2 Maps of late Mesozoic–Cenozoic Gondwana break-up: some palaeogeographical implications

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The nature and positions of neighbouring land areas have been significant factors in the evolution of the Australian flora, both directly in determining migration routes and indirectly in influencing ocean currents and climate. The maps (Figures 2.3 to 2.10) show the approximate positions of the continents at 10 million years (Ma) intervals from 150 Ma onwards, based on the data of Scotese & Denham (1988), with modifications referred to in the notes below. Separation of continental fragments by sea-floor spreading was commonly preceded by rifting. Where the relative motion of the fragments was oblique, some fault blocks were uplifted and eroded and others were deeply buried by sediment, resulting in zones with a varied and changing mosaic of complex environments by comparison, for instance, with adjacent interior areas. These zones, peripheral to the Australian land mass, are shown together with some of the larger areas of sedimentation and volcanicity (from BMR Palaeogeography Group, 1990) which would have influenced soil type and vegetation. The time scale shown in Figure 2.1 has been used for the reconstructions. The key for Figures 2.3–2.10 is shown in Figure 2.2.

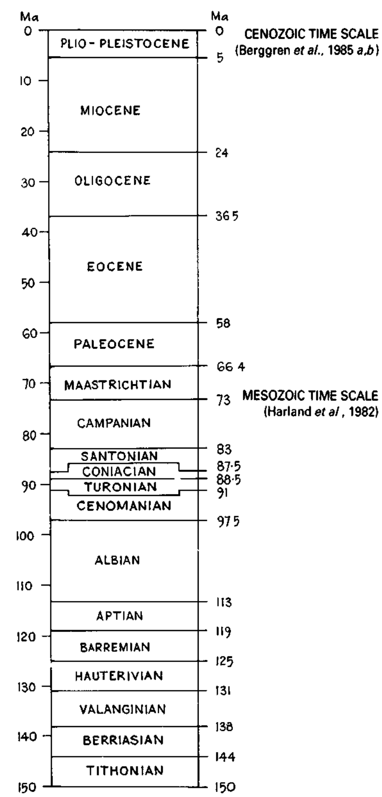


Figure 2.1 Time scale on which the following palaeogeographical maps are based.

150 Ma (Figure 2.3)

At about 150 Ma the 'Antarctic' coastline of Gondwana was positioned close to the South Pole

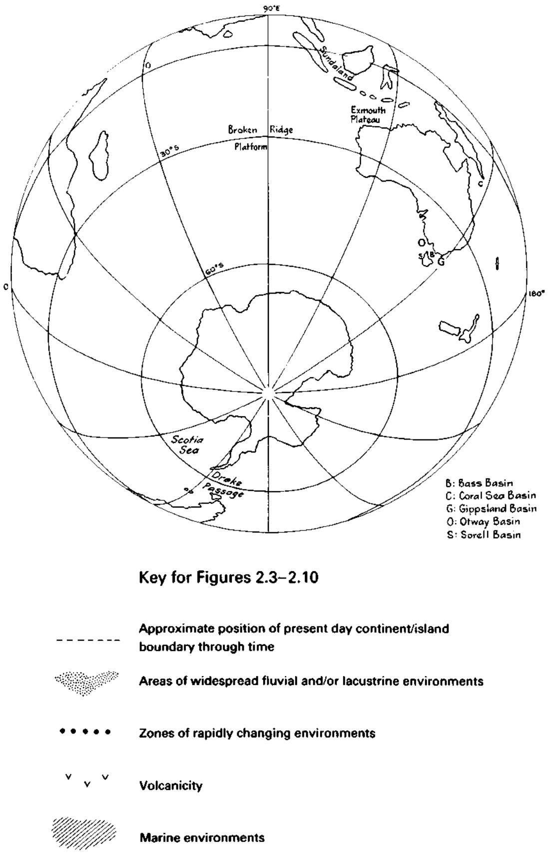


Figure 2.2 Reference to localities referred to in the text, and the key to symbols used in Figures 2.3–2.10.

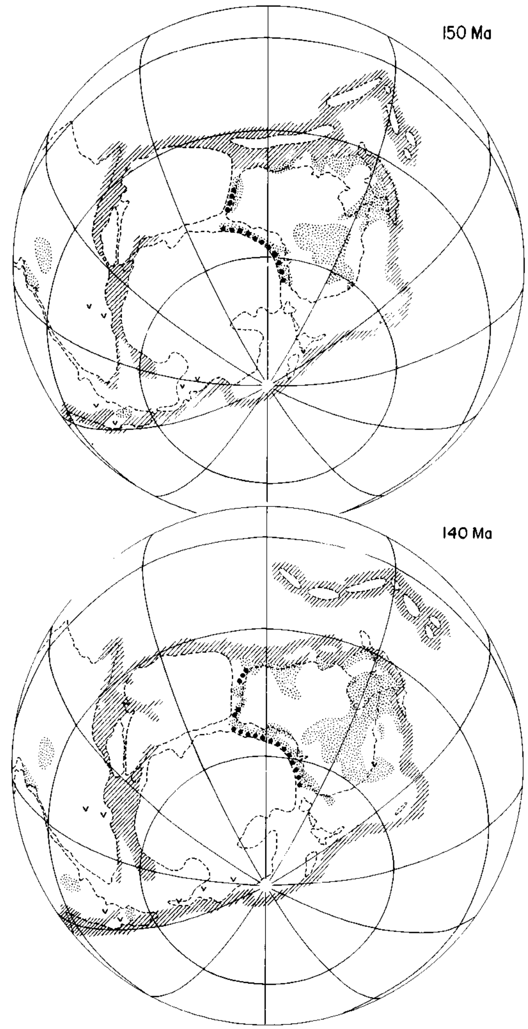


Figure 2.3

and western Tethys was connected to the proto-Pacific Ocean. Continental slivers from the north-east margin (Northwest Shelf region of Australia) and eastern tip (New Guinea region) of Gondwana may have rifted off periodically and been carried northwestwards from Permian time onwards. Such fragments now lie in South Tibet and various parts of Southeast Asia, but little definitive information exists on their time of movement and even less on their palaeogeographical configuration during transit across Tethys. Following Audley-Charles *et al.* (1988), who favoured a later, rather than earlier migration of fragments, the maps show them as a string of possible islands, assuming most departed after the Callovian (*c.* 167 Ma) sea-floor spreading event along that part of the edge of Gondwana. The fragments accreted to the southeastern part of the then Asian continent to form a promontory (Sundaland), which has remained in equatorial latitudes to the present day. It is shown on the maps by a group of 'hypothetical' islands to indicate possible 'stepping stone' links between Australian Gondwana and the Asian mainland, although the palaeogeography of the area will have changed quite dramatically with time.

At about 150 Ma, the present-day eastern Australian coastline was separated from the proto-Pacific Ocean by a strip of terrain now marked by the present-day Lord Howe Rise, Queensland Plateau and New Caledonia.

Gondwana break-up was preceded, in early to mid-Jurassic time, by widespread basaltic magmatic activity (dolerites of Tasmania, southeastern Australia; Karoo dolerites of South Africa; Ferrar Super Group, Dufek Intrusion in Antarctica), reflecting a major thermal event. By 150 Ma, movement between Africa–South America (West Gondwana) and Antarctica–Madagascar–Greater India–Australia (East Gondwana) had been initiated. However, the break-up was dominated by strike–slip movement, narrow basins were formed and it is likely that land connections between the two major fragments existed from time to time. Rifting along the southern margin of Australia was initiated at about this time (Willcox & Stagg, 1990).

140 Ma (Figure 2.3)

By 140 Ma narrow seaways existed along much of the split between Africa and Antarctica–Madagascar–Greater India–Australia and the fragments from the northeastern margin of Gondwana had moved towards the Equator. The incipient separation of Australia from Antarctica and Greater India was marked by the continued developments of rifts along the former's western and southern boundaries, although evidence for sedimentation in East Antarctica is virtually restricted to recycled palynomorphs (Truswell, 1983). Rifting along Australia's southern margin was accompanied by initial extension in a northwest to southeast direction of about 300 km and this was accomplished by about 120 Ma (Willcox & Stagg, 1990). New Zealand at this time was part of a considerable land mass flanking East Antarctica and southeast Australia. This land mass probably reached its greatest extent in the Early Cretaceous as a result of the Rangitata Orogeny (Stevens, 1989).

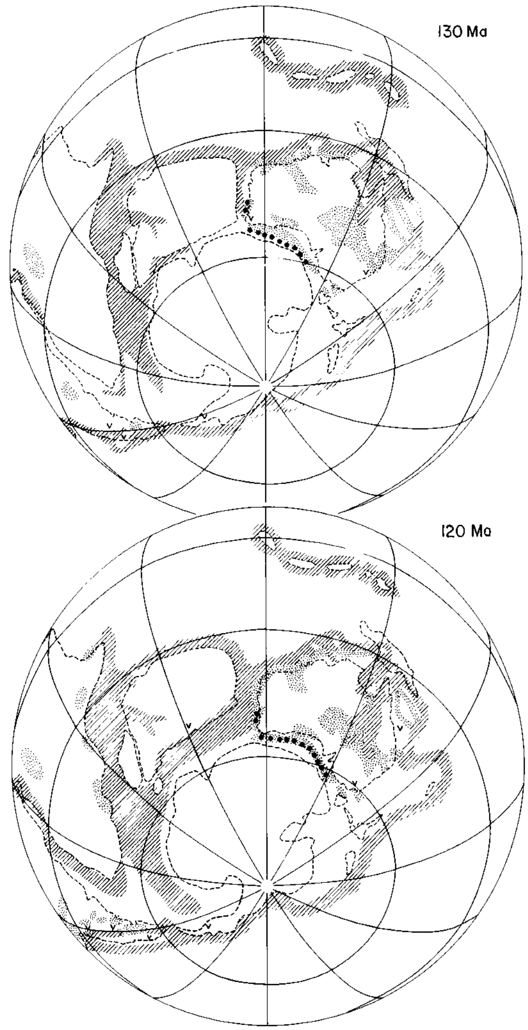


Figure 2.4

130 Ma (Figure 2.4)

By 130 Ma, Greater India, Australia and Antarctica had begun to move apart, although no significant seaways had developed between them (Powell *et al.*, 1988), the rate of separation between the last two being of the order of only a few millimetres per year. Break-up began at the southwest margin of the Exmouth Plateau at about 132 Ma and progressed southwards, then eastwards along the southern margin of Australia. The South Atlantic started to open about this time, propagating northwards (Nurnberg & Muller, 1991).

120 Ma (Figure 2.4)

By 120 Ma, substantial seaways existed along the east coast of Africa and between Greater India and Antarctica–western Australia. The slow continental extension between Australia and Antarctica continued but the earlier NW–SE direction changed to NNE–SSW with movement in the east of 120 km leading to the formation of the Gippsland and Bass Basins and modifying the development of the Otway and Sorell Basins (Willcox & Stagg, 1990).

110 Ma (Figure 2.5)

The map shows the Australian continent at the height of the marine transgression that culminated in the Aptian (*c.* 116–113 Ma), when extensive areas were covered by shallow seas. At about this time rifting commenced along the southeastern ('Australian') margin of Gondwana, and along the western margin of New Zealand, the former eventually leading to the formation of the Tasman Sea (Stevens, 1989). Rifting, together with the rotation of crustal blocks locally, affected the Antarctic Peninsula and adjacent areas of West Antarctica until about 100 Ma but had no major effect on the overall geography (Storey *et al.*, 1988). Spreading between Australia and Antarctica allowed the proto-Indian Ocean to enter from the west, initiating the formation of the Southern Ocean.

100 Ma (Figure 2.5)

By 100 Ma, erosion and subsidence had reduced the land masses around New Zealand, allowing the sea to flood a number of rift zones, although a land connection to Antarctica persisted in the south (Stevens, 1989). Uplift of the Australian Eastern Highlands may have started about this time, associated with the subsequent opening of the Tasman Sea (Wellman, 1987). At about 95

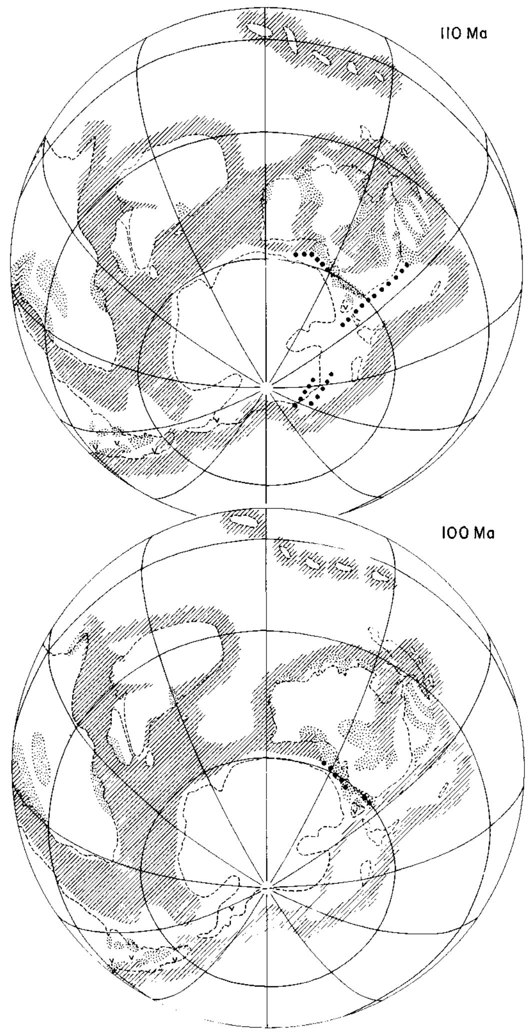
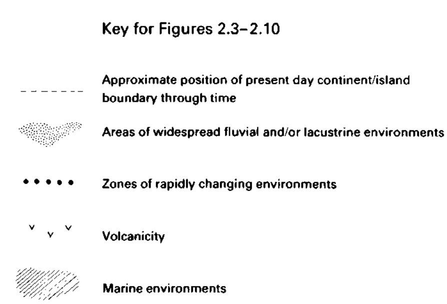


Figure 2.5



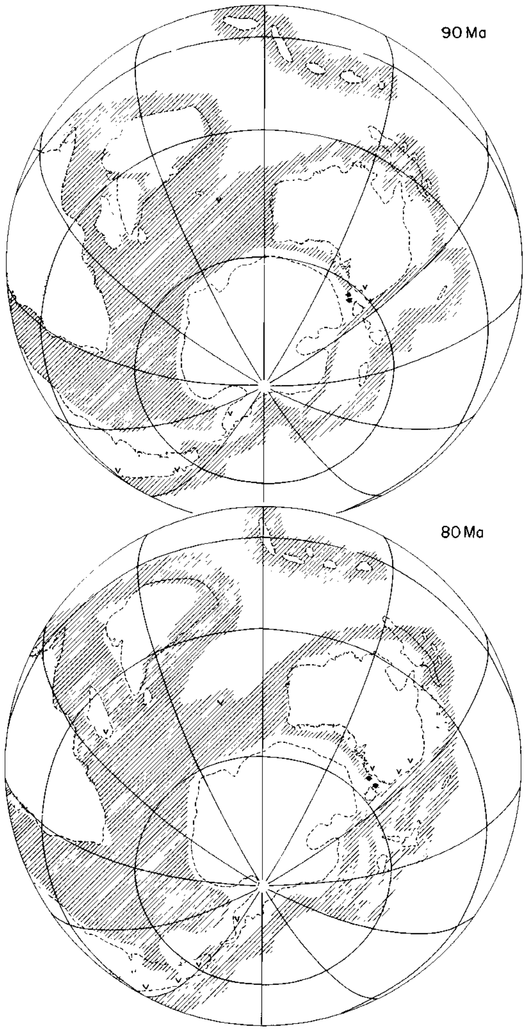


Figure 2.6

Ma the rate of Greater India's northward movement rapidly increased.

90 Ma (Figure 2.6)

Slow sea-floor spreading in a NNW direction between Antarctica and Australia continued until, by about 90 Ma, a tongue of the proto-Southern Ocean extended almost to Tasmania. Sea-floor spreading also resulted in the establishment of open ocean in the Tasman Sea and to the south of New Zealand isolating 'New Zealand' and 'New Caledonia' from the remainder of Gondwana (Stevens, 1989). Following Stevens (1989, figs. 5, 6), we show a land link between 'New Zealand' and 'New Caledonia' until about 70 Ma, although direct evidence for this is lacking. Subaerial volcanism existed in the open ocean west of Australia from 90 to 60 Ma, sited at the northern edge of the Broken Ridge platform (Rea *et al.*, 1990), and might have provided a 'stepping stone' for floral migration.

At about this time sea-floor spreading was under way between northeastern Australia and eastern New Guinea, leading to the formation of the Coral Sea Basin by the end of the Paleocene. Coeval sea-floor spreading in the vicinity of eastern New Guinea may have given rise to the separation of continental fragments that, in post-Paleocene times, were carried westwards by Pacific plate movements and are now located in the eastern islands of Indonesia (Pigram & Symonds, 1991).

80 Ma (Figure 2.6)

Madagascar separated from greater India at about this time, both being isolated in a surrounding ocean. Tasmania was still close to Antarctica and connected to Australia, the present-day Bass Strait area being occupied by mainly lowland, depositional environments until flooded by the sea in the Oligo-Miocene.

70 Ma (Figure 2.7)

The paucity of clastic sediments of this and earlier Late Cretaceous ages on and around the Australian continent (except for parts of the tectonically active southern margin), together with the widespread presence of thick, weathered profiles, indicate that relatively uniform humid climates were typical of much of Late Cretaceous time (G. E. Wilford, R. P. Langford & E. M. Truswell, unpublished data).

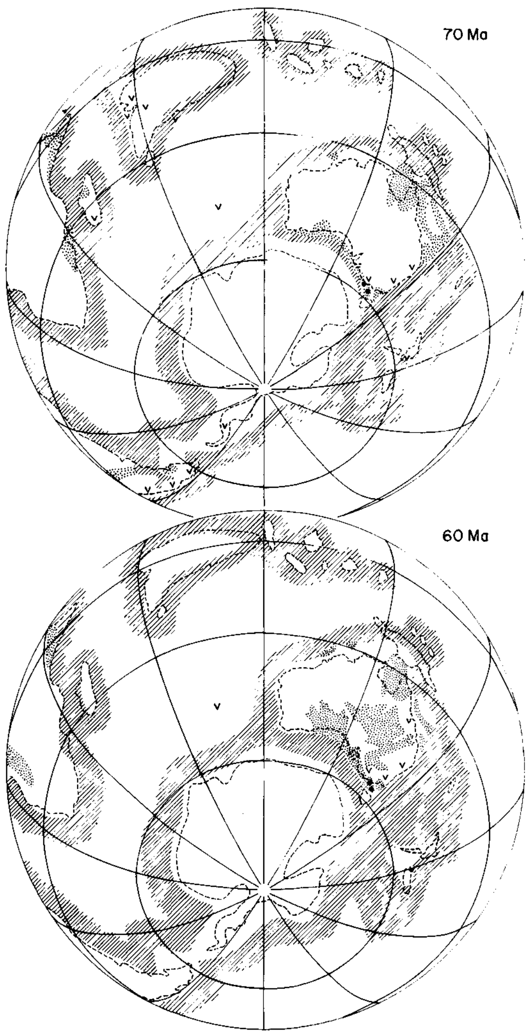


Figure 2.7

Key for Figures 2.3–2.10

Approximate position of present day continent/island boundary through time

Areas of widespread fluvial and/or lacustrine environments

Zones of rapidly changing environments

Volcanicity

Marine environments

60 Ma (Figure 2.7)

By about 60 Ma, sea-floor spreading ceased in the Tasman Sea, although Australia's slow northward drift away from Antarctica continued. In the early Cenozoic, one or more cooling events, probably associated with ice build-up on Antarctica, triggered widespread erosion and deposition across much of Australia. Broad, swampy, alluvial channels were formed in the west, and extensive sandy fans accumulated in the east (G. E. Wilford, R. P. Langford & E. M. Truswell, unpublished data). These conditions continued intermittently until about Early Oligocene.

50 Ma (Figure 2.8)

Uplift of the Transantarctic Mountains at about this time (Fitzgerald & Gleadow, 1988) would have encouraged accumulation of snow and ice which was to become a major feature of Antarctica for much of the remainder of the Cenozoic.

40 Ma (Figure 2.8)

At about this time movement of the Pacific Plate changed from a northerly to a more west-northwesterly direction, resulting eventually in collision with the Australian Plate in New Guinea and mountain building there from the mid-Oligocene onwards (Pigram & Symonds, 1991) and subduction of the Australian Plate beneath Sundaland. At about 44 Ma, the spreading rate between Australia and Antarctica increased as the former moved northwards, and by about 38 Ma a deep marine strait had formed between Tasmania and Antarctica (Kennett, 1980), allowing circum Antarctic oceanic flow for the first time and resulting in the increased cooling of Antarctica and the adjacent oceans.

Until about this time microcontinental blocks formed a link between the Antarctic Peninsula and South America. They have subsequently become dispersed by plate movements and sea-floor spreading, associated with the opening of the Scotia Sea. However, considerable uncertainty

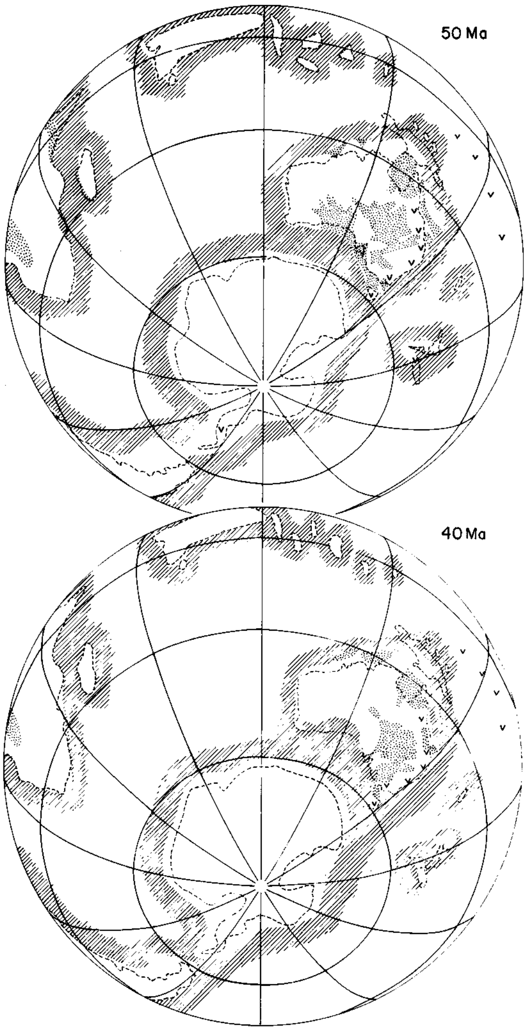


Figure 2.8

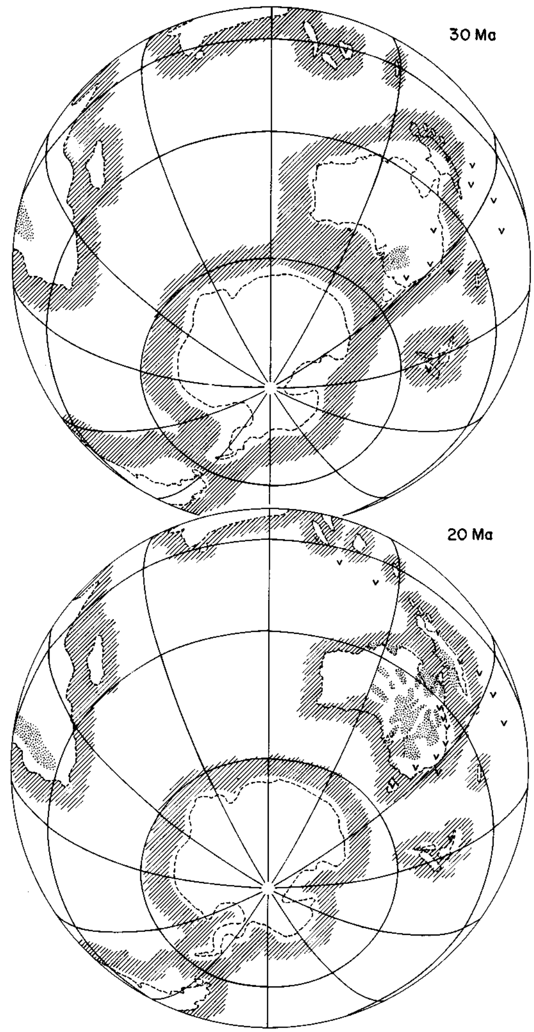


Figure 2.9

surrounds the exact timing of the opening of Drake Passage, the oceanic seaway between the Antarctic Peninsula and southern South America. Lawver *et al.* (1985) suggested the Passage opened between 64 and 34 Ma, whilst Barker & Burrell (1977) favoured a younger age of 30–25 Ma.

A possible 'stepping stone' island on which Cretaceous limestone and chert were exposed existed in the vicinity of Broken Ridge, a submarine feature 2000 km west of Perth, about 42 Ma but was probably short lived (Rea *et al.*, 1990).

30 Ma (Figure 2.9)

Large-scale ice sheet development became established in East Antarctica by Early Oligocene (38–36 Ma) times (Ocean Drilling Program, 1988), causing a change to a much drier climate over much of Australia and the formation of widespread duricrusts (G. E. Wilford, R. P. Langford & E. M. Truswell, unpublished data).

Although there is no evidence for a land connection between New Caledonia and Australia during the Tertiary, volcanic islands between the

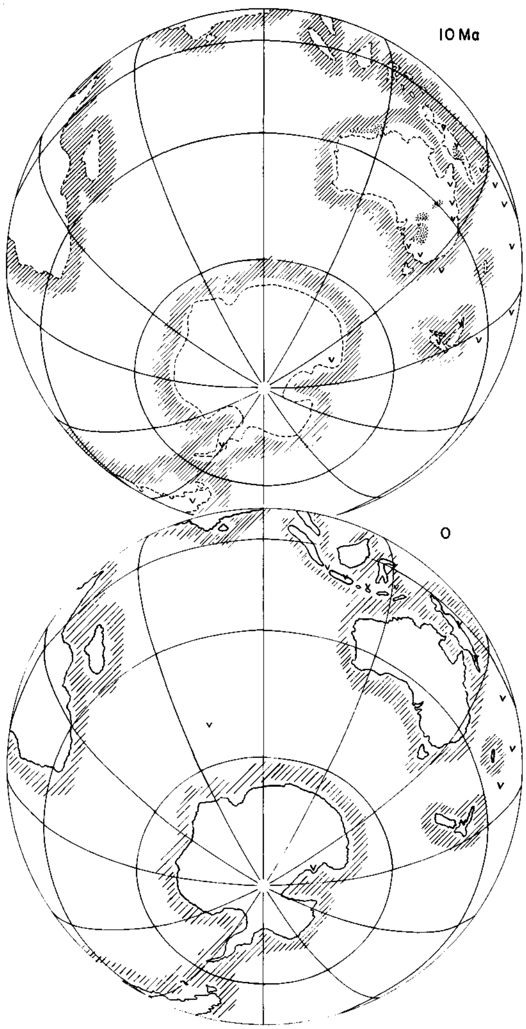
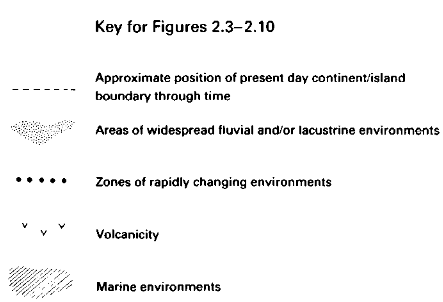


Figure 2.10



two from about 30 Ma onwards could have influenced plant migration during the Neogene. Except for Lord Howe Island, just over 6 million years old, these islands are now submerged and form seamounts in the Tasman Sea (McDougall & Duncan, 1988).

Major mountain building in New Guinea dates from about 30 Ma (Pigram & Symonds, 1991).

20 Ma (Figure 2.9)

By 20 Ma, Australia's drift towards the equator had brought its northern fringes within the reaches of a tropical monsoonal climate, resulting in bauxite formation at well-drained coastal sites. Elsewhere, rivers flowed in channels and basins that were active in the early Tertiary, but less rainfall and a partly duricrusted surface reduced erosion. Lakes were common.

As the Australian plate continued to collide with that of Southeast Asia, sporadic volcanism along the junction provided island connections between the Southeast Asian mainland and the Australian continent that have persisted, albeit in a changing form, to the present day.

10 Ma (Figure 2.10)

By 10 Ma and despite the continued equatorwards movement of the Australian continent, the expansion of Antarctic ice sheets began to cause increasing aridity, particularly in the interior of Australia. This resulted in less widespread erosion and deposition compared to that in earlier periods.

The Australian plate's northward movement has continued to the present day, with accompanying volcanic activity along the junction with the Pacific plate in the rugged mountainous terrain of Papua New Guinea.

During the Quaternary the waxing and waning of polar ice caps produced sea level fluctuations that resulted in large areas of the continental shelf periodically becoming dry and both Tasmania and Papua New Guinea being continuous with the continent during these times.

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