Tectonic and sedimentary history of the Argo Abyssal Plain, eastern Indian Ocean


Bathymetric and seismic reflection profiles totalling about 2800 km, and covering about 110 000 km² of the Argo Abyssal plain, have been analysed. The early emplacement of oceanic crust and volcanic edifices (Late Jurassic and Early Cretaceous) was followed by cooling, and marked subsidence until the Miocene. The principal structural features have been identified as the right-laterally sheared Wombat Graben in the south, the N-S trending Joey Rise in the west, the parallel sediment-filled Joey Graben to its east, a NW-trending eastward tilted and subsided volcanic massif to its east, a NW-trending linear volcanic massif on the old oceanic plate farther east, the deformed and uplifted sediments and basement in the north, and the central basin with 1.2 km thick sediments. The Joey, Wombat and Kiwi Grabens are newly identified.

The N-S trending Joey Graben is 400-450 km long, parallel to and east of the Joey Rise, and it is filled with up to 1 km of sediment. Beneath it, the mantle has been identified at depths of 12–15 km and deepening westward. The other two grabens form units hundreds of metres deep, at the foot of the Australian margin in the south. The right-lateral displacements in the axis of the Wombat Graben reflect the initial shearing and rifting of the thinned crust. The widespread faulting in the basement, and the persistence of some faults upward into sediments as young as early Miocene, indicate that tectonism was marked until then. The eastern and northern parts of the abyssal plain have been uplifted as they came within the peripheral fore-bulge south of the Sunda Trench.

Five sequences (A–E) overlie the oceanic crust and they have been correlated with the lithology of ODP Site 765 and DSDP Site 261. They probably represent Plio-Pleistocene, upper Miocene–lower Pliocene, middle Miocene, upper Oligocene–lower Miocene and uppermost Jurassic to lower Cretaceous strata, respectively. The depositional trends in the Mesozoic and Miocene sediments are controlled by basement structure. Isopach maps of the Mesozoic and Cainozoic sediments reveal that their maximum thicknesses are about 0.6–0.8 km and 0.2–0.4 km, respectively, with the bulk of the sediments (calcarenite turbidites and claystone) laid down in the Early Cretaceous and the middle Miocene to Pliocene. During the Oligocene to early Miocene period (37–16 Ma), a remarkable geologic event led to non-deposition or erosion of sediments.

Introduction

The Argo Abyssal Plain in the northeastern Indian Ocean is bounded by the Australian continental marginal plateau (Exmouth/Wombat and Scott) in the south and east, the eastern Sunda Arc–Trench in the north and the Joey and Roo Rises in the west (Fig. 1). The plain’s oceanic crust is the oldest, 108–156 Ma, in the Indian Ocean. Volcanic rises separate the Argo Abyssal Plain from the Gascoyne Abyssal Plain to the west. The plain is a quadrangle with water depths generally exceeding 5000 m, and it is a depositional plain with a regional inclination down to the southwest. Important papers dealing with the plain include Cook et al. (1978), Heirtzler et al. (1978), Hinz et al. (1978), Powell & Luyendyk (1982), Veevers et al. (1985), Powell & Luyendyk (1988), Fullerton et al. (1989), Pilipenko & Sivukha (1990), Exxon et al. (1982), and Gradstein & von Rad (1991). Other important papers are included in the DSDP and ODP volumes of Veevers et al. (1974); von Rad et al. (1992), and Gradstein et al. (1990, 1992).

Mesozoic M10–M25 magnetic anomalies are aligned N 70°E, and offset by northwest-trending fracture zones (Powell & Luyendyk, 1982; Fullerton et al., 1989). The crust was drilled at Deep Sea Drilling Project (DSDP) Site 261 and Ocean Drilling Program (ODP) Site 765 (Figs 2 and 5), and the site investigations revealed the litho-, bio- and magneto-stratigraphy of the sediments, and the magnetostratigraphy of the igneous basement. In the south, ODP Site 765 identified 155 Ma oceanic basement, as compared to the older age (160 Ma, pre-Oxfordian) of the basal sediments in the north, identified at DSDP Site 261. Thus, both site investigations confirm the Jurassic opening of the Indian Ocean, but some uncertainty about the exact age of initial opening of the plain remains. The present geomorphological and seismic investigations were done to map structural elements, the nature and temporal distribution of sediments, and the tectonics of the Argo Abyssal Plain region. Study of the sediments helps decipher the ongoing tectonic processes at the time of their deposition.

The study area of about 110 000 km² covers the Argo Abyssal Plain and lies in water depths exceeding 5000 m (Fig. 1). The various morphological units of the plain and the bordering continental margin (plateaus, rises and ridges) were identified from the bathymetric and seismic reflection studies. The data used in this study are six north–south and nine east–west profiles, totalling about 2800 line km (both multichannel and single-channel seismic) within the Argo Abyssal Plain, and carried out by the Soviet Research Vessels “Izvestedativ”, “Yuzhmorgeologiya”, and “17 Syed Profosyuzov” during 1986–1988 under the auspices of the Trans Indian Ocean Geotraverse (Fig. 2). Seismic sequences were identified using the reflection patterns on seismic records (Figs 3 and 4), and correlated with the sequences in ODP Site 765. The chronostatigraphie of the sequences is interpreted by correlation with the DSDP and ODP results. Isopach and structure contour maps were prepared from the interpreted seismic profiles.

Regional distribution of seismic sequences in the Argo Abyssal Plain

Five seismic sequences have been recognised (A–E, Figs 3 and 4A–D). Ages and average thickness are shown in Table 1. This study is complementary to that of Buffer (1994 — see this issue), who has correlated ODP Site 765 and DSDP Site 261 in the eastern Argo Abyssal Plain with key horizons and sequences on a seismic line that connects the sites. A correlation of Buffer’s seismic sequences with ours is shown in Figure 5.
Figure 1. Geomorphology of the Argo Abyssal Plain.

Table 1. Seismic sequences.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Lithostratigraphic Age</th>
<th>Average thickness in depocentres (m)</th>
<th>Seismic character</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>L. Miocene, Recent</td>
<td>150</td>
<td>Well-stratified</td>
</tr>
<tr>
<td>B</td>
<td>L. Miocene, E. Pliocene</td>
<td>150</td>
<td>Well-stratified, semi-transparent</td>
</tr>
<tr>
<td>C</td>
<td>M. Miocene</td>
<td>300</td>
<td>Well-stratified, semi-transparent</td>
</tr>
<tr>
<td>D</td>
<td>Oligocene, E. Miocene</td>
<td>150</td>
<td>Well-stratified</td>
</tr>
<tr>
<td>E1</td>
<td>Palaeogene</td>
<td>200</td>
<td>Well-stratified, semi-transparent, Hummocky clinoforms</td>
</tr>
<tr>
<td>E2</td>
<td>L. Jurassic, Cretaceous</td>
<td>200</td>
<td>Hummocky clinoforms</td>
</tr>
</tbody>
</table>

The reflectors of the seismic sequences A to D are parallel laminated; the lower sequence E is subdivisible into a lower discontinuous sequence E2 which has hummocky clinoforms, and an upper ubiquitous sequence E1 which is continuously stratified and acoustically semi-transparent. Several broad submarine depressions, filled with Late Miocene and Quaternary sediments (sequences A and B) were reported by Cook et al. (1978). The present study, of the morphology of basement (Fig. 6) and the surface of the plain (Fig. 1), delineates the major structural elements (Fig. 7); Wombat Graben, Joey Graben, northern and eastern steps; central basin; volcanic massif and Sunda Rise. The thickness of the various sequences in the different structural elements is summarised in Table 2.

The total sediment thickness within the plain is generally 1.0–1.2s two-way time (TWT) (Fig. 8). The Mesozoic and Cainozoic sediments are about 0.8s and 0.4s in maximum thickness (Figs 8 and 9). The major morphological units on the plain are described below.

The Wombat Graben
The newly defined sediment-filled Wombat Graben, at the northern foot of the Wombat Plateau of the northwestern Australian shelf base, is about 35 km long, 20 km
Figure 2. Generalised bathymetry (in metres) of the Argo Abyssal Plain area and index map of the study area. Tracks of seismic reflection and bathymetric investigations (dashed lines). Very thick lines refer to parts of seismic profiles shown in Figures 3 and 4. Thick dashed and continuous lines represent fracture zones and magnetic chronos respectively (after Powell & Luyendyk, 1982). Open and closed circles represent DSDP and ODP drill sites, respectively. Stippled areas mark the identified continental crust (after Vevers et al., 1985).

Table 2: Sediment thickness of Argo Abyssal Plain structures.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Thickness of seismic sequences (m)</th>
<th>Total sediment thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[A]</td>
<td>[B]</td>
</tr>
<tr>
<td>Wombat Graben</td>
<td>30-130</td>
<td>70-110</td>
</tr>
<tr>
<td>Joey Graben</td>
<td>130-160</td>
<td>60-200</td>
</tr>
<tr>
<td>The western and eastern parts of volcanic massif</td>
<td>100-150</td>
<td>70-200</td>
</tr>
<tr>
<td>Axial graben</td>
<td>170-200</td>
<td>140-200</td>
</tr>
<tr>
<td>Central basin</td>
<td>120-240</td>
<td>220-270</td>
</tr>
<tr>
<td>Axial graben in central basin</td>
<td>100-160</td>
<td>210-220</td>
</tr>
<tr>
<td>Northern step</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>Eastern step</td>
<td>170-190</td>
<td>100</td>
</tr>
<tr>
<td>Average thickness in the grabens and depressions</td>
<td>140</td>
<td>130</td>
</tr>
</tbody>
</table>

Note: Thickness in metres estimated using average velocity of 2.2 km/s on sediments (after Bolmer et al., 1992).
wide and several hundred metres deep (Figs 4 and 9 D). It trends almost WNW close to the edge of the Argu Abyssal Plain, and is bounded by the Wombat Plateau in the south and a basement high in the north. There are several elongated, 10–12 km long, basement depressions reaching depths of 6800–7000 m, within the central graben and bounded by basement faults. These trend northwesterly, oblique to the graben edge, and are right-laterally displaced (Fig. 6). Gradual deepening and thickening of seismic sequence E occurs towards the north (Fig. 4D); its reflectors are nearly parallel and acoustically semi-transparent. Sequence D is absent in the axial graben, and reflectors in sequences C to A onlap underlying sequences and basement. The older sequence E gradually thins southward up the plateau slope (Fig. 4D). In the graben, axis sediments are up to 1.2s thick. The NNE-trending Kivi Graben (Figs 6 and 7), separated from the Wombat Graben by the Joey Rise, is also a newly defined similar feature that lies NW of the Wombat Graben, north of the Australian margin and between the Joey Rise and a basement high farther west.

The Joey Graben

The newly defined Joey Graben is a north-south trending, 400–450 km long and 20–25 km wide feature, in 5400–5800 m water depths, with a smooth seafloor (Figs 3 and 4 B). It parallels and lies east of the Joey Rise and is oblique to the Mesozoic oceanic fracture zones (Figs 6 and 7). Multichannel seismic reflection profiles covering the eastern Joey Rise and part of the graben reveal intense reflectors dipping towards the Joey Rise at 9.0 to 10.5s (ca. 12–15 km) depth. The graben extends northward beyond the Joey Rise to terminate against the Roo Rise (Fig. 4B). It consists of local subgrabens trending west-northwest to north-south (Fig. 6), which have faulted basement blocks bounded by normal faults (Figs 3 and 4 B). The maximum sediment thickness within the graben is about 1.8s (TW1), and a maximum of about 0.6s of Mesozoic sediments is confined to the central graben close to the eastern slope of the Joey Rise. Miocene and Pliocene-Pleistocene sediments are about 0.2s thick in the graben and they thicken to the east.

The southern, north-trending, subgraben is about 150 km long and contains up to 1.0s of sediments. The northern, WNW-trending, subgraben is 100 km long and has sediments about 0.6s thick. Basement is generally about 6400 m deep (Fig. 6). In the northwest of the northern subgraben, upper Miocene (Sequence B) sediments are covered by Pliocene-Pleistocene (Sequence A) mass-wasting deposits from the Joey Rise (Fig. 4 B). Sequence C sediments are absent in the central Joey Graben. Numerous basement faults extend through the older sediments (Sequences D and E) and displace them. Sequences A, B, and C thicken eastward, while sequence D thins and dips eastward. The variable disposition of the depocentres implies changes in the tectonic regime with time.

Step-like structures

In the northeast of the plain, two steps within the basement are separated by a northeast-trending basin (Figs 7 and 8). Within the northeastern basin, small linear grabens separate the northern and eastern steps (Fig. 6). The northern step is broad and dips gently to the southeast and east (Figs 4 A and 6). It is down-faulted southward by up to 400 m, forming local horsts (around 6000 m
Figure 4. Line drawings of analogue seismic reflection records (TWT in seconds): A, B, C, D, and E are identified seismic sequences. A: Profile across the central basin and northern step; B: Profile across the Jomo Graben; C: Profile across the volcanic massif; D: Profile across the volcanic massif; E: Profile across the volcanic massif.
Figure 5. Lithological log of ODP Site 765 and correlation with our seismic sequences. ODP seismic sequences and lithological descriptions from Gradstein et al. (1990).

Deep and grabens (around 6400 m deep) about 5 to 6 km wide. The seismic sequences in the area can be grouped into two units. The lower sequences (C, D and E) fill the axial graben and are up to 0.7–0.8s thick. Sequence E sediments are up to 0.2s thick within the deepest parts of local grabens. The top of seismic sequence D is an unconformity which dips southward, with the lower reflectors of Sequence C overlapping it. All seismic sequences thin to the north toward the Sunda Rise (Fig. 4 A). Sequences E and D are dislocated by basement faults, resulting in local antilene-like structures. The sediments are between 0.25–0.8s thick on the northern step, and 0.45–0.85s on the eastern step. Up to 1.0s of sediment occurs at the intersection of the northern and eastern steps, where the basement is broken by numerous fractures (Fig. 6). Seismic sequence E is absent in the north (Fig. 4 A). Flexural deformation decreases upward. Local folds, in both acoustic basement and sediments, form a chain of subsurface hills in the northeast (Fig. 6).

Central basin

The central basin covers a large area of the plain (Figs 4A and 7). Sediment thickness varies from 1.0s to 1.2s (Fig. 8), and the thickest sediments are in the southeast where Mesozoic sediments of Sequence E are present. Sequence E is nearly twice as thick in the axial parts of the grabens within the basin as it is on basement rises. The entire central basin is covered with Cainozoic sediments 0.5–1.0s thick. Isopachs of the Plio-Pliocene reveal a dominant northeast–southwest trend (Fig. 9 D), concurrent with the Mesozoic crustal features, but unlike...
the intervening sequences.

Flexural deformation of sequences E, D and C occurs above most of the fracture zones. Acoustically transparent zones, within parallel and horizontal seismic sequences, are widespread through sequences C, D and E and above local basement rises. Cook et al. (1978) identified them as mud diapirs, but the present multichannel seismic records show that the “diapirs” are faulted folds, and seismic reflectors continue across them. Seismic sequences A, B and C onlap onto them.

The graben northeast of the volcanic massif (Figs 4C and 7) is 12-20 km wide and contains 1.0 to 1.2s of sediments, and basement there is 6850-7000 m deep. The lower sequences and basement are severely faulted against the eastern slope of the volcanic massif, and sequences D and E thin up its slope.

**Volcanic massif**

Southwest of the central basin are two lengthy NW-trending features: an oceanic basement rise and a volcanic massif further west (Figs 4C and 7). The volcanic massif itself consists of three linear basement ridges separated by two linear depressions or grabens. At a number of places basement ridges reach the sea floor (Fig. 8). Several local grabens, and submarine seamounts with complex structure, occur along the western part of the massif. Sediment thickness varies from zero on some of the volcanic seamounts to 1.0s in the grabens. In this area, the basement subsides in steps (Fig. 4A). West of the massif, the down-faulted basement consists of blocks 2-8 km wide, which are displaced 100-150 m by faults. A seismic section across the axial graben of the volcanic massif reveals downfaulted basement blocks, 70-80 km wide, at 6400-6600 m depth.

Thus, the eastern part of the volcanic massif (Fig. 4C)

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**Figure 6. Map of depth to acoustic basement (depth in metres). Open and closed circles represent the DSDP and ODP drill well locations, respectively.**
is characterised by a less-rugged basement than the western part. Sequence E is thicker above deeper basement: 0.05–0.15s above the uplifted blocks, and 0.2–0.3s in depressions. It is everywhere overlain by about 0.1–0.2s of sequence D, and about 0.2s of sequence C. The C and B sequences unconformably overlie the older sequences on the eastern volcanic massif. Sequence B is 0.1 to 0.2s thick.

Crustal structure, sequences and tectonic evolution

Seismic sequences

The seismic sequences A, B, C, D and E are generally present throughout the Argo Abyssal Plain, excepting sequence C in the Joey Graben and sequence D in the Wombat Graben.

In large areas of the Argo Abyssal Plain, the Mesozoic (sequence E) and Early Cainozoic (sequence D) sediments occur in palaeodeeps, in areas of downfaulted basement. DSDP site 261 revealed Cretaceous pelagic clays with glauconite in the northeastern plain (Veevers et al., 1974), while ODP Site 765 revealed hemipelagic clays and claystones overlain by calcareous turbidites in the southeast (Gradstein et al., 1990). This points to thick infill of pelagic sediments and turbidites in the grabens close to the continental margin, and pelagic sedimentation on the northeastern plain. Further, downfaulted basement, and faulting of the overlying Mesozoic to early Miocene (E and D) sediments in the central basin, the grabens of the volcanic massif, and the step-like structures, clearly indicate relatively intense tectonism till the end of the
early Miocene. The confinement of the oldest sediments to the axial graben denotes early faulting, and its control of sedimentation. The regional tilt of the abyssal plain, with the basement deeper in the south and southwest, and higher in the west and in the north in the tectonic bulge south of the Sunda Arc, may have developed early, on the evidence of the thicker older sequences there.

The low frequency and high amplitude reflections of seismic sequence D mark near-bottom, high-energy sedimentation. DSDP site 261 revealed a sharp reduction of the sedimentation rate in the early Paleogene, and palaeogeographic changes. A notable change in near-bottom sedimentation at the end of the early Miocene (sequence C) is inferred. Sequence D dips eastwards in the Joey Graben (Fig. 4 B) and across the adjacent volcanic massif, due to tectonism during the Oligocene/Miocene period. This may have caused erosion or non-deposition, as suggested by the absence of sequence C.

Gradstein & von Rad (1991) interpreted structural tilt northward of the Wombat Plateau into the Argo Abyssal Plain as having been caused by isostatic rebound due to subsidence of the Wombat half-graben (south of the plateau) along normal faults unloading it in the latest Jurassic, just before breakup. The faulted basement and the overlying Mesozoic sediments also suggest early tectonic activity of the area.

Increase in areal extent with time, and the thickness of sequences C to A, point to gradual migration of depocentres to the east, and increase in extent of sedimentation with time. The ubiquitous Plio-Pleistocene sediments of sequence A gradually thicken eastward. However, there are notable changes in sedimentation during the Oligocene-Miocene period (37–16 Ma) as shown by the absence of middle Miocene sediments (sequence C) in the Joey Graben; the presence of upper Oligocene–lower Miocene (sequence D) sediments northwest of the Wombat Graben;

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**Figure 8. Isopach map of total sediments. Thickness values are in seconds (TWT). Open and closed circles are DSDP and ODP drill well locations, respectively. KG = Klvi Graben; WG = Wombat Graben.**
and the identification of the top of sequence D as an unconformity south of the step-like structures in the northern Argo Abyssal Plain. Bottom currents probably resulted in erosion or non-deposition.

**Tectonics**

The widespread fault-controlled deformation of earlier sediments, and the less-widespread deformation of younger sediments, suggest continued compressional stress, which is more pronounced in the northeast than the south. The basement in the northeast is broken into numerous local blocks 50–70 km across with vertical displacements of 250–300 m. Deformation continued until the early Miocene in the north, much later than in the south. Furthermore, there are altogether different structural and tectonic fabrics on either side of the volcanic massif (Figs 6 and 7). The presence of Upper Jurassic–Cretaceous and upper Oligocene–lower Miocene sediments along the slopes of the extinct volcano on the massif suggests that it originated in the Upper Jurassic. Downbending and increasing thickness of seismic sequences E and D toward the volcanic massif, with flat-lying sequences above them, mark its subsidence till the late Miocene (about 14 Ma). The increase of basement depth and earliest sediment thickness north of the Wombat Graben, and the right-lateral shift of the axial parts of the graben (Fig. 6) appear to be a manifestation of the initial shearing and rifting of the crust. Thick Mesozoic and Cainozoic deep-sea basin sediments surrounding the Australian continental margin in the Indian Ocean were also reported by Piplinenko & Sivukha (1990), who believed that they originated during an early stage of graben/basin evolution.

In the deep grabens, the basement contour map (Fig. 6) shows about 7000 m depth to acoustic basement, and the total sediment isopach map (Fig. 8) shows about 1200 m thickness of sediments. The individual isopachs of Mesozoic to upper Miocene sediments are closely controlled by the northwest structural trend of the Mesozoic ocean floor.
A comparison of the isopacks of the Mesozoic, upper to middle Miocene, and Plio-Pleistocene, with maps of basement features (Figs 6, 7 and 9), shows how sediment distribution has changed with time. The Mesozoic isopack (Fig. 9 B) represents the sediments that infilled the Late Jurassic to Early Cretaceous volcanic surface, and shows obvious control by the basement features. In the various areas, different basement features exert control: in the far north, NE trends; in the east, centric and northwest, NW trends; in the south the WNW-trending Australian continental margin, and in the west the north-trending Joey Rise. The sequence is absent only on local highs, and most of the plain is covered by more than 0.4s of section. There are local depocentres along the Australian margin where sediment was derived as turbidites from Australia (as first mapped off the Swan Canyon by Cook et al. 1978). There was little deposition between the Early Cretaceous and the Miocene.

The Miocene isopack (Fig. 9 C) shows that the area sediments was smaller than in the Mesozoic, with little deposition near the Australian margin, and the depocentre was in the middle of the abyssal plain. NW-trends predominate in the central basin and NE trends in the north. The Plio-Pleistocene isopack (Fig. 9 D) is similar to the Miocene isopack, but NE-trends are prominent farther south, perhaps because of cracking of the oceanic crust in that direction, as it climbed the peripheral fore-bulge of the Sunda Trench. The tilt down to the south, and the deposition of unstable volcanic ash from the Indonesian Arc, caused the flow of sediment to the south.

Seafloor spreading started with early Mesozoic anomaly M26 (ca. 156 Ma). Spreading ridges trend NE and there are complementary NW-trending fractures zones. The trends of the major grabens like the Joey Graben (Fig. 7), oblique to the fracture/transform trends in the plain, point to further shearing and rifting of the crust in NNE to northerly directions. Seismic reflectors at 9.0-10.5s (12-15 km) depth near the Joey Rise are most likely from the upper mantle. The shallow mantle in the Joey Graben, and the right-laterally displaced axial parts of the Wombat Graben, suggests the present shallow rifted and rifting crust in the grabens. In the southwest, too, the volcanic massif subsided till the Oligocene-Miocene, and there is early block-faulting of basement on either side of it. The regional tilt and increasing areal extent of the sediments on the accumulative plain to the south, and the shearing, rifting, subsidence and faulting of basement until the Miocene period, have been the keys to the present structural configuration of the Argo Abyssal Plain.

Conclusions

The Argo Abyssal Plain is limited by the Sunda Trench to the north, the Joey and Roo Rises to the west, the Scott Plateau and Rowley Terrace to the east, and the Exmouth Plateau to the south (Fig. 1). It started to form in the Late Jurassic as Gondwana broke up, and the Late Jurassic and Early Cretaceous oceanic crust should, according to magnetic mapping (e.g. Fullerton et al., 1989), be structured by fracture zones trending NNW and spreading ridges trending ENE. However, the basement structure of the western two-thirds of the plain mapped here does not show these trends at all (Fig. 6): the dominant trend is west to west-northwest is much of the area, northeasterly trends predominate in the north, and northerly and northwesterly trends in the north. This discrepancy could be the result of limitations in the mapping of the magnetic trends by various workers, or of the seismic mapping reported here, together with a complex tectonic history. In both cases, the line-spacing is open at 50 km or more, and perhaps we must await the release of GEOSAT images to be sure of the fabric. The volcanic edifices of the Joey and Roo Rises were built soon after the ocean floor formed.

The isopack maps show the broad changes in sediment pattern with time (Figs 8 and 9) and these can be related to the depositional pattern in ODP Site 765 (Fig. 5). The Mesozoic saw widespread sedimentation, about 400-600 m thick, of bentonite and clays, and carbonate and other types of turbidites (Fig. 5), derived largely from erosion of the Australian margin. Fan-like depocentres were present along the Australian margin, both in the area of the Wombat Plateau mapped here (Fig. 9 C), and in the area farther east off the Swan Canyon mapped by Cook et al. (1978). The trends in the isopacks mimic the basement trends in many areas, but northwesterly trends are more common in the isopack than the basement map (Fig. 6), for unknown reasons.

The next major sequence is the Miocene (Figs 5 and 9 C), consisting of carbonate turbidites, debris flows and clay deposits. It is thinner than the Mesozoic, averaging 300 m thick, and is not as widespread around the margins of the abyssal plain. Trends in the isopacks are not dissimilar to those in the Mesozoic, with northeasterly trends prominent in the north, and northwesterly trends in the centre of the plain. The Plio-Pleistocene isopack (Fig. 9 D) shows a similar distribution and thickness to the Miocene isopack, but the northwesterly trends have largely been eliminated by sedimentation. This sequence consists of carbonate turbidites and debris-flow accumulations, much like the earlier ones (Fig. 5).

The structural and isopack maps, and the seismic sections, suggest that on-going movement on basement faults affected sedimentation through into the Miocene, but in the Plio-Pleistocene the only tectonism has been the uplift of the Sunda Trench peripheral fore-bulge as the plain moved north, and associated jostling of the northwesterly trending faults. The basement and the abyssal plain tilts southwestward down from the fore-bulge, and some seismic evidence suggests that turbidites are flowing in that direction. However, that tilt does not apply in the southwest, with its rugged basement relief.

The map of crustal structural elements (Fig. 7) summarises the tectonic situation. It shows the importance of northeast to north-northeast-trending structures in the north and west: Roo Rise, northwest graben, Sunda Rise, northern step, and northeastern basin. Northwesterly and northerly trends predominate in the southwest, with a series of NW-trending volcanic massifs and troughs, and the Joey Graben stretching about 400 km to the north, from east of Joey Rise to join the northwest graben. Along the WNW-trending Australian margin in the southwest (Fig. 6), the subsidence of the Australian margin has developed a moat up to 50 km wide, which extends eastward from the Kivi Graben of Figure 6. Figure 7, although a sketch, does indicate that the interplay of seafloor spreading, later volcanism, continental subsidence, and movement northward into the peripheral fore-bulge, has probably involved strike-slip as well as normal faulting. The seismic evidence of shallow mantle (12-15 km) below the Joey Graben suggests thinned crust.
that may have been readily sheared.

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References


