

Seafloor spreading around Australia

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(a) Abstract

The Australian Plate has undergone major changes in plate boundary geometry and relative plate velocities since the breakup of Gondwanaland. We illustrate the history of seafloor spreading around Australia by reconstructing gridded ocean floor ages and plate boundary configurations in a fixed Australian reference frame. In the Argo Abyssal Plain, seafloor spreading started at M25 dated as 154.3 Ma Late Jurassic (Oxfordian). The onset of seafloor spreading west of Australia at ~136 Ma marks the breakup between Greater India and Australia. Roughly at the same time, long-lived subduction east of Australia ceased, probably due to subduction of the Phoenix-Pacific spreading ridge, changing this plate boundary to a transform margin. A drastic change in spreading direction between the Indian and Australian plates from NW-SE to N-S occurred at about 99 Ma. Slightly later, at 95 Ma, rifting started between the Lord Howe Rise and eastern Australia, resulting in the opening of the Tasman Sea. The spreading direction between Australia and Antarctica changed from NW-SE to N-S at chron 27 (~61 Ma), accompanied by the initiation of rifting between Broken Ridge and the Kerguelen Plateau. The Coral Sea started opening off NE Australia at the same time and the direction of spreading between the Pacific and Antarctic plates changed. Both the 99 Ma and 61 Ma events could have been caused by the stepwise subduction of the Neo-Tethyan Ridge; the 99 Ma event could also be due to a change in absolute motion of the Pacific Plate. Preliminary reconstructions to close the Pacific-Australian plate circuit based on recently collected geophysical data indicate that a tectonic event at about 43 Ma may mark the onset of renewed subduction east of Australia. Prior to 43 Ma a triple junction formed north of the Ross Sea, accommodating incipient motion between East and West Antarctica. At the same time spreading in the Wharton Basin between India and Australia ceased. Around Late Eocene, subduction of the Solomon Plate north of Papua New Guinea was initiated. Major tectonic events since 20 Ma include the breakup of the Indo-Australian plate, and various collisional processes and plate boundary reorganizations north and east of Australia.

(b) Introduction

We have used isochrons from Gaina et al. in the Tasman Sea and from Gaina et al. (1999) in the Coral Sea, from Mihut west of Australia, and from Müller et al. to construct grids of the age of the ocean floor. The isochrons are based on magnetic anomaly identifications and fracture zone picks from gravity anomalies, which were used jointly to derive finite rotations describing relative plate motions around Australia. Previous studies of the oceanic crust adjacent to the Australian margin (Veevers & Li, 1991; Veevers et al., 1991) have been revised by using the time scales for Mesozoic and Cenozoic magnetic anomaly identifications of Gradstein et al. and Cande and Kent, as used elsewhere in this book. Müller et al. reconstructed the spreading history in an absolute frame of reference. Here we have used their isochrons and rotations to reconstruct gridded ages in a fixed Australian reference frame, to conform with other drawings in this book. Because a wider area was treated, we used a Lambert equal-area projection, and a map centre at 34°S and 136°E. Each continent is covered with a 5° x 5° grid, and the grid about the map border refers to Australia. In the figures, fine stipple denotes continental crust, coarse stipple denotes no knowledge.

(c) M25 Late Jurassic (Oxfordian) 154.3 Ma

Seafloor spreading started along the NW margin in the Late Jurassic. By extrapolating the age of the boundary between the continental and oceanic crust (COB) in the central part of the Argo Abyssal Plain, Müller et al. estimated that break-up between Argo Land and Australia at about 156 Ma. This was the first step along a propagating rift, which migrated S-ward in several steps. The NE Exmouth Plateau margin formed as a stepped transform margin. After the onset of sea floor spreading, Argo Land moved NW relative to Australia.

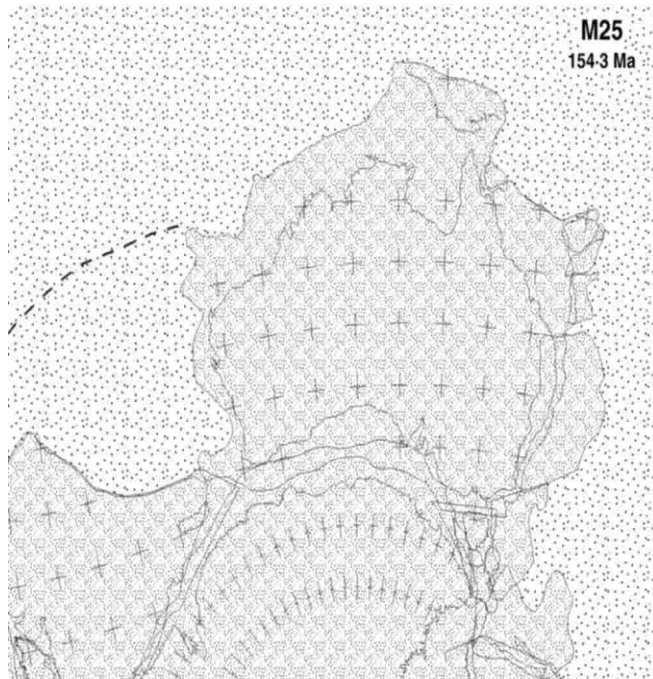


Fig. 1. M25 Late Jurassic (Oxfordian) 154.3 Ma. Seafloor spreading starts off NW Australia. The broken line marks the outline of Greater India.

(d) M10 Early Cretaceous (Hauterivian) 131.9 Ma

At M10 (131.9 Ma), seafloor spreading started in the Gascoyne and Cuvier Abyssal Plains. The Gascoyne Abyssal Plain is separated from the Argo Abyssal Plain to the north by the Roo and Joey Rises, and bounded to the east by the Platypus Spur and the Exmouth Plateau. Fullerton et al. recognised M10 as the oldest anomaly found in all spreading compartments in both the Gascoyne and Cuvier Abyssal Plains, and suggested a nearly simultaneous breakup time along the western Australian margin. According to Müller et al. , three major fracture zones with a N45°W orientation that at M5 time changes to N55°W divide the plain into three sectors; two rift propagation events were recognised.

At about 131.9 Ma seafloor spreading started between Greater India and Australia. Our isochrons in the Perth Abyssal Plain are similar to those of Veevers et al. (1985). The age of breakup between Australia and East Antarctica remains controversial. Based on the identification of seafloor spreading magnetic anomalies adjacent to the margin , or by extrapolation of the spreading rate , the age of separation of Australia and Antarctica has been determined to be around 100 Ma. Stagg & Willcox determined the age of breakup as Valanginian (135 Ma) from the relationship of the continental margin sequences and the oceanic crust from seismic data. Willcox & Stagg demonstrated that the direction of extension and possibly early seafloor spreading south of Australia was NW-SE instead of N-S, as previous suggested, in a pattern since confirmed by gridded gravity anomalies from satellite altimetry . In the southeast, the Otway, Bass and Gippsland Basins were formed during two main periods of Late Jurassic-Early Cretaceous intracontinental extension.

The direction of Late Jurassic extension in Bass Strait is also controversial. Seismic data collected along the southern Australian margin, north of Tasmania reveal extensional features with different orientation: NW-SE, NE-SW and N-S. Etheridge et al. inferred Late Jurassic-Early Cretaceous NNE-SSW extension, Willcox et al. inferred NW-SE transtension, and Hill et al. suggested that Early Cretaceous extension was oriented N-S across an area with NE and NW basement fabric. NE-SW oriented Cretaceous extension between Australia and Tasmania would have led to compression between the South Tasman Rise and East Antarctica, because relative motion between Australia and East Antarctica was oriented NW-SE. The middle Lord Howe Rise continental block east of Tasmania moved together with Tasmania along an incipient NE-SW oriented strike-slip fault that remained active during the 90-52 Ma opening of the Tasman Sea. Therefore, our model for opening the Bass Strait concurs with Willcox et al. , and implies a NW-SE oriented extensional regime from the Naturaliste Plateau to Tasmania in the Cretaceous.

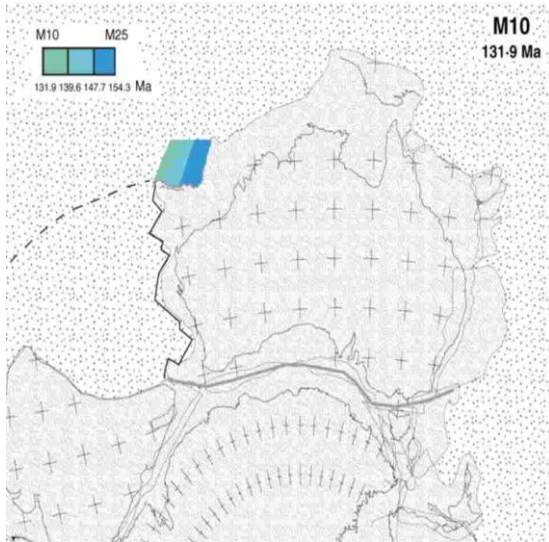


Fig. 2. M10 Early Cretaceous (Hauterivian) 131.9 Ma. Continued seafloor spreading in the Argo area. The ridge propagates S-ward along the margin past the Gascoyne-Cuvier areas,, to the area off Perth. Rifting (grey line) which started in the Late Jurassic continued between Australia and India-Antarctica.

(e) M0 Early Cretaceous (Aptian) 120.4 Ma

At about M0 spreading had started between southern Greater India and Antarctica. A relatively late onset of spreading along the Enderby margin of Antarctica, southwest of Kerguelen, is supported by the lack of identified M-anomalies off the eastern Indian conjugate margin (there are virtually no magnetic data from the Enderby Basin) and by seismic data and the biostratigraphy from the Mac. Robertson Shelf, NW of Prydz Bay, East Antarctica . They found evidence for half-graben formation on the Antarctic margin until at least until the early Aptian, which started at 121 Ma.

Figs 1 to 3 show crustal ages for the Perth, Cuvier, Gascoyne and Argo Abyssal Plains, including oceanic crust on the Indian Plate which is now subducted, based on Müller et al' s plate model. The plate reconstructions illustrate the evolution of the propagating rift which gradually separated Greater India from Antarctica, the development of transform margins as well as the rift propagators, which transferred large parts of the Indian Plate to the Australian Plate.

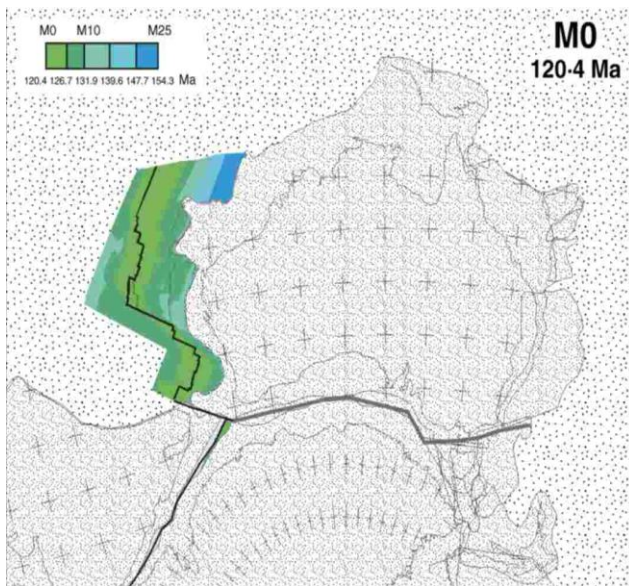


Fig. 3. M0 Early Cretaceous (Aptian) 120.4 Ma. Seafloor spreading off the western margin had widened, with ridge jumps leaving extinct ridges, and the ridge propagated between India and Antarctica. Rifting continued between Australia and Antarctica. Fig. Muller 3

(f) mid-Cretaceous (Cenomanian) 99 Ma within the Cretaceous Normal Superchron (KN)

At 110 Ma, seafloor spreading between Antarctica and India had created sufficient space for the southern Kerguelen Plateau (SKP) to form. In our model, most of the SKP initially formed on the Indian Plate, but it was transferred to the Antarctic Plate by a ridge jump/propagator after 99 Ma, while Elan Bank formed on the Indian Plate.

Early Cretaceous magnetic anomalies in the Gascoyne and Cuvier Abyssal Plains are oriented NE-SW, normal to the fracture zones east of Christmas Island. The pattern of spreading in the Early Cretaceous west of Australia persisted until about 99 Ma, when the spreading direction changed drastically from NW-SE to N-S, resulting in the roughly N-S spreading in the Wharton Basin. This event is expressed by a major bend in many fracture zones and some unusual linear troughs, ridges and knolls visible in Sandwell & Smith's gravity anomaly grid southeast of the Wharton Basin, as described by Müller et al. (1998).

The breakup unconformity on the southern margin of Australia straddles the 99 Ma Albian-Cenomanian boundary between the volcanogenic Otway Group and the quartzose Sherbrook Group, dated by the *Phimopollenites pannosus* palynological zone. Veevers regarded the southern margin breakup and the major tectonic reorganisation between India and Australia as marking the onset of the Potoroo tectonic regime, during the 99 Ma swerve in the Pacific (Veevers, 2000; chapter POT-INNA). The varying distance between the 99 Ma isochron and the M0 isochron west of Australia suggests that west of the Perth Abyssal Plain a major ridge propagation event transferred a 500 x 500-km segment of the Indian Plate to the Australian Plate.

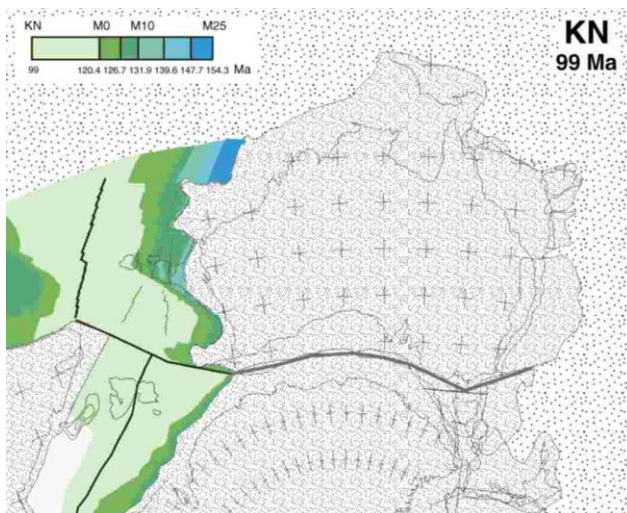


Fig. 4. Mid-Cretaceous (Cenomanian) 99 Ma within the Cretaceous Normal Superchron (KN). Seafloor spreading off the W margin, including a long ridge jump towards India, between India and Antarctica, and from a triple junction in between these systems continued through this normal superchron. Various volcanic upgrowths extended from the Wallaby Plateau to the complexes of the Kerguelen Plateau.

(g) C34 Late Cretaceous (Santonian) 83.5 Ma

According to Gaina et al. 1998), the magnetic fabric of the Tasman Sea shows that the eastern margin does not represent a single pre-breakup isochron. Because the record of the pre-anomaly 33o tectonic history is sparse, the pre-breakup configuration is constrained by strike-slip faults (as in the case of the Lord Howe Rise and the Dampier Ridge) and failed rifts (between Tasmania and the South Tasman Rise, Tasmania and the East Tasman Rise, Gilbert Seamount Complex and the Challenger Plateau). Prior to opening of the Tasman Sea, rifting and a short period of seafloor spreading occurred between Australia and the East Tasman Rise.

Seafloor spreading in the Tasman Sea started first in the south as a result of rifting between the Challenger Plateau (the southern part of the Lord Howe Rise) and the middle part of the Lord Howe Rise. Short-lived left-lateral transtension between the Challenger Plateau and the middle Lord Howe Rise led to the formation of the Bellona Trough before the onset of seafloor spreading in the Tasman Sea. Following this event, the Challenger Plateau, attached to the middle Lord Howe Rise, separated from Australia. Early rifting commenced at about 84 Ma, after short lived strike-slip motion between the Gilbert Seamount Complex and the South Tasman Rise, and

stopped prior to anomaly 33y time when the Gilbert Seamount Complex was transferred to the Challenger Plateau. At 84 Ma, extension began between the subsequent Dampier Ridge (still part of Australia) and the northern part of the Lord Howe Rise creating the Lord Howe and Middleton basins.

The 83.5 Ma reconstruction illustrates that cumulative seafloor spreading between India and Antarctica has been asymmetric, especially in the Kerguelen Plateau area, where about two-thirds of the ocean floor created up to this time has been left on the Antarctic plate, resulting in successive transfer of parts of the Kerguelen Plateau from the Indian to the Antarctic Plate.

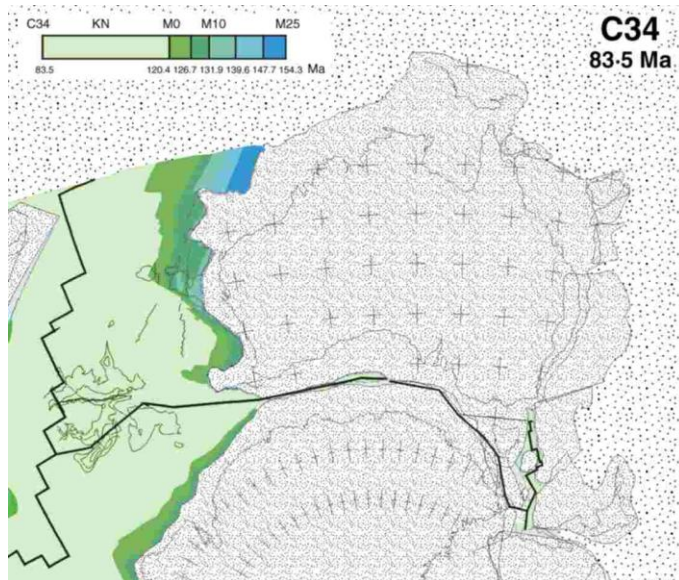


Fig. 5. C34 Late Cretaceous (Santonian) 83.5 Ma. Rapid N-ward spreading continued in the west. Very slow spreading between Australia and Antarctica involved splitting Broken Ridge and the Kerguelen Plateau but by a negligible gap because they lay near the pole of rotation. Cumulative seafloor spreading between India and Antarctica has been asymmetric, especially in the Kerguelen Plateau area, where about two-thirds of the ocean floor created up to this time has been left on the Antarctic plate, resulting in successive transfer of parts of the Kerguelen Plateau from the Indian to the Antarctic Plate. Seafloor spreading and localised rifting started in the Tasman Sea.

(h) C31 Late Cretaceous (Maastrichtian) 67.7 Ma

Gaina et al. (1998) showed that rifting in the Tasman Sea propagated from south to north transferring continental crust from the Australia to the Lord Howe Rise. At 72 Ma the entire Dampier Ridge became attached to the Lord Howe Rise and rifting in the Lord Howe and Middleton basins ceased. The northern Dampier Ridge moved along the Australian margin shortly before the onset of seafloor spreading in the northern Tasman Sea. After C34, the South Tasman Rise (divided into two blocks by a transform fault) started moving southward slowly relative to Australia. The southward movement led to extension between Tasmania (attached to the Australian plate at the time) and the South Tasman Rise and to E-W seafloor spreading between the South Tasman Rise and East Tasman Rise. These events were contemporaneous with the onset of seafloor spreading in the Tasman Sea. The eastern South Tasman Rise became attached to Australia shortly before chron 31y (~ 70 Ma); the west South Tasman Rise became fixed to the east South Tasman Rise at 40 Ma, after about 70 km of left lateral strike-slip.

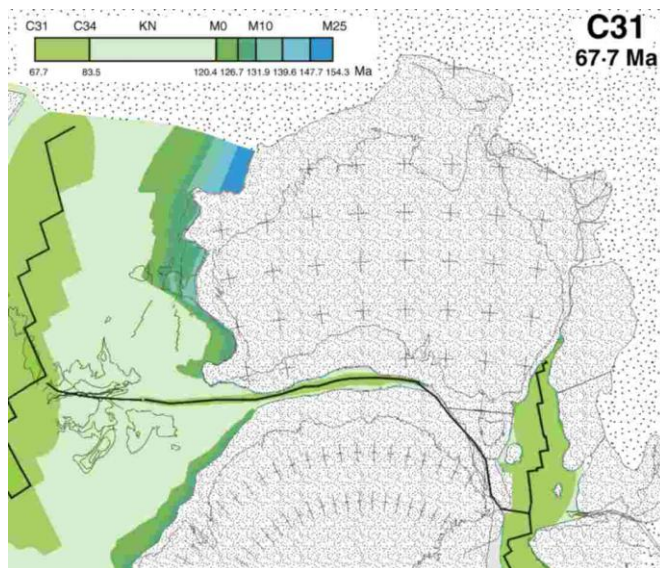


Fig. 6. C31 Late Cretaceous (Maastrichtian) 67.7 Ma. The ridge in the Tasman Sea propagated N-ward. S-ward the ridge propagated between the Campbell Plateau and Antarctica. The ridge jumped N-ward between Broken Ridge and Kerguelen Plateau.

(i) C25 late Paleocene 55.9 Ma

The spreading direction between Australia and Antarctica changed from NE-SW to NNW-SSE. At C27 (61 Ma), a counterclockwise change in the spreading direction led to the fusion of the Bellinghousen Plate in the SE Pacific and West Antarctica, and changed the direction of opening in the Tasman Sea basin. This episode did not affect the western part of the Australian Plate, so that the chain of events that modified the East Gondwanaland margin from 65 Ma to 61 Ma may reflect the change in absolute motion of the Pacific plate from N to NNE associated with an important decrease in spreading rate (from 68 mm/yr to 28 mm/yr), and the attachment of the Bellinghousen Plate to West Antarctica.

The last stage of rift propagation at C28 (64 Ma) separated the Chesterfield Plateau and the Australian Plate and established a continuous spreading centre in the Tasman Sea. At the same time the northern Lord Howe Rise became attached to the middle Lord Howe Rise after 260 km of left-lateral strike-slip motion.

In the early Paleocene, Tasman Sea seafloor spreading propagated northward into the Cato Trough. Using the finite rotations for the Tasman Sea, Gaina et al. inferred that breakup and seafloor spreading in the Cato Trough began between 63 and 61.2 Ma. At the same time, seafloor spreading began in the Coral Sea and, presumably, in the Louisiade Trough, with a triple junction active between the Australia, Lord Howe Rise (and plateaus north of it), and the Louisiade Plateau Gaina et al. . This extensional regime lasted until a major plate reorganisation at C26 (57.9 Ma). Relative motion between the Australian Plate and Kenn Plateau-Mellish Rise and between the Mellish Rise and the Louisiade Plateau changed from extension to strike-slip motion. Between C26 (57.9 Ma) and C25 (55.8 Ma) the triple junction migrated S-ward, the transform fault in the Louisiade Trough became extinct, and at about 57 Ma the strike-slip motion was transferred south of the Mellish Rise and north of the Kenn Plateau. The ridge-fault-fault (RFF) configuration remained unchanged until all relative motion stopped at 52 Ma. The Cato Trough was affected by a transtensional regime that began at C26 (57.9 Ma), with slow seafloor spreading in a NNW-SSE direction along its axis. The transform fault segment that was active at C26 along the NW part of the Kenn Plateau might explain the N-S trending volcanic features that characterize the NE Cato Trough. The NE-ward motion of the Eastern Plateau relative to Australia from C26 (57.9 Ma) initiated the opening of the Osprey Embayment west of the Coral Sea Basin.

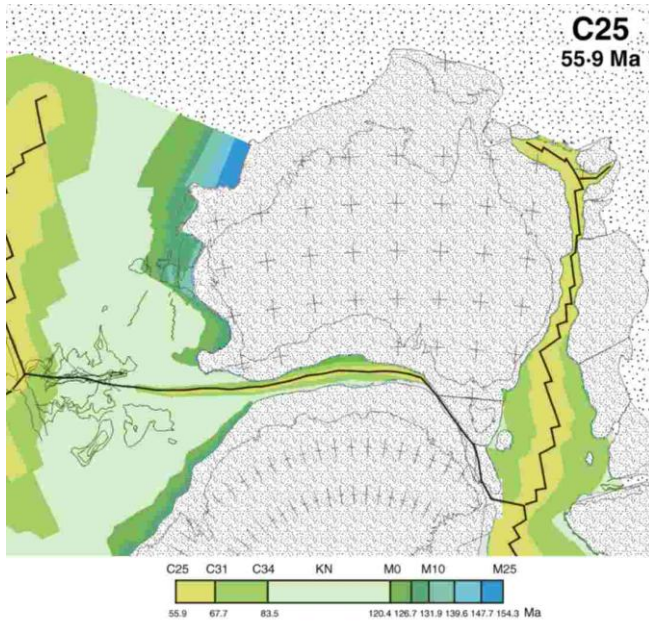


Fig. 7. C25 late Paleocene 55.9 Ma. The ridge propagated N-ward into the Cato Trough, Louisiade Trough, and Coral Sea.

(j) C21 mid-Eocene 47.9 Ma

C24y (52 Ma) marks the end of seafloor spreading along the entire eastern and northeastern Australian margin and the onset of a compressional event in the Papua-Rennell-New Caledonia region. The end of seafloor spreading in the Tasman Sea and Coral Sea and the onset of compressional events in New Caledonia at about 50 Ma seem to be related to 1) the change in both direction and velocity of absolute motion in the Pacific Plate that caused oblique compression between the Australian and the Pacific plates, or (2) the inception of India-Eurasia collision, or to both. Prior to 43 Ma, relative motion between East and West Antarctica is assumed to have started with extension between the Iselin Bank (attached to West Antarctica) and Eastern Antarctica.

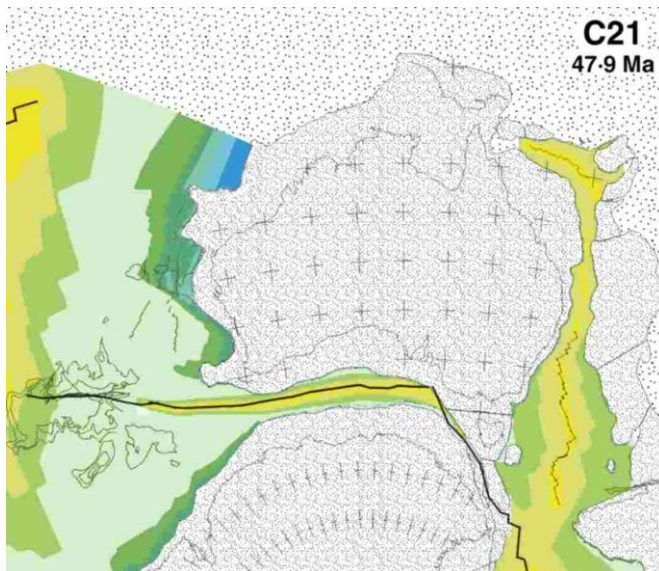


Fig. 8. C21 Mid-Eocene 47.9 Ma. Spreading stopped in the east.

(k) C18 late Eocene 40.1 Ma

West Antarctica continued to move relative to East Antarctica, and seafloor spreading started in the Adare Trough. Northward motion of Australia accelerated after 43 Ma, with seafloor spreading changing from 0.8 cm/yr

prior to C20 (44 Ma) to 3.0 cm/yr until C18 (40.1 Ma) at the same time as the Pacific Plate swerved (Veevers, 2000). The Southeast Indian Ridge now completely separated the Australian and Antarctic Plates. The western South Tasman Rise was separated from the Antarctic Plate and joined the Australian Plate at about 40 Ma .

The age of breakup between the Broken Ridge and Kerguelen Plateau is established at about 43 Ma. Earlier estimates ranged from ~43 Ma , 88-87 Ma and 69-66 Ma , and 90 Ma . The northern Australian margin was also affected by the 43 Ma event. Basement subsidence curves from three wells in the offshore eastern Papuan Basin indicate an increased rate of subsidence at 43 Ma (Pigram & Symonds, 1991), and Hill et al. suggested that around the late Eocene slow, low-angle subduction occurred along the Papua New Guinea margin. The Solomon Plate by separated the remaining Neo-Tethyan ocean floor from Australia, resulting in the subsequent accretion of various terranes to New Guinea and initiating foreland basins.

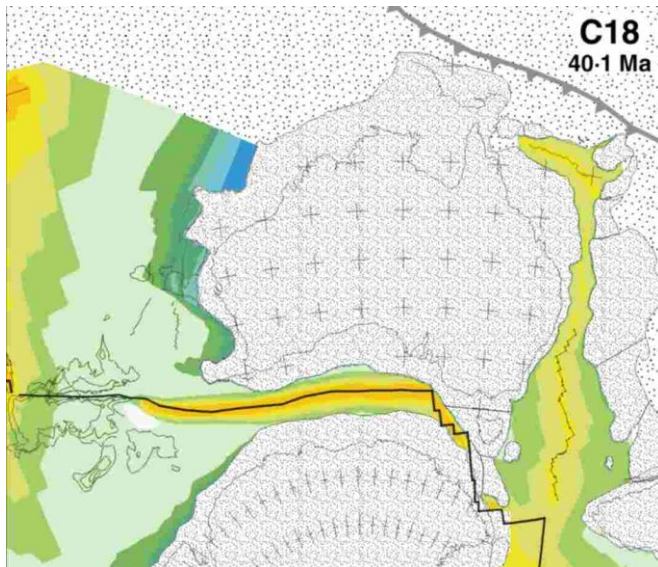


Fig. 9. C18 late Eocene 40.1 Ma. The 43 Ma event was reflected in the N-ward acceleration of Australia, the separation of Kerguelen Plateau and Broken Ridge, and S-ward subduction north of Papua New Guinea.

(I) C13 early Oligocene 33.1 Ma

Wood et al. identified C11 to C18 in the SE Tasman Sea and postulated that spreading began in the Eocene, at about 40 Ma, between the Pacific and Australian Plates. But they are not included in our age grid yet.

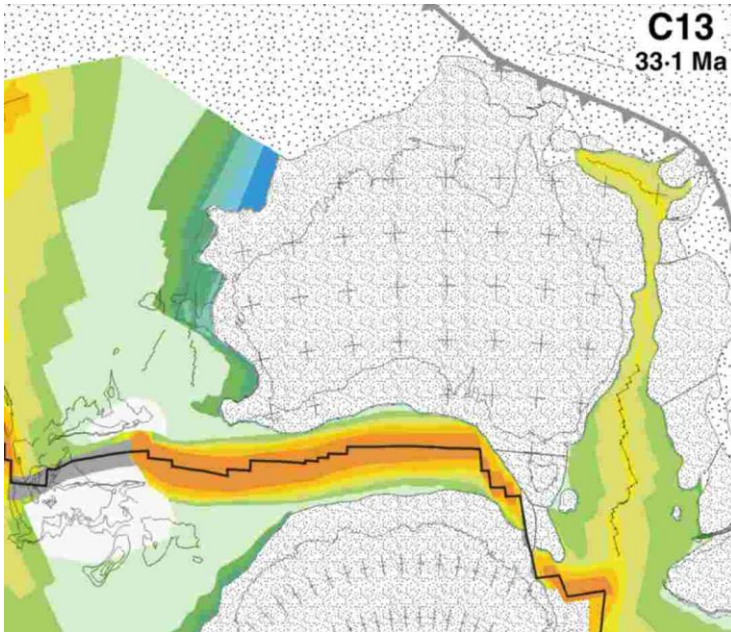


Fig. 10. C13 early Oligocene 33.1 Ma. A trench N of New Guinea anticipates terrane accretion at 25 Ma.

(m) C6 early Miocene 20.1 Ma

The increasing effect of rising subducted slab material from the transition zone underneath the Southeast Indian Ridge is postulated as creating the Australian-Antarctic Discordance (AAD), with its thin crust, anomalous depth, and fracture zone offsets. An earlier manifestation of the AAD is described below in the section on Australian-Antarctic connections.

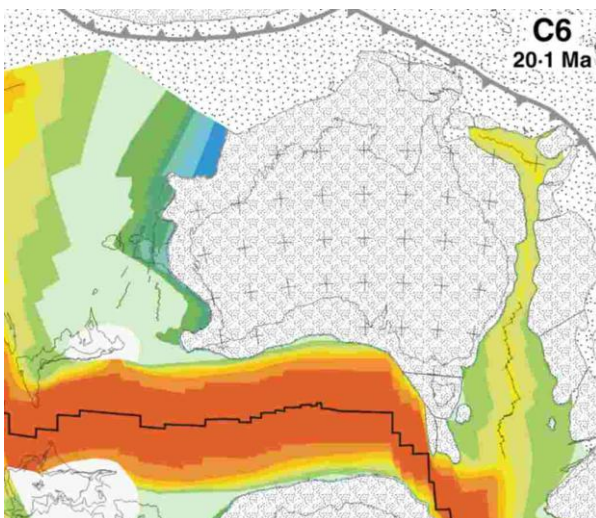


Fig. 11. C6 early Miocene 20.1 Ma. Northward subduction NW of Australia and terrane accretion in New Guinea have started. Seafloor spreading between East and West Antarctica has stopped.

(n) C5 late Miocene 10.9 Ma

The tectonics of the New Guinea-Banda Arc were driven principally by W-NW convergence of the Pacific Plate and the northward movement of the Australian Plate. Taking into account the length of the subducted slab in the vicinity of Timor and the rate of Australia-Eurasia convergence, Packham (1996) estimated the inception of the Banda Arc to be about 12 Ma. The collision of the Ontong Java Plateau (on the Pacific Plate) with the Melanesian arc at about 15 Ma reversed the polarity of the Melanesian arc, transferring it from the Australian plate to the Pacific plate. It collided with northern Papua New Guinea about 5 Ma.

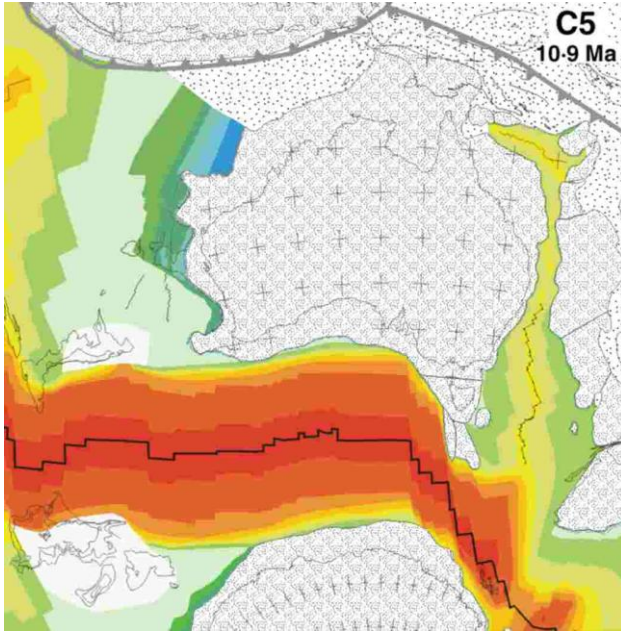
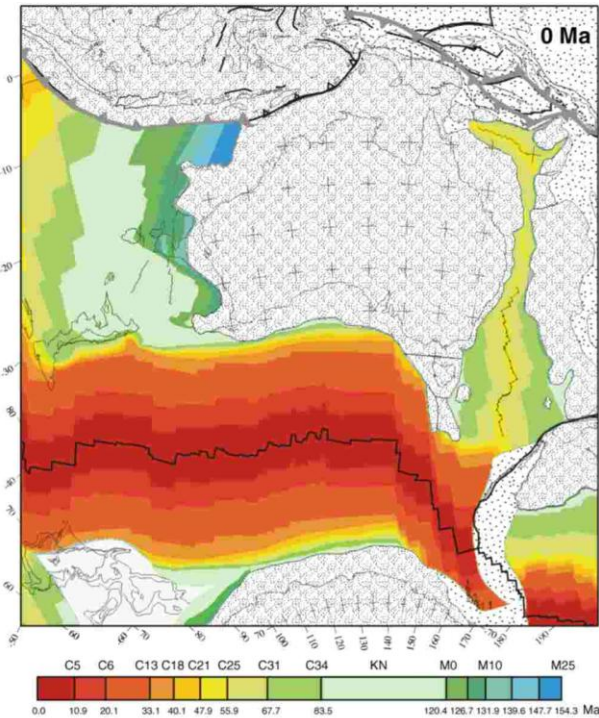


Fig. 12. C5 late Miocene 10.9 Ma.

(o) C1 Holocene 0 Ma

Subduction along the Solomon Trough and other changes in plate boundaries north of Australia generated an extensional regime NE of the Papuan Peninsula and created the Woodlark Basin starting at 5 Ma . The Caroline Plate was subducted under the Australian Plate along the Manus Trench, which became a transform fault, and along the New Guinea Trench. Collision along the Banda Orogen northwest of Australia created a post-5 Ma foreland basin including the Timor Trough and the outer North West Shelf . Timor appears to be moving northward at about the same rate as Australia, suggesting that shortening is accommodated N of Timor . Details can be found below in the account of the Northern margin.



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