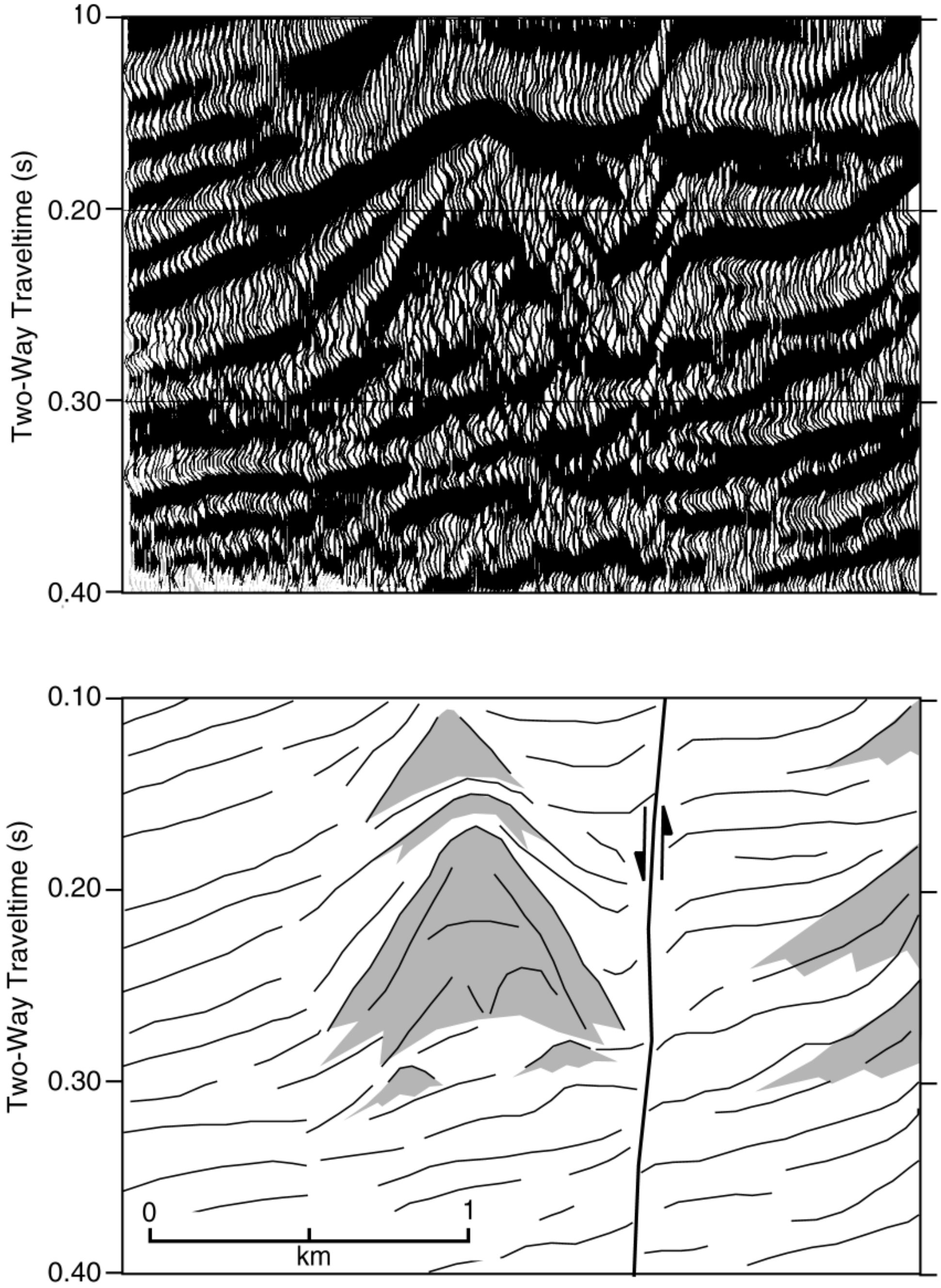


Figure 3—Portion of seismic line JA90-23, together with line-drawing interpretation, showing a stacked reef complex (dark shading) in the sequence 6B escarpment zone. Note the strong impedance contrast between the reef upper surfaces and surrounding sediments. The small fault is probably related to differential compaction.

deposition is 450 km wide, and extends up to 130 km inland to a feather edge. The Abrakurrie Limestone is of middle Oligocene to early Miocene age (Li et al., 1996).

The Nullarbor Limestone (Figure 6) is a hard, fossiliferous, muddy limestone that ranges in age from late early Miocene to early middle Miocene (Lindsay and Harris, 1975; Benbow and Lindsay, 1988). This limestone has a distinctively warmer water aspect than the underlying Abrakurrie Limestone, as is reflected by ubiquitous coralline algae, numerous large benthic foraminifers, more abundant mollusks, and local concentrations of zooxanthellate corals (Lowry, 1970). The middle Miocene highstand, which resulted in deposition of the Nullarbor Limestone, was higher than the Abrakurrie Limestone highstand, and as a result the Nullarbor Limestone overlies the Abrakurrie Limestone near the coast and the Wilson Bluff Limestone inland. At the landward margin of the

Eucla Platform, the Nullarbor Limestone passes into a complex mosaic of strandline terrigenous and carbonate facies (Benbow, 1990). The top of the Nullarbor Limestone is truncated by modern or Neogene erosion.

The late Miocene and early Pliocene was a period of surface and subsurface karstification of the exposed Eucla Group limestones, and extensive ferricrete and silcrete formation inland from the Eucla basin. The central part of the Nullarbor Plain near the modern shoreline is veneered with the late Pliocene (McGowran et al., 1997) Roe Calcarenite, a thin (1–2 m) limestone particularly rich in a diverse assemblage of shallow-water gastropods, bivalves, and large foraminifers (Ludbrook, 1969).

OFFSHORE SEISMIC STRATIGRAPHY

The offshore succession in the Great Australian Bight is divisible into two megasequences separated by a basinwide unconformity: (1) a Mesozoic [late Jurassic(?)–Cenomanian] (Stagg et al., 1990), siliciclastic-dominated, synrift to early postrift section; and (2) a Cenozoic (Paleocene to Holocene), carbonate-dominated section. The area of study for this paper is the upper, carbonate-dominated succession, comprising a sigmoidal series of sequences reaching a maximum thickness beneath the present-day outer shelf (Figure 5).

The extensive erosional unconformity at the top of the synrift and early postrift section forms an easily recognizable and mappable surface; seven unconformity-bounded seismic sequences overlie this surface (Figure 5). The ages assigned to this succession are tentative and based (1) on correlation of sequence 6B with the onshore Eucla Group (see following paragraphs); (2) on limited data from the Jerboa 1 well; (3) on the similarity in depositional style between the sequence 7 progradational wedge and Paleocene(?) to early middle Eocene progradational sequences recorded elsewhere along the Australian southern margin; and (4) on the division of the remainder of the sequences into a reasonable time-stratigraphic framework based on correlations with the Haq et al. (1987) sea level model and regional geology (Figure 6). Vibracores across the modern shelf have encountered Eucla Group limestone out to at least the middle shelf (Feary et al., 1993b; James et al., 1994), linking the eroded sea floor of the inner shelf to the seismic images.

Sequence 7: Progradational Siliciclastic Wedge

This sequence is an east-west–oriented elongate sediment body occurring immediately seaward of a large basement high northeast of the seismic grid (Figure 7). The thickness of this wedge-shape body increases seaward to its thickest part (up to 230 m), and then abruptly downlaps onto the underlying unconformity (Figures 5, 8). In some places, a thin sediment apron is visible basinward of the clinoform front. Complex clinoform geometry (Figure 8) reflects sequential deposition of predominantly south-directed, high-frequency shelf-margin progradational wedges. A thin aggradational component at the top of the sequence represents a minor increase in accommodation space, probably resulting from sediment compaction and sag.

Sequence 6A: Deep-Water Carbonate Lobes

This relatively thin sequence (up to 195 m) underlies the present-day Eyre Terrace. Sequence 6A occurs seaward of, and at a lower elevation than, the sequence 6B carbonate shelf, but appears broadly coeval with that sequence (see Figure 5). Sequence 6A is composed of three overlapping sediment lobes (Figure 9) separated by unconformities. The lower sequence boundary onlaps landward against the sequence 7 siliciclastic wedge, and downlaps seaward onto the Cenomanian–middle Eocene unconformity. The upper sequence boundary is a prominent reflection onto which younger sequences downlap. Internal unconformities indicate that later lobes downlapped and onlapped against earlier lobes. With the exception of these sub-sequence boundaries, sequence 6A is characterized by a relatively coherent, continuous reflection character and few, generally small biogenic mounds (40–60 m thick and up to 1 km across).

Sequence 6B: Progradational Carbonate Shelf and the Little Barrier Reef

Sequence 6B is the most extensive and geometrically most dramatic sequence within the offshore Cenozoic succession. It makes up the entire Cenozoic succession beneath the inner half of the present-day shelf, and correlates with the carbonate component of the Eucla Group exposed onshore (Figures 10, 11).

The sequence can be areally divided into three zones: (1) an inner shelf zone, (2) an escarpment zone, and (3) an outer shelf zone (Figure 10). The sequence overlies either crystalline basement or a relatively thin Mesozoic succession within the inner shelf zone (Figure 5). The escarpment zone is a thick (400–450 m), relatively narrow band where the top of this sequence abruptly dips from close to the present sea floor more than 250 m into the sediment pile (Figures 5, 12). The outer

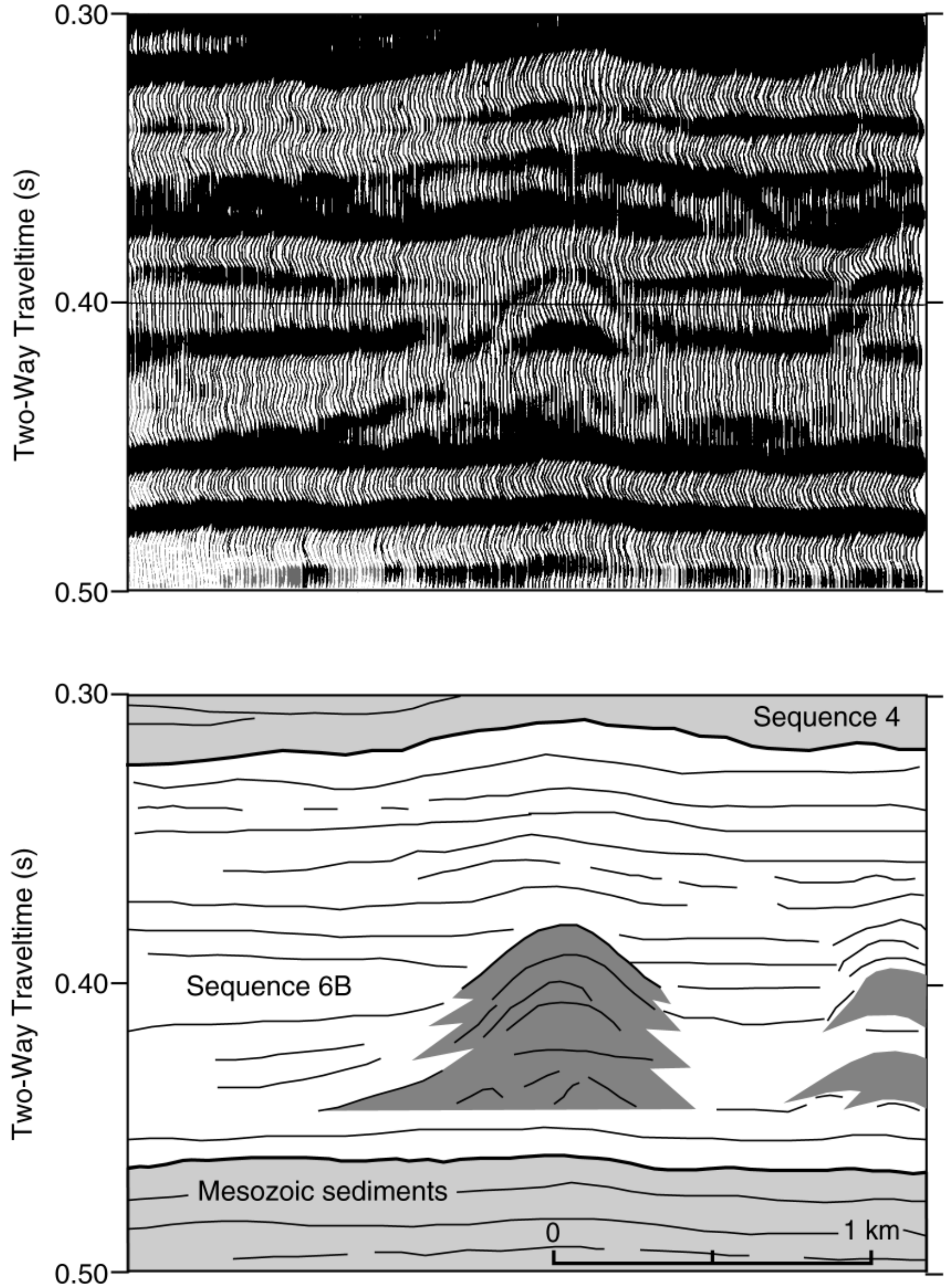


Figure 4—Portion of seismic line JA90-09, together with line-drawing interpretation, showing moderately well-defined mounds (dark shading) within the sequence 6B (other sequences are lightly shaded) outer shelf zone, with moderate impedance contrast with overlying sediments. Note the differential compaction over this feature.

shelf zone is a thin (up to 170 m thick) apron that extends seaward below the present outer shelf from the base of the escarpment to near the position of the present shelf edge, where it wedges out by downlap onto the underlying unconformity. The basal sequence boundary unconformity is marked by reflections that downlap, in different parts of the basin, onto Precambrian basement, Mesozoic siliciclastics, and the sequence 7 progradational siliciclastic wedge. The upper sequence boundary in the outer shelf and escarpment zones is a dramatic onlap surface onto which sequences 2–5 onlap. Within the limits of seismic resolution, this sequence forms the sea floor of the modern inner shelf zone.

A broad clinoform structure is within the inner shelf zone, with older parts of the sequence occurring closer inshore. Clinoforms range from gently dipping, almost planar ramps in the oldest part of the sequence to more steeply dipping, oblique sigmoidal surfaces toward the escarpment. Reflections within the inner shelf zone are characteristically discontinuous and display considerable

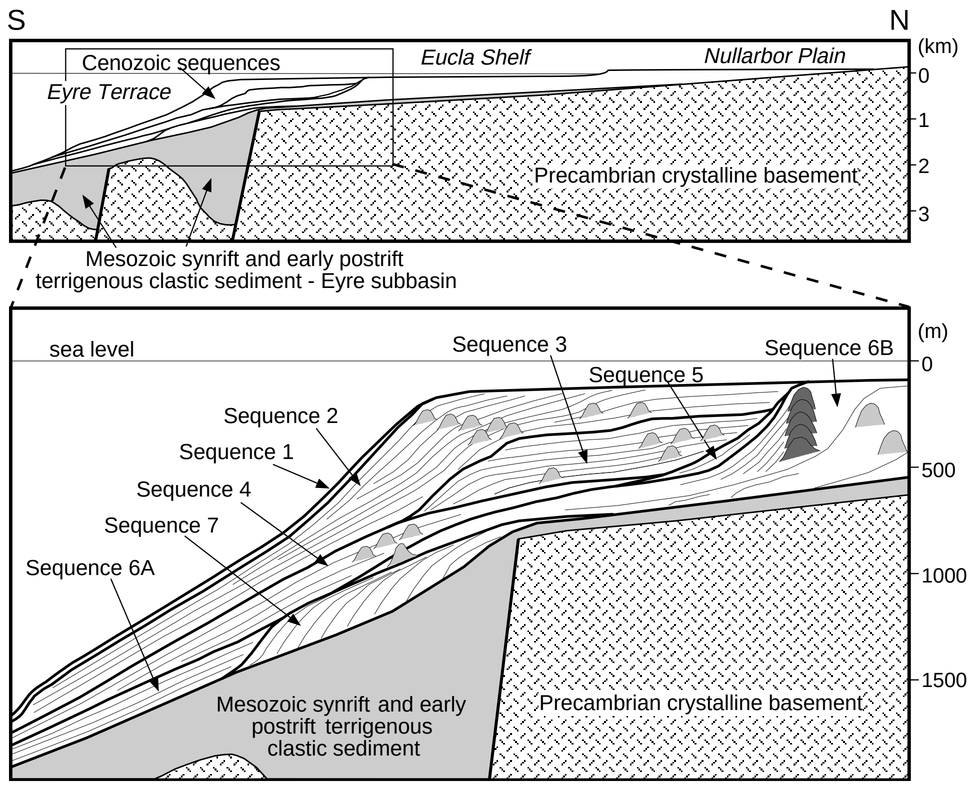


Figure 5—Schematic north-south diagram from the Nullarbor Plain to the upper continental slope, across the Eyre Terrace (along longitude 128°E), showing the distribution and internal relationships of seven Cenozoic sequences defined from seismic data, overlying Mesozoic synrift and early postrift siliciclastic sequences and Precambrian crystalline basement. Note the distribution of reefs (dark shading) and biogenic mounds (light shading) within many of the Cenozoic sequences. Vertical scales are approximate. Modified from Feary and James (1995).

amplitude variation, contrasting with more continuous, moderate-amplitude reflections in the outer shelf zone, and high-amplitude, well-defined reflections in the escarpment zone. A combination of seismic geometry, seismic facies, and the relatively simple structure beneath the inner shelf and nearshore area permits a confident correlation between offshore sequences and the onshore stratigraphic succession (Figure 11).

Wilson Bluff Formation Equivalents

The gently inclined ramp geometry of reflections within the oldest parts of sequence 6B, beneath the modern inner shelf, correlates with the Wilson Bluff Limestone onshore. These shallowly dipping reflections (gradients of less than 0.7°) indicate predominantly aggradational deposition with only a slight basinward progradational component. This portion of the sequence contains relatively few biogenic mounds; however, where present, mounds preferentially overlie higher amplitude reflections that in many cases appear to represent unconformities.

Abrakurrie Limestone Equivalents

Several surfaces beneath the modern inner shelf appear to be unconformities, one of which is likely to correlate with the unconformity at the base of the Abrakurrie Limestone; however, the disruption of seismic reflectors by biogenic mounds and the wide (~25 km) seismic line spacing preclude the confident identification of any particular unconformity. On the basis of overall reflector geometry, it is likely that the Abrakurrie Limestone basal unconformity corresponds to the transition from essentially planar ramp to more oblique sigmoidal clinoform reflector geometries exhibiting more pronounced basinward progradation with more abundant mounds. A combination of the broad inner shelf (~50 km) and the relatively thin sequence (~400 ms) prevents showing seismic data illustrating this relationship in a figure.

Nullarbor Limestone Equivalents

The transition to more oblique sigmoidal geometry with significant basinward progradation culminated with the formation of the escarpment zone beneath the modern middle shelf. We correlate this transition from ramp to rimmed-platform geometry with the transition from cooler water carbonates of the Wilson Bluff and Abrakurrie limestones to warmer water carbonates of the Nullarbor Limestone (Feary and James, 1995). A zone approximately 8–10 km wide immediately landward of the escarpment top is marked by an

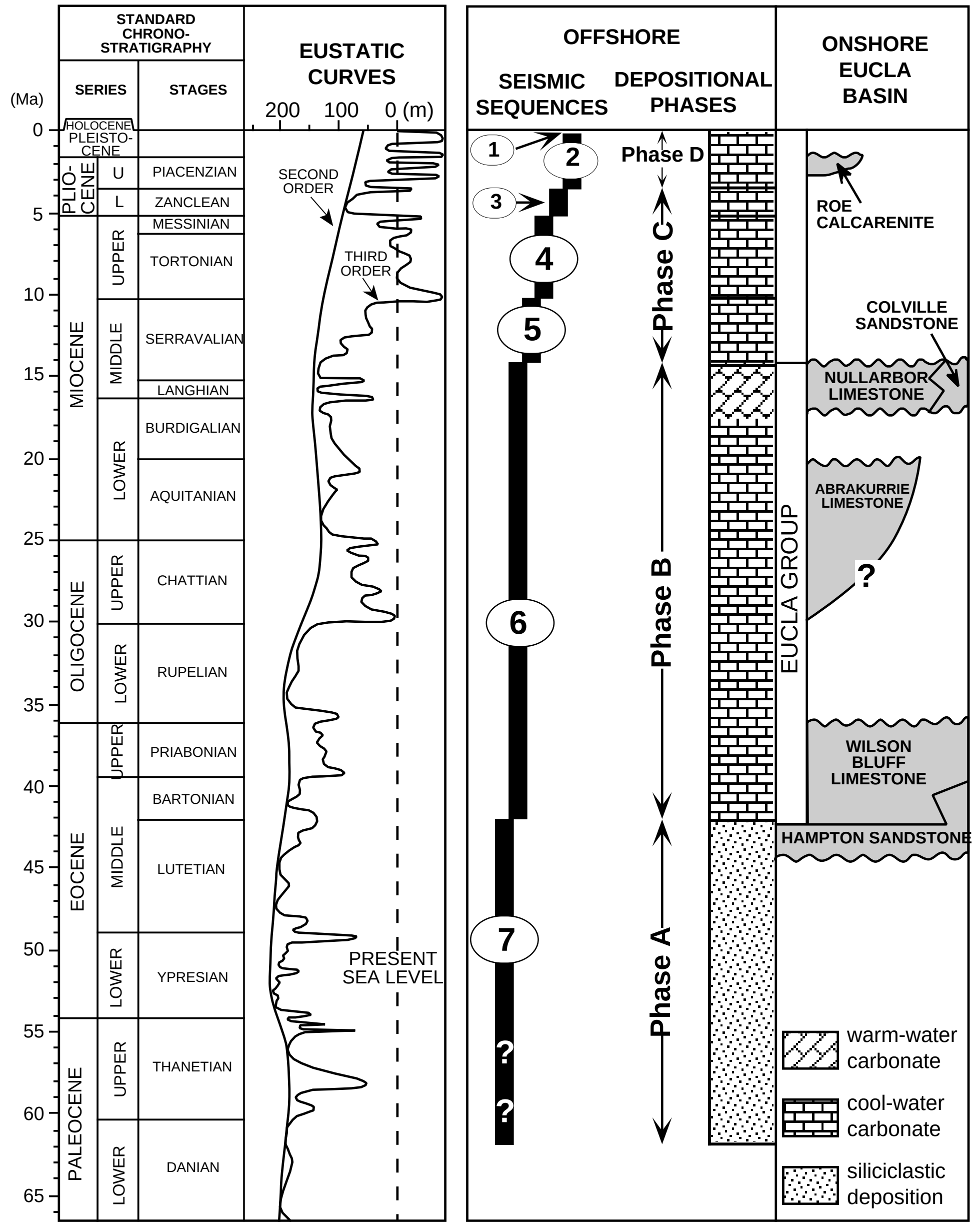


Figure 6—Tentative chronostratigraphy of Cenozoic offshore seismic sequences, depositional phases in the western Great Australian Bight, and onshore Eucla basin stratigraphy (after Lowry, 1970; James and Bone, 1991), plotted against the global sea level model (Haq et al., 1987). The absence of existing age dates for offshore sequence boundaries (and depositional phases) means that it is not yet possible to show the extent of hiatus intervals between each sequence; accordingly, deposition is shown as being continuous. Modified from Feary et al. (1994).

abundance of relatively large reefs with high-amplitude capping reflections indicating more strongly cemented surfaces. As a consequence of the greater seismic reflectivity associated with these high-amplitude surfaces, there is considerable fade-out of reflections beneath this zone (marked by discontinuous, low-amplitude reflections with considerable seismic noise), and minor velocity pull-up. This reefal escarpment has been interpreted as the Great Australian Bight "Little Barrier Reef" (Feary and James, 1995). The Little Barrier Reef is best developed and steepest (2–3.5°) in central parts of the basin (e.g., Figure 12), and flattens out to a more shallow-dipping ramp (<0.6°) toward both the east and the west. The outer shelf zone is the basinward extension of this youngest part of sequence 6B, consisting of evenly spaced reflections with a minor carbonate mound component, although in one case an unusually large mound (100 m thick; 2.3 km across) extends well up into the overlying sequence.

The combined offshore and onshore components of sequence 6B thus comprise an areally extensive (some 350,000 km²) carbonate platform that developed through a large portion of the early–middle Cenozoic (over approximately 28 m.y.), but nevertheless attained a thickness of only 450–500 m.

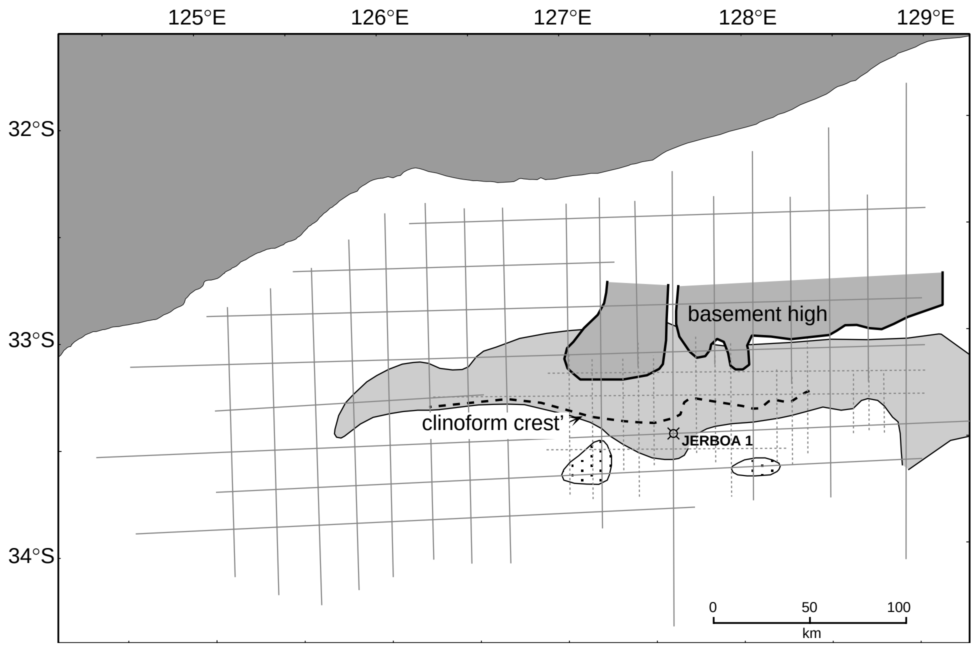


Figure 7—Map showing distribution of sequence 7, the Paleocene–middle Eocene siliciclastic wedge, lying seaward of a Precambrian basement high. The dashed clinoform crest marks the position of the youngest part of this sequence.

Sequence 5: Lowstand Debris Apron

This sequence is a small sediment wedge with restricted distribution lying at the foot of the steepest part of the progradational carbonate shelf escarpment zone in the eastern part of the area (Figures 12, 13). Sequence 5 reflections onlap against the steepest segment of the sequence 6B escarpment and downlap onto the prominent unconformity at the top of the sequence 6B outer shelf zone (Figure 5). The upper boundary of this sequence, in turn, is onlapped by reflectors of sequences 2–4 (Figure 12). In most places, the internal character of this sequence is a coherent pattern of approximately constant thickness, low- to moderate-amplitude, continuous reflections (Figure 14). On some lines, reflection relationships indicate that there were two sedimentation pulses separated by an unconformity. The earlier phase is comprised of subhorizontal reflectors, whereas the later phase is more steeply dipping and downlaps onto the early phase.

Sequence 4: Aggradational Deep-Water Carbonate Sequence

Sequence 4 is a thin interval (<160 m thick) characterized by relatively abundant biogenic mounds on many lines, occurring beneath much of the present-day outer shelf, Eyre Terrace, and uppermost slope (Figure 15). Sequence 4 is thickest in the central part of its distribution, beneath the present-day shelf edge, and has a broadly sigmoidal shape in dip section. The lower sequence boundary in the inner, landward portion is an onlap surface with reflections onlapping against the sequence 6B outer shelf zone and, where present, the sequence 5 debris apron. Sequence 4 reflections over the remainder of its distribution downlap onto the basal sequence boundary. The upper sequence boundary is onlapped by sequence 2 reflections, and both onlapped and downlapped by sequence 3 reflections. This upper sequence boundary is a high-amplitude reflection toward the landward extent of this sequence in the central part of the area. We speculate that this reflection may represent a hardground surface. Truncation of sequence 4 reflections toward the seaward margin of this sequence resulted from erosion during the hiatus between deposition of sequences 2 and 3. Stratal patterns indicate that initial deposition occurred along a relatively narrow zone immediately seaward of the toe of the sequence 6B outer shelf zone sediment apron. Subsequently, deposition spread landward across this outer shelf zone, and then extended both farther seaward and toward the west. The distribution of mounds is variable both along and between lines. Higher concentrations of mounds appear to define a discontinuous linear zone of elongate mound complexes that may mark a paleoshelf edge (Figure 15). The size of mounds varies from the limit of resolution (~25 m thick × 450 m across) up to 50 m thick × 1.2 km wide. Extensive coalesced mound complexes landward of the sigmoid crest are up to 55 m thick × 5 km across in dip section.

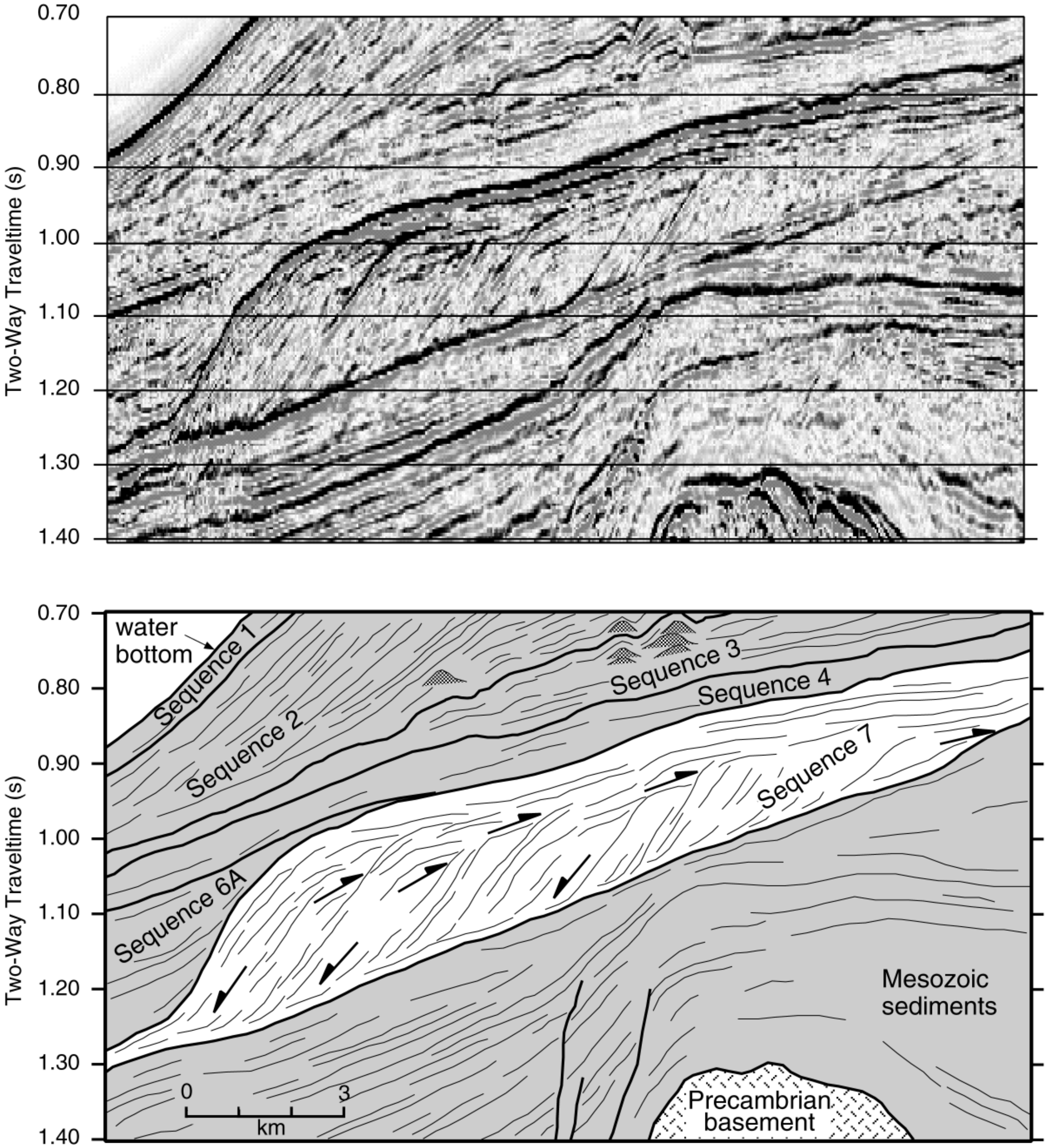


Figure 8—Part of seismic line JA90-23, together with line-drawing interpretation, showing the shape and internal stratal characteristics of the sequence 7 shelf margin wedge (other sequences shaded). Note the interaction between downstepping prograding clinoforms and aggradation.

Sequence 3: Aggradational Shelf

Sequence 3 is an areally extensive unit (Figure 16) underlying much of the present-day outer shelf. The sequence is thin in the west (<50 m), and reaches its maximum thickness (235 m) toward the middle of the area. Internal reflection geometry is dominantly aggradational with only a slight

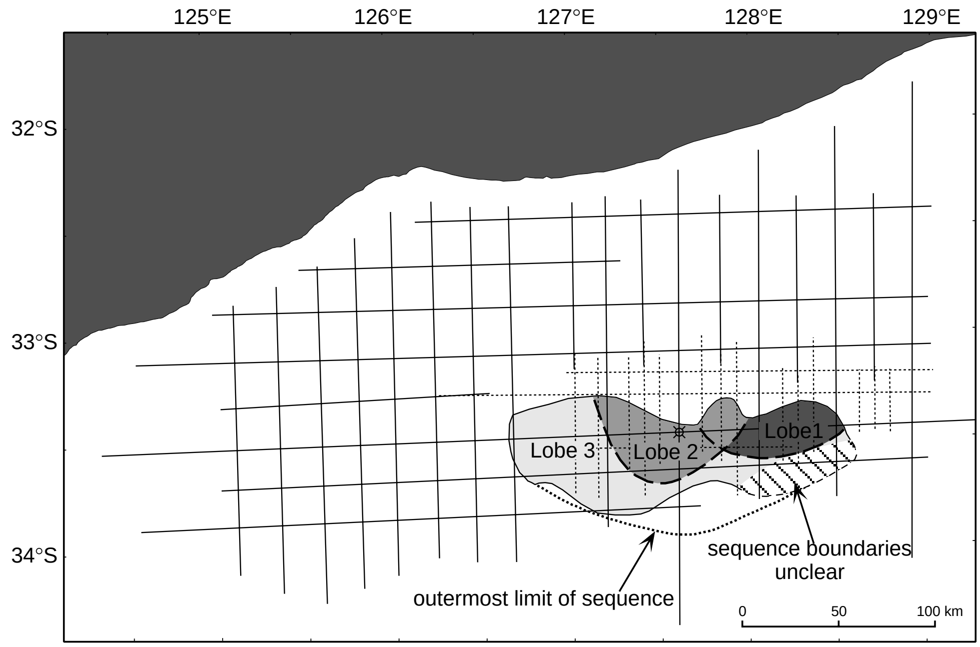


Figure 9—Map showing distribution of the three middle Eocene–early middle Miocene sequence 6A sediment lobes; lobe 1 is the oldest, and the widely distributed lobe 3 is the youngest.

progradational element. The lower sequence boundary is an onlap surface against the sequence 6B escarpment at the landward edge, and a downlap surface onto the underlying sequence 4 farther seaward (Figures 5, 12). The upper sequence boundary is a marked erosional unconformity, with truncated reflections both in the upper parts of the sequence and on the seaward margin attesting to significant erosion (see Figure 17). The upper sequence boundary is also a high-amplitude reflection in the central part of the area where no erosion is apparent. As with the sequence 4 upper boundary, we speculate that this high-amplitude reflection represents a well-lithified surface.

Over much of its distribution, sequence 3 can be divided into two subsequences; however, our inability to trace the subsequence boundary into the remainder of the area precludes formal subdivision. The lower subsequence is more extensive toward the west of the basin, whereas the upper subsequence extends farther both seaward and landward in the central and eastern parts of the area, indicating an eastward shift in the locus of sedimentation during the course of sequence 3 deposition. The lower subsequence is characterized by low- to moderate-amplitude, essentially continuous aggradational reflections that feather out seaward, and contains few mounds. By contrast, extensive mound growth in the upper subsequence has resulted in markedly discontinuous reflections. Prolific biogenic mound development within the landward part of the upper subsequence in the central and eastern parts of the area has produced a coalesced mound complex 90–110 m thick and up to 30 km wide across the shelf. This complex is much thinner and more restricted toward the west, where it is composed of individual mounds ranging from 90 to 110 m thick and 1.2 to 1.5 km across toward the landward edge, compared to 30 to 45 m thick and 0.4 to 1 km across farther seaward.

Sequence 2: Progradational Outer Shelf/Shelf Edge/Upper Slope Sequence

This sequence is a spectacular sigmoidal unit that forms a thin succession over the outer shelf (70–90 m), reaches peak thickness at the present shelf edge (350–400 m), and thins as a wedge farther seaward beneath the modern slope (Figures 5, 17, 18). The lower sequence boundary is a concordant to low-angle downlap surface in the more landward parts of this sequence, with the exception of the reflectors that onlap against the sequence 6B escarpment or the sequence 5 debris apron. Farther seaward, onlapping and downlapping reflectors represent infilling of the eroded upper surface of underlying sequences; sequence 2 basal reflectors are generally concordant with the lower sequence boundary where there was no apparent erosion. The upper sequence boundary over the width of the present-day outer shelf, within the limits of seismic resolution, is the modern sea floor. Markedly progradational internal reflectors within the upper arm of the sigmoid, beneath the modern outer shelf, are truncated at the modern sea floor, indicating that this

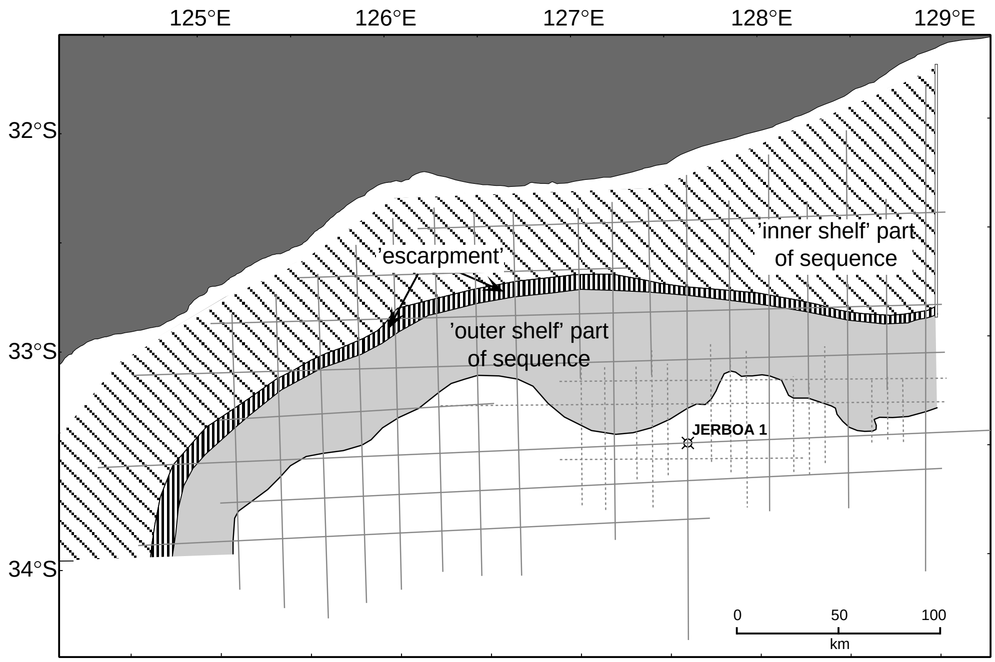


Figure 10—Map showing the distribution of the middle Eocene–early middle Miocene sequence 6B carbonate platform and its division into inner shelf, escarpment, and outer shelf zones. The escarpment zone beneath the modern middle continental shelf marks the position of the inferred middle Miocene Little Barrier Reef. Modified from Feary and James (1995).

sequence boundary is an erosional surface. Farther seaward, the upper sequence boundary also is marked by low-angle truncated reflectors.

Reflectors in the thickest part of the sequence, beneath the modern outermost shelf, shelf edge, and uppermost slope, possess a marked sigmoidal clinoform geometry (Figure 17). Complex reflector onlap and erosional truncation patterns within this clinoform package reflect hiatus or erosional episodes; however, the density of seismic lines is insufficient to permit subsequences defined by these surfaces to be mapped around the seismic grid. Abundant mounds form a broadly linear belt on dip sections, extending from immediately seaward of the modern shelf edge to the base of the sequence further landward (Figures 5, 17);

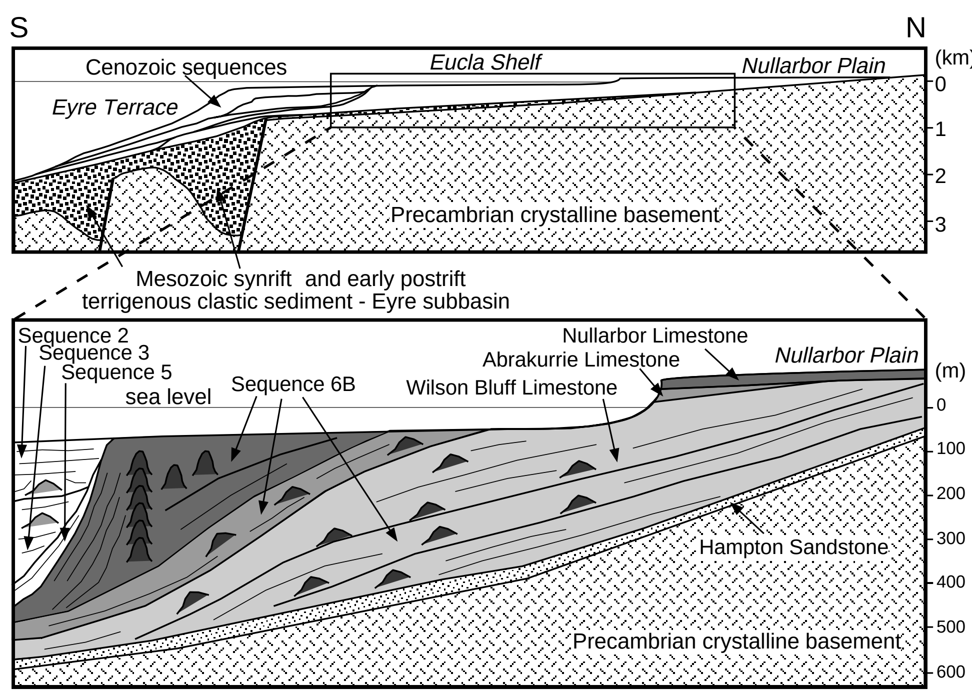


Figure 11—Schematic diagram illustrating the inferred correlation between onshore and offshore components of the Eucla basin succession (note the considerable vertical exaggeration). Unconformities in the onshore succession (between the Wilson Bluff, Abrakurrie, and Nullarbor limestones) cannot reliably be correlated with specific unconformities within the sequence 6B section offshore; however, the inferred relationship is consistent with all available data.

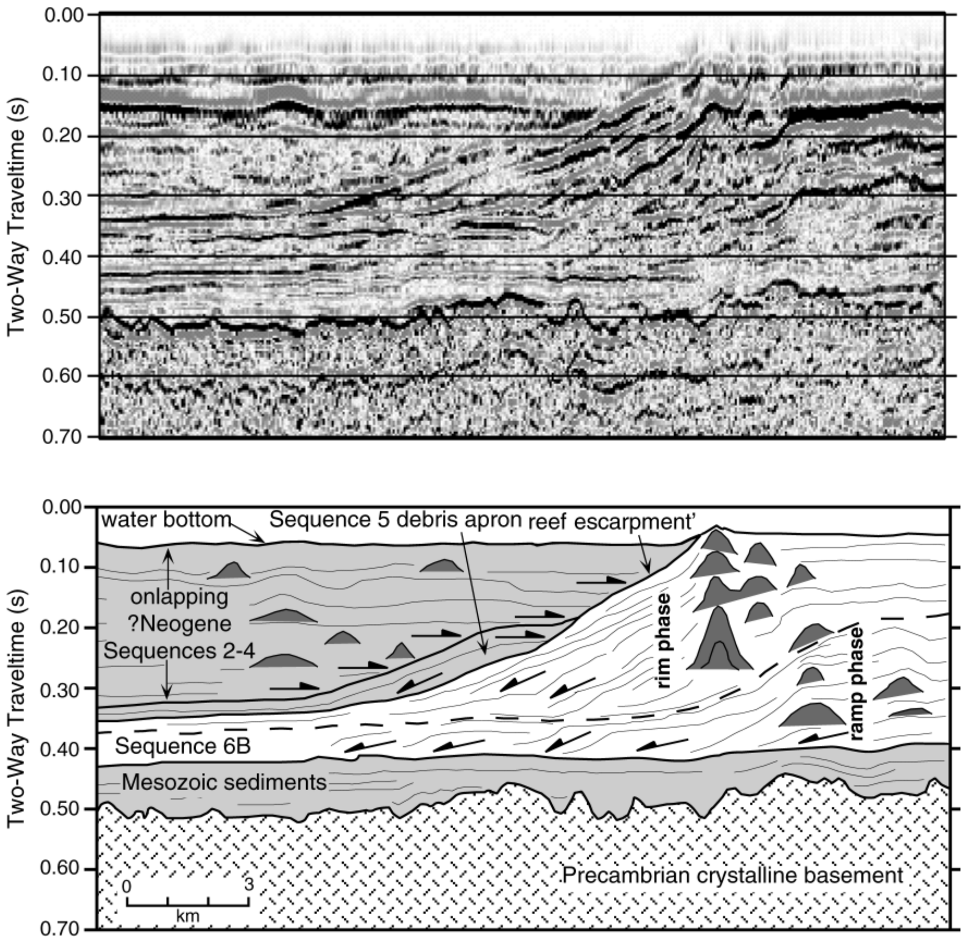


Figure 12—Part of seismic line JA90-23, together with line-drawing interpretation, showing stacked reefs interpreted as warm-water (tropical) features (the rim phase) that formed the extensive western Great Australian Bight Little Barrier Reef (Feary and James, 1995) within sequence 6B (other sequences lightly shaded). The underlying ramp phase mounds are interpreted as cooler water (temperate or cool subtropical) buildups that grew in a broad, gently sloping shelf environment. Note the debris apron (sequence 5) abutting the escarpment. Modified from Feary and James (1995).

we infer that this trend marks the position of the paleoshelf edge throughout sequence 2 deposition.

Sequence 2 also contains individual mounds within the upper arm of the sigmoid, beneath the modern outer shelf. No mounds have been identified within the deeper water segment, beneath the modern slope; this lower arm of the sigmoid is characterized by continuous, regular, moderate-amplitude reflections. The stratal geometry of the sequence as a whole indicates contraction of the depositional area over the duration of sequence 2, resulting in the eventual concentration of sedimentation on the present shelf edge.

Sequence 1: Deep-Water Drape

Sequence 1 is an extremely thin sequence (up to 50 m thick) that mantles deeper parts of the margin (below 150–200 m water depth) and is inferred to be wholly muddy carbonate facies; seismic pulse interference restricts any interpretation within this sequence.

PLATFORM EVOLUTION

The following interpretation of the Cenozoic sequences of the western GAB in terms of four depositional phases (Figures 6, 19) is based on the character of the seismic sequences as outlined, the global sea level model, and our current understanding (principally resulting from onshore studies) of southern Australian Cenozoic stratigraphy.

Phase A: Paleocene–Middle Eocene Lowstand/Transgression (Sequence 7)

After the Cenomanian–Paleocene erosional hiatus throughout southern Australia (Stagg et al., 1990), the early Cenozoic is marked by deposition of terrigenous clastic sands in environments that range from fluvial to paralic to fully marine. We interpret the sequence 7 seaward-prograding marginal wedge as a lowstand manifestation of this event, deposited adjacent to the rift edge within accommodation space created

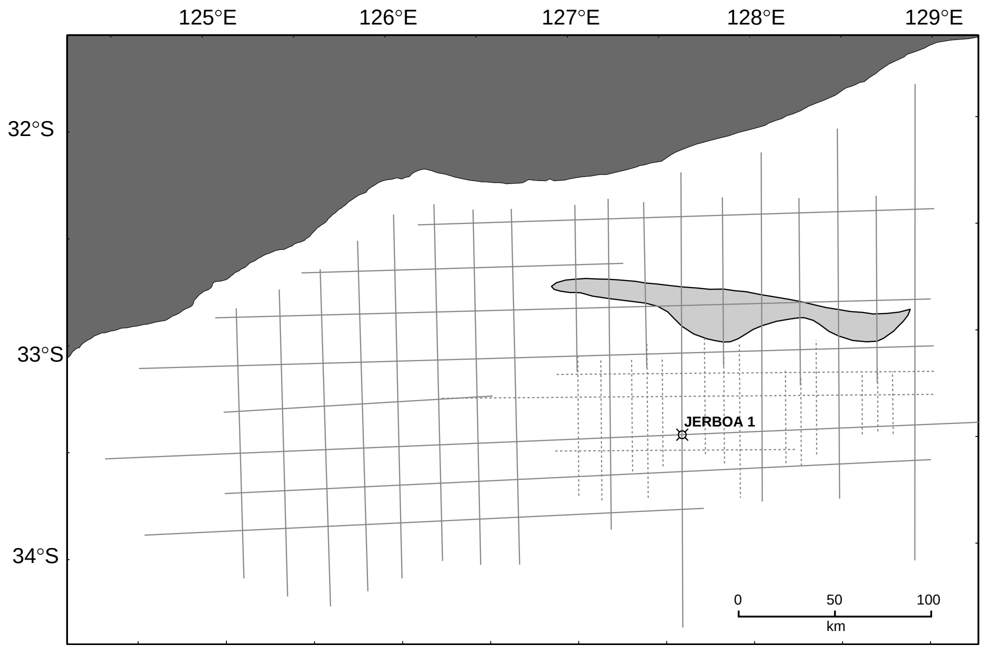
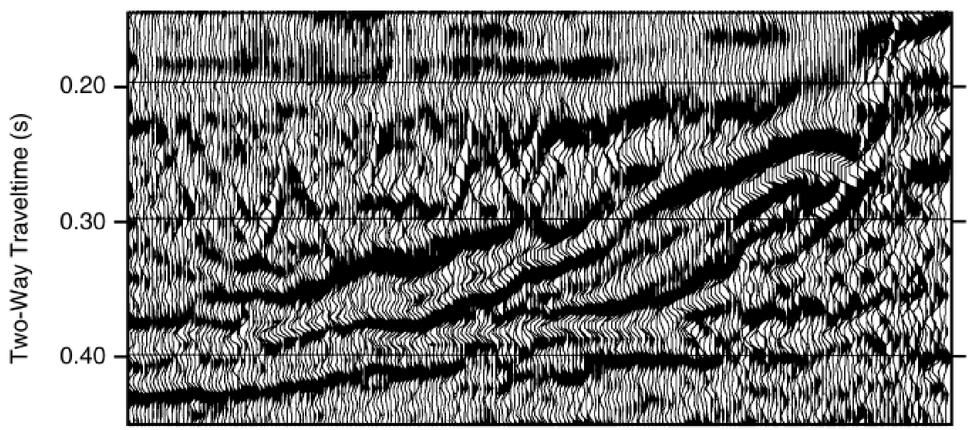


Figure 13—Map showing distribution of the late middle Miocene sequence 5 debris apron, lying against the base of the sequence 6B escarpment.



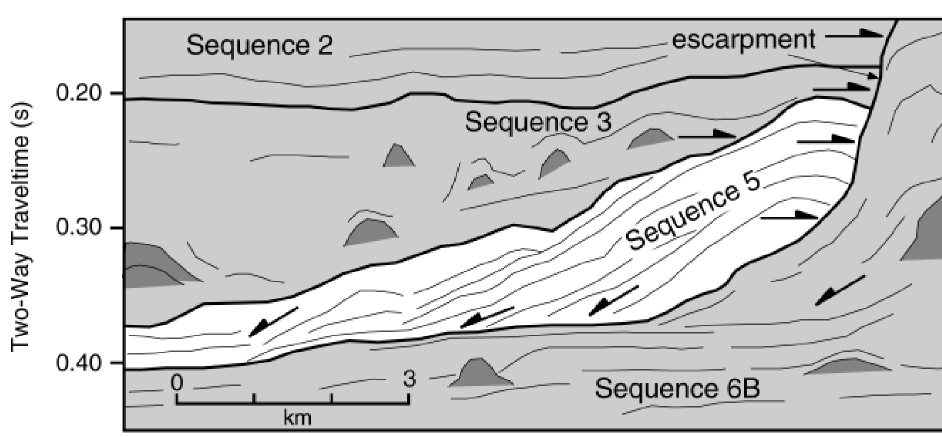


Figure 14—Part of seismic line JA90-29, together with line-drawing interpretation, showing typical sequence geometry and reflector relationships within the sequence 5 debris wedge (other sequences lightly shaded) abutting the sequence 6B escarpment.

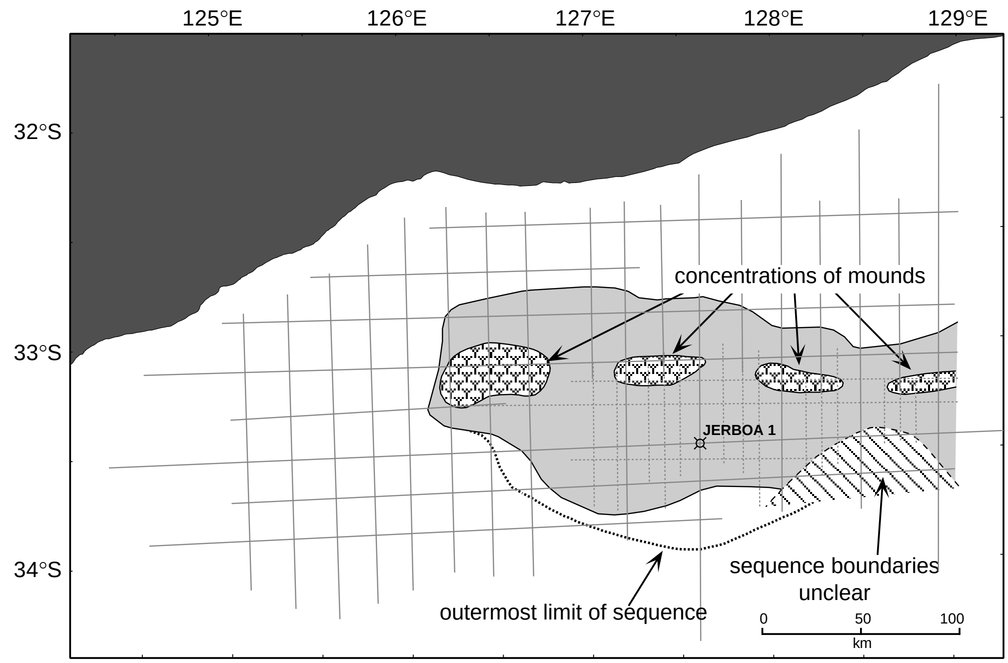


Figure 15—Distribution of the late Miocene(?) sequence 4 aggradational deeper water carbonate unit showing concentrations of biogenic mounds.

by compaction subsidence of the Mesozoic Eyre subbasin rift succession, with sedimentation largely constrained to progradation beneath erosional base level (presumably wave base) during successive lowstands. Complex downstepping clinoform geometries within this sequence (Figure 8) almost certainly resulted from eustatic sea level fluctuations superimposed on the overall progradational trend.

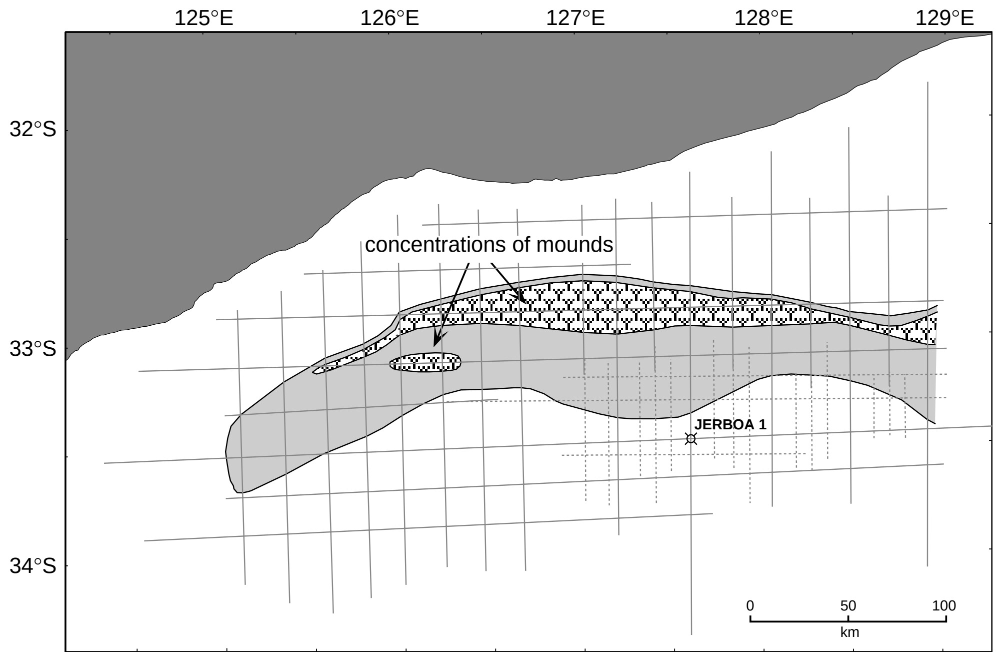
We infer that the youngest sequence 7 sediments are the thin, latest early or earliest middle Eocene mudstones intersected at the base of the Tertiary succession in Jerboa 1 (Bein and Taylor, 1981; Stagg et al., 1990). We interpret this unit as a thin foredelta apron extending seaward from the toe of the clinoform front at the limit of seismic resolution that was deposited during the final sequence 7 transgression. Thus, sequence 7 sediments are of Paleocene to latest early or earliest middle Eocene age, and correlate with the Hampton Sandstone recognized onshore (where it is of middle Eocene age) and offshore in the eastern GAB (where it is called the Pidinga Formation) (Fraser and Tilbury, 1979; Stagg et al., 1990). In some places, reflectors are disrupted by volcanic intrusions that in most cases apparently are related to leaky basement faults that fed extrusions onto the top sequence 7 paleosurface. The upper sequence boundary is onlapped by overlying sequences, but shows no evidence of erosion, whereas onshore the top of this succession is locally an erosional unconformity.

Phase B: Middle Late Eocene–Early Middle Miocene, Cool-to-Warm Platform Evolution (Sequence 6)

The transition from a siliciclastic depositional regime to a carbonate depositional environment resulted from intrusion of oceanic waters from the west as the gulf between Australia and Antarctica continued to open. This intrusion was accompanied by a predictably dramatic change in seismic sequence character. Instead of the areally restricted sequence 7 progradational wedge, depending upon the source and rate of terrigenous sediment supply, the offshore region was subject to carbonate sedimentation over a much wider area. In shallower waters, the extensive sequence 6B carbonate platform developed, apparently coeval with the deposition of the sequence 6A lobes in deeper water (Figures 5, 9, 10).

The carbonate platform component (sequence 6B) has two distinct phases of growth. The lower phase has clear ramp geometry with biogenic mounds disrupting otherwise gently prograding clinoforms. These fit well with our understanding of cool-water carbonate ramp geometries (Ahr, 1973; Burchette and Wright, 1992) and are offshore equivalents of the cool-water Wilson Bluff and Abrakurrie limestones of the Eucla Group onshore. The upper phase has all the attributes of a flat-topped, rimmed platform (Handford and Loucks, 1993); reflectors across most of the platform are subhorizontal and terminate abruptly against a

Figure 16—Map showing distribution of the early Pliocene sequence 3 aggradational shelf unit. Note the concentrations of biogenic mounds along the innermost part of this sequence.



series of stacked transparent to domed reflections that form a massive zone in front of which are seaward-dipping reflections that downlap onto earlier ramp-phase strata.

Deposition of sequence 6B was largely controlled by the balance between relative sea level movements and organic growth capability as dictated by prevailing environmental conditions. Initially, deposition of the broad ramp sequence beneath the present-day innermost shelf (and probably extending some distance inland) followed a major rise in relative sea level and the incursion of normal or near-normal cool to cold marine waters. The obliquely progradational phases represented sequential episodes of relative sea level rise in a situation where there was increased growth potential, causing a progressive seaward shift in the depositional maximum. These rising sea level episodes, which together form an overall relative sea level rise, were interrupted by episodes of relative sea level fall represented by the unconformities and onlap geometries within this sequence. We interpret the formation of the steep escarpment zone, reflecting a dramatic increase in organic growth potential, to be the result of warmer marine conditions (Feary and James, 1995).

Sequence 6A is physically separated from sequence 6B and lies in deep water as a series of gently seaward-dipping reflectors forming broad lobate bodies. At Jerboa 1, this sequence consists of calcilutites and marls (Huebner, 1980) that indicate deposition in progressively deeper water upward (McGowran et al., 1997). We interpret this as a multi-lobed, deep-water slope sediment apron (Cook and Mullins, 1983; Coniglio and Dix, 1992). The zone between the two sequences was likely a bypass slope (sensu McIlreath and James, 1979) across which sediment, derived from the developing platform, moved to accumulate in a depression in front of the sequence 7 terrigenous clastic wedge.

The two factors that determined the nature and distribution of sequence 6A were the presence of an extensive carbonate platform upslope (sequence 6B), from which carbonate detritus was derived, and the existence downslope of a relatively flat-lying paleobathymetric terrace that provided a suitable depositional environment. This paleobathymetric terrace, which broadly coincides with the seaward half of the present-day Eyre Terrace, was formed by compaction and sag of the Eyre subbasin; the sequence 6A carbonate lobes were able to occupy the portion of this terrace not already infilled by the sequence 7 siliciclastic wedge (Figures 7, 9). Although the distribution of the sequence 6B carbonate platform shows that shelf deposition extended farther west, and that presumably fine material was also derived and moved offshore in that area too, the absence of a suitable paleobathymetric terrace meant that the sequence 6A lobes did not extend into that area. Furthermore, even though compaction and sag of the Mesozoic sequence initially formed the paleobathymetric terrace, the presence of individual subsequences spanning both basement highs and lows indicates that sag did not exert as close a control on sedimentation as it did for the sequence 7 siliciclastic wedge sequence.

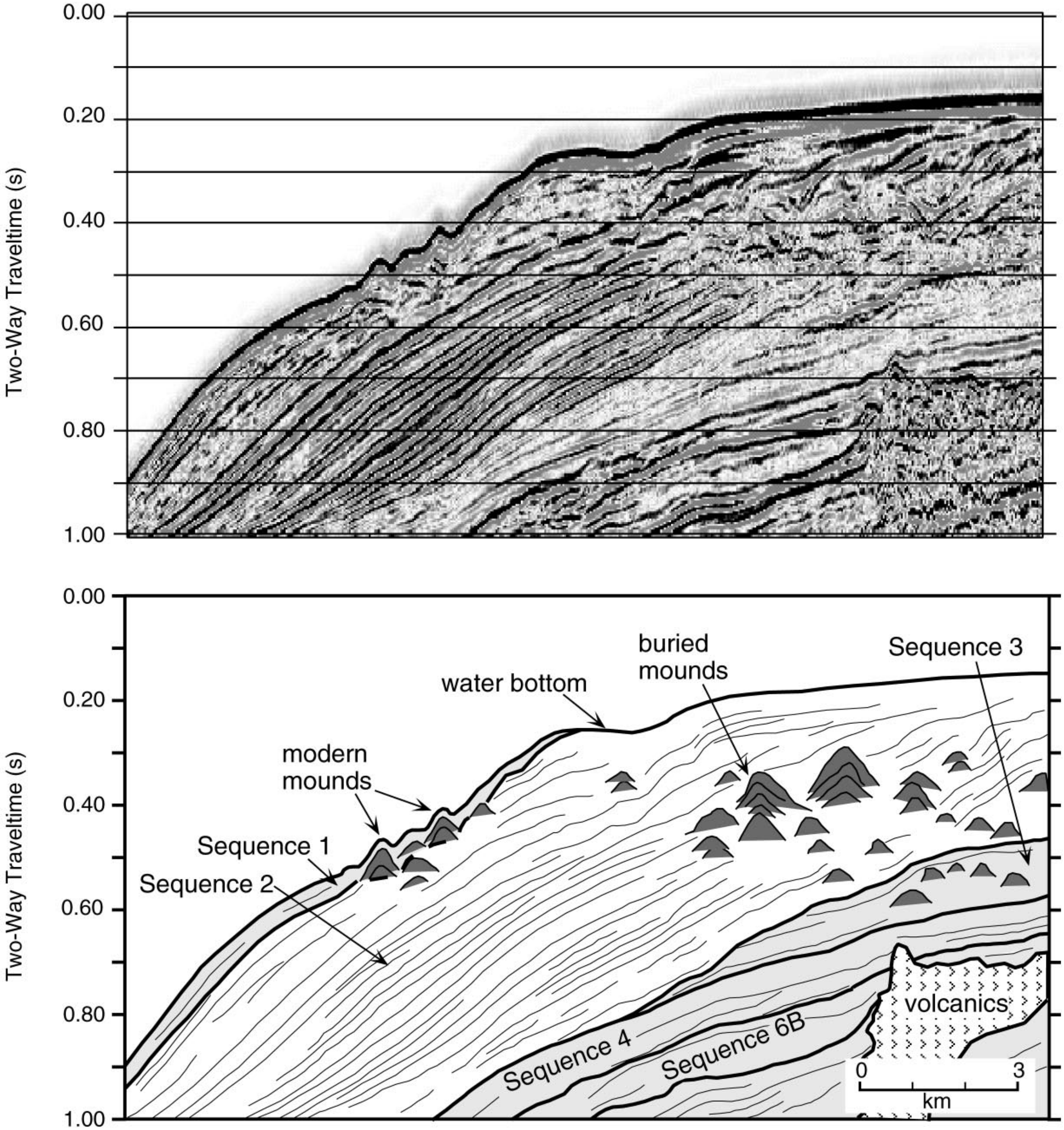


Figure 17—Part of seismic line JA90-31, together with line-drawing interpretation, showing the spectacular clinoforms comprising sequence 2 (other sequences lightly shaded) beneath the modern shelf edge. Mounds forming immediately downslope from the modern shelf break also are clearly visible, along with older biogenic mounds inferred to have formed in a similar bathymetric position, but which have since been overwhelmed by prograding sediments. Modified from Feary and James (1995).

The scarcity of mounds within sequence 6A indicates that conditions for mound development in this deeper muddy environment were marginal compared to the more favorable conditions that caused greater mound growth on the sequence 6B shelf. Location of these shelf mounds on sequence or subsequence boundaries implies either that initial mound growth required firm, stable, and perhaps

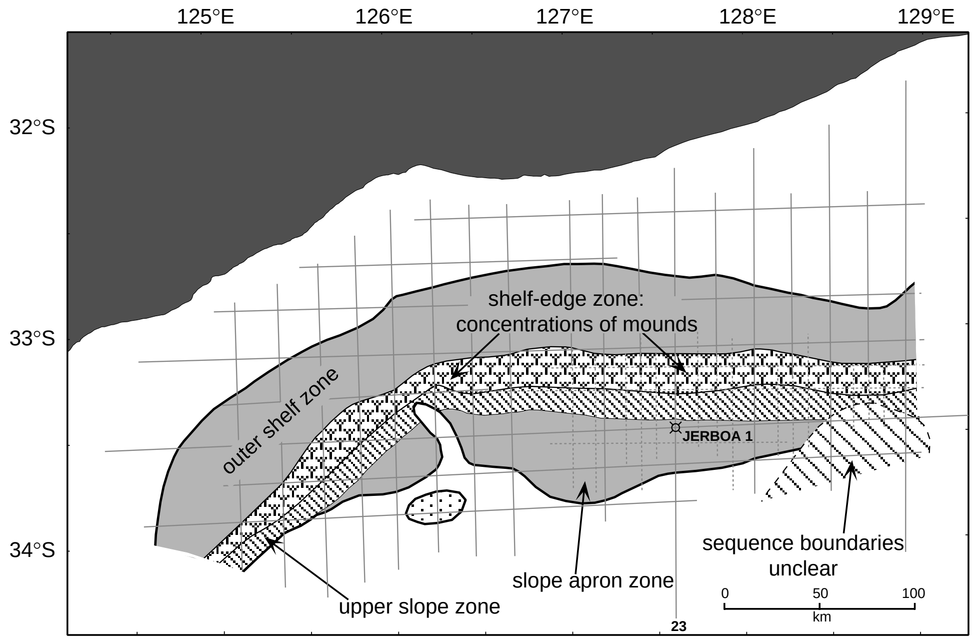


Figure 18—Map showing distribution of the sequence 2 late Pliocene–Pleistocene progradational shelf to upper slope unit. The outer limit of the band containing high concentrations of biogenic mounds corresponds to the modern shelf edge.

cemented surfaces, or that these surfaces represent times of diminished fine-sediment supply that encouraged mound development. Irrespective of where in the eustatic sea level cycle these buildups grew, they are clearly deep-water mounds; so little is known about such mounds that it is not possible at present to make more detailed inferences concerning the controls on their growth and distribution.

The tectonic tilting that uplifted the onshore portion of the Eucla basin succession and resulted in restriction of carbonate deposition to seaward of the sequence 6B escarpment zone is tentatively dated at middle Miocene (Lowry, 1970); this age is in accord with our interpretation. By uplifting the sequence 6B carbonate platform, this tilting dramatically reduced the area available for shallow-water carbonate accumulation and terminated this early phase of carbonate platform development. The seaward margin of this platform has been subject to wave erosion from the time of tilting until the present day, resulting in the present broad, essentially flat, inner continental shelf.

Phase C: Late Miocene–Early Pliocene Cool-Water Platform (Sequences 5, 4, 3)

Tectonic tilting combined with the late middle Miocene global sea level fall (Haq et al., 1987; Figure 6) exposed middle Miocene and older innermost shelf strata. Sequences 5, 4, and 3 all accumulated seaward of the sequence 6B steep platform margin, and there is no record of them overlying any more landward parts of the platform. Sequence 5 is of very local distribution, occurs adjacent to the base of the escarpment (Figure 5), and has internal reflectors indicating upward and outward accretion from the base of the escarpment. Localization of this sequence to the central and eastern part of the area probably is a result of the steepness of the escarpment; the sequence is present only where the escarpment is steeper than 2.2–2.4°, and does not occur farther west where the escarpment progressively decreases to a low angle (<0.6°) ramp. We interpret this feature as a lowstand wedge (Figure 20) that formed as sea level fell dramatically in late middle Miocene, reaching its lowest level at the end of the middle Miocene. Such an interpretation implies that the Little Barrier Reef at that time was a shoreline cliff, subaerially exposed much like the seaward cliffs of the Nullarbor Plain are today, and subject to meteoric diagenesis. The geometry of sequence 5 is remarkably similar to the debris aprons occurring below the Pleistocene escarpments of modern reef platforms today that consist of the products of debris accumulation and lowstand reef growth (James and Ginsburg, 1979; Grammer et al., 1993).

Sequence 4 is confined to relatively deep water and is mainly stratified, but with some mound complexes. This sequence is difficult to decipher because it was not sampled in Jerboa 1, and its distribution, geometry, and stratal relationships provide few unambiguous indications of depositional conditions. The aggradational geometry and widespread distribution indicate, however, that there were no areal or vertical constraints on

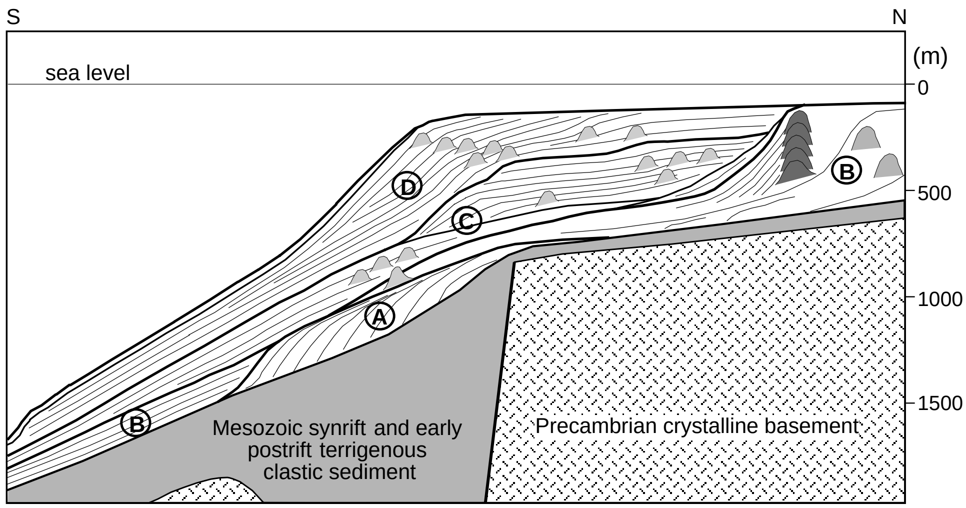


Figure 19—Schematic north-south diagram (dip section) from the Eucla Shelf to the upper continental slope showing the relationship between the four interpreted depositional phases. Phase A corresponds to sequence 7 on Figure 5; phase B corresponds to sequences 6A and 6B; phase C corresponds to sequences 5, 4, and 3 (see Figure 20); and phase D corresponds to sequences 2 and 1.

sediment accumulation. The presence of broad, low-relief mounds points to a return to cooler water deposition following the warm subtropical or tropical interval responsible for the Little Barrier Reef. Sequence 4 best corresponds to the late Miocene lowstands (Figures 6, 20).

Sequence 3 has a distinctive ramp geometry, abuts the Little Barrier Reef escarpment, is dominantly aggradational, and can be divided into a stratified lower portion and biogenic mound-rich upper portion. None of the mounds in this succession have the attributes of coral reefs. All of the mounds are located inboard and do not form a barrier of any sort. This cool-water ramp likely represents increased accommodation during the latest Miocene and early Pliocene relative highstands (Figure 20).

The tops of both sequence 4 and sequence 3 are truncated by a major erosional unconformity marked by abrupt reflector truncation. The location of this erosional surface in deep water implies marine erosion controlled by current flow.

Phase D: Pliocene–Pleistocene Highstand Cool-Water Platform (Sequence 2)

This extensive late Neogene platform buries all older sequences seaward of the sequence 6B escarpment, laps down onto the outer shelf, and directly underlies the late Quaternary surficial cool-water sediment veneer (Figures 5, 17). We interpret this sequence as a cool-water deposit correlated with exposed marine late Pliocene and Pleistocene highstand deposits throughout southern Australia (Figure 6). An innermost shelf, feather-edge component of this platform is exposed along the seaward margin of the Nullarbor Plain as the Roe Calcarenite.

This late Neogene sequence probably is composed of sediments similar to those of the modern shelf and upper slope (Feary et al., 1993b; James et al., 1994). The upper surface is truncated by both the high energy of the present environment and by erosion and nondeposition during the repeated high-amplitude, short-period sea level fluctuations of the Pleistocene. These dynamics, although preventing much shelf sediment accumulation, did result in carbonate detritus being moved seaward and deposited below wave base at or beyond the shelf edge as a shelf-margin wedge. In an environment of minimal tectonic subsidence, this deposition resulted in essentially horizontal progradation of the shelf edge over most of the area (although slightly oblique progradation over the Eyre subbasin indicates that there was minor continued compaction and base-level sag). Oceanographic conditions immediately beyond the shelf edge were suitable for abundant organic growth to produce the linear trend of deep paleoshelf edge mounds that were progressively buried by the advancing progradational sediments. Occurrences of onlapping and downlapping reflections within sequence 2 resulted from minor sea level fluctuations.

DISCUSSION

Platform Growth in the Context of Southern Ocean Paleo-Oceanography

With the exception of the short interval in the latest early Miocene–early middle Miocene, the post-Paleocene faunal record across Australia's southern margin indicates a prevalence of cool to subtropical surface water conditions (James and Bone, 1991; McGowran et al., 1997) corresponding to sea surface temperatures of generally less than

20°C. Although there is also faunal evidence for intermittent intervals of warm subtropical to tropical conditions during the Oligocene and late Quaternary (Shafik, 1992; Almond et al., 1993), these warmer intervals apparently resulted from northward movement of the Subtropical Convergence Zone, and possibly also involved increased flow of warm Leeuwin Current waters into the western GAB; however, the brevity of these intervals has meant that they had little impact on the overall sedimentary record.

Based on correlation with the onshore sequence, we infer that the escarpment zone containing reefs is the offshore equivalent of the Nullarbor Limestone. The escarpment was deposited in the global warm period during the latest early Miocene–early middle Miocene (Savin et al., 1985). It is unclear whether input of a warm Leeuwin Current watermass accentuated the effects of global warming in the western GAB. We suggest that these reefs are warm subtropical or tropical reefs that grew close to sea level in waters of perhaps 18–22°C.

Comparison With Other Extant Cenozoic Platforms

With the documentation of the Eucla Shelf presented here, there are now seismically imaged examples of four major Cenozoic carbonate platforms: the Great Bahama Bank, West Florida Shelf, northeast Australia margin, and Eucla Shelf. Each platform has its own individual characteristics that prevent its definition as an ideal example (the Great Bahama Bank on a leeward margin, the erosive currents of the West Florida Shelf, the northward drift from cooler to warmer depositional realms of northeast Australian platforms, and tectonism in the midst of growth of the Eucla Shelf). Nevertheless, they respectively represent carbonate platform deposition in situations that are wholly tropical, subtropical, warm-water with an initial cool-water phase, and cool-water with a warm-water phase. The differing seismic geometries within these platforms provide insights into the variability of response to the different factors controlling platform evolution in a range of temperature regimes.

Great Bahama Bank

The leeward margin of the Great Bahama Bank is a thick accumulation of markedly prograding seismic sequences (Eberli and Ginsburg, 1987, 1989), but of a different character than the prograding clinoforms of the Eucla basin. Great Bahama Bank sequences, beginning in the late Oligocene, are either (1) simple sigmoid sequences that have no obvious reef structures and are thought to be continuous slopes of platform-derived sediments extending into the basin (i.e., ramps) or (2) complex sigmoid-oblique sequences that are interpreted as a platform margin of reefs or carbonate sands separating subhorizontal lagoonal and steeply dipping forereef facies. Eberli and Ginsburg (1989) suggested that these geometries characterize warm-water highstands (complex sequence) and lowstands (simple sequence) in this tropical area. These correspond to the same sequences that we interpret as cool-water ramp and warm-water reef platform, respectively, illustrating the difficulties in classifying the nature of carbonate platforms on geometry alone.

The latest middle Miocene is represented by a strong reflector interpreted as an exposure surface. Earlier Oligocene–Miocene sequences are aggradational and progradational, grading upward from simple sequences to complex sequences. The late Miocene–Holocene sequences, although still progradational, have a greater aggradational component than underlying sequences, implying increased accommodation space. This is opposite to the Eucla Shelf situation, illustrating the strong local control of relative sea level as a function of the relationship between subsidence and rates of sediment production.

West Florida Shelf

The West Florida Shelf, located in a subtropical setting with incursions of fresh water from the Mississippi and periodic current-induced upwelling, is characterized by ramplike architecture throughout the Cenozoic (Mullins et al., 1988; Gardulski et al., 1991). This platform was affected by large-scale gravity collapse in the latest early Miocene, followed by rapid infilling by prograding clinoforms. Similar to the Eucla Shelf, but on a smaller scale, the early middle Miocene is characterized by the presence of local carbonate reefs occurring sporadically along the outer shelf, perhaps attesting to global oceanic warming during this highstand, as well as to local effects. Deposition during and following the latest middle Miocene was dramatically affected by strong flow of the Loop Current, as a consequence of oceanic closure of the central American seaway. Sea level fall in the late Miocene resulted in a widespread karst unconformity, which is now overlain by Pliocene–Pleistocene slope-front-fill clinoforms.

The history of the West Florida Shelf particularly illustrates the importance of oceanographic effects on platform deposition because the intensification of current flow resulted in the transformation from

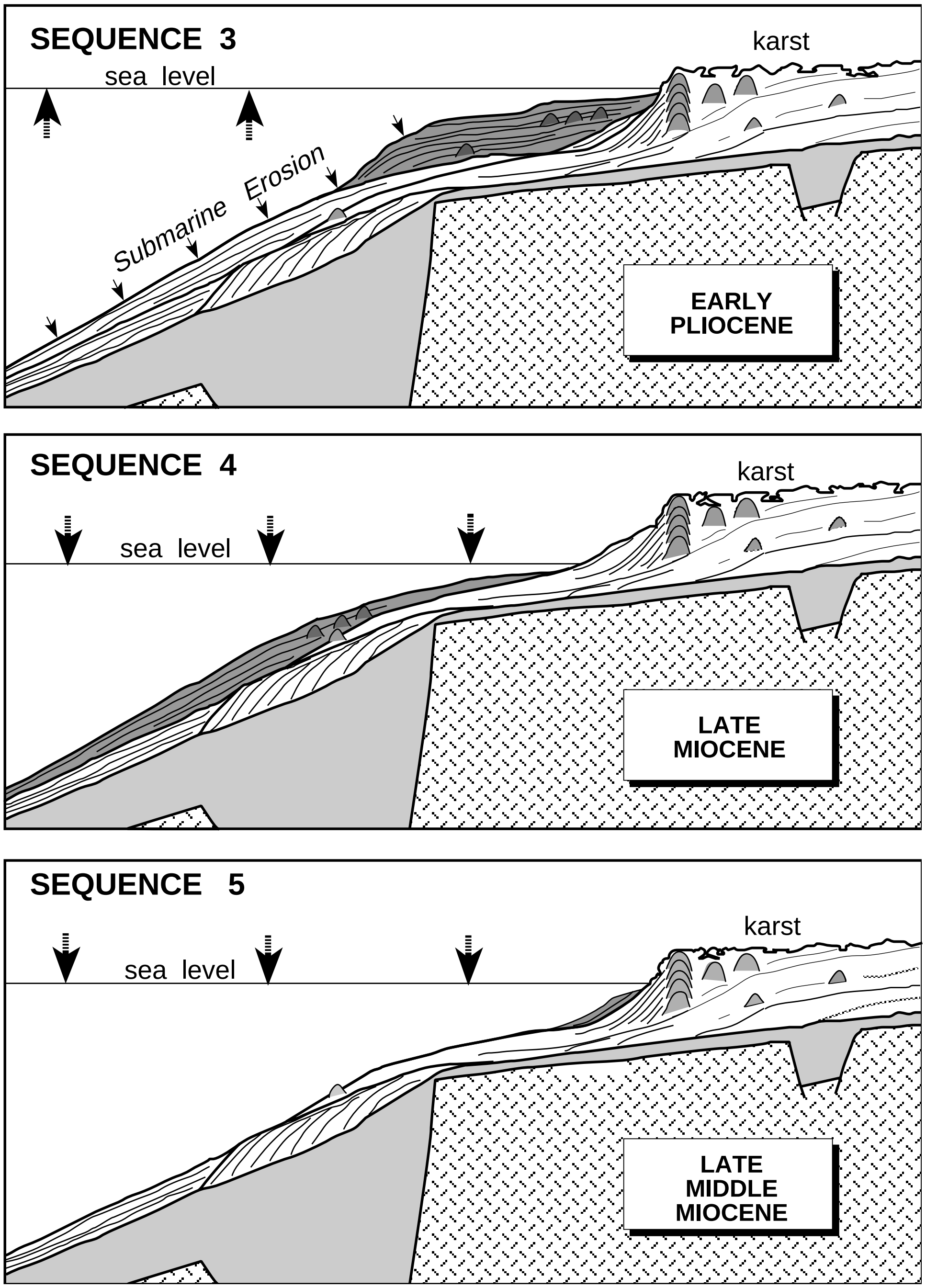


Figure 20—Schematic diagram, based on seismic data, showing the interpreted depositional history relative to sea level movements for depositional phase C, corresponding to sequences 5, 4, and 3.

prograding clinoform deposition fundamentally controlled by sea level fluctuations to current-controlled pelagic ramp deposition. We interpret the erosional truncation of Eucla basin sequences 3 and 4 reflectors during the Pliocene to be the result of a similar along-slope current; however, in this case the oceanographic effect was short lived, and later Pliocene–Pleistocene deposition was again fundamentally controlled by sea level fluctuations.

Northeast Australia Platforms

Analysis of extensive seismic data over the carbonate platforms of northeast Australia enabled the identification of rifting, subsidence, plate motion and collision, and paleo-oceanographic and sea level fluctuations as the factors controlling the development of these platforms (P. J. Davies et al., 1989). Ocean Drilling Program drill holes on the Great Barrier Reef margin (Davies et al., 1991) resulted in a more detailed understanding of the factors controlling Pleistocene progradation and aggradation on this margin. Feary et al. (1993a) showed that sequence geometry at the Great Barrier Reef shelf edge was controlled by the interaction between sediment supply (controlled by formation of the outer barrier reef) and depositional base-level variations (controlled by sea level fluctuations), with the progradational phase reflecting relatively high rates of sediment supply from the warm-water, tropical carbonate shelf. Although probably representing a considerably greater time interval, the shelf-edge component of the Pliocene–Pleistocene sequence 2 in the Eucla basin succession displays remarkably similar progradational clinoform geometry. We similarly speculate that this geometry was controlled by the interaction between eustatic sea level fluctuations (acting on a stable, essentially nonsubsiding shelf margin) and sediment supply derived from the extensive cool-water carbonate shelf of the GAB. The similarities between these two areas indicate that water temperature is not one of the factors controlling shelf-edge depositional geometry, although with the proviso that rates of deposition may vary considerably between warm- and cool-water realms.

Implications for the Older Rock Record

Earlier studies of cool-water carbonates have been largely on the microscale or mesoscale (Nelson, 1988; Boreen and James; 1995; James and Clarke, 1997) and focusing on sediment composition, facies dynamics, and local sequence analysis. This study provides the macroscale perspective for these sediments that is so important if they are to be recognized elsewhere, and if they are to be useful for interpreting ancient limestones. This analysis of the Eucla Shelf platform indicates that seawater temperature and sea level are fundamental in determining the nature of any carbonate platform. The attributes most affected are geometry of the internal packages and rates at which the structure grew. The images of cool-water sequences from the Eucla Shelf are remarkably similar to the numerous illustrated examples of carbonate ramps from the rock record (Burchette and Wright, 1992). These similar geometries indicate that Cenozoic cool-water ramps are good analogs for many ramps in the older rock record, but with the caveat that not all ancient ramps are cool-water in origin.

CONCLUSIONS

The modern southern Australian continental margin constitutes the largest cool-water carbonate platform on Earth. Seismic stratigraphic analysis of the offshore succession in the western GAB shows that the Eucla basin contains a discontinuous record of predominantly cool-water carbonate sedimentation throughout the Cenozoic, and that deposition was controlled by the interaction between sea level fluctuations and tectonic and paleo-oceanographic processes. This analysis indicates that the earliest Cenozoic sequence was a Paleocene(?)–middle Eocene progradational siliciclastic wedge with reflector geometry dictated by accommodation constraints. This analysis also indicates that deposition of this sequence was controlled by the interaction between sea level fluctuations and tectonic movements associated with formation of the Eyre subbasin. The overlying middle Eocene–early middle Miocene carbonate shelf evolved from an extensive cool-water ramp to a warm-water rimmed platform as a consequence of (1) influx of open-oceanic cool waters resulting from development of the Southern Ocean basin following separation of Australia and Antarctica, (2) restriction of terrigenous sediment input arising from the tectonic stability of the basin hinterland, and (3) the transition to a warm-water environment during the early middle Miocene climatic optimum, with the possible contribution of warm waters by the Leeuwin Current. Late middle Miocene tilting and uplift of the platform and a eustatic fall in sea level resulted in the middle(?) late Miocene debris apron at the foot of the steepest part of the subaerially exposed platform rim. Cool-water, lowstand deposition during the late Miocene–early Pliocene was restricted to the outer shelf seaward of the reef escarpment, and was terminated by a major erosional episode. The final depositional phase reflects Pliocene–Quaternary highstand cool-water deposition in a swell-dominated paleo-oceanographic regime, and resulted in an extensive seaward-prograding ramp with numerous biogenic mounds.

We conclude that in the western Great Australian Bight, paleo-oceanographic variations produced seismic geometries that are strikingly different depending on sea-surface temperature. Broad, low-relief buildups and ramp morphology resulted from cool-water depositional processes, contrasting with higher relief reefs and rimmed platform morphology resulting from warmer water deposition. In the case of these ramps, organic growth potential apparently was distributed over a much greater water depth range and, accordingly, over a much broader area compared with the warmer water platform where the reefs that formed the platform rim concentrated organic growth potential into a narrow zone close to sea level.

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