Hypothesis for Cretaceous rifting of east Gondwana caused by subducted slab capture

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ABSTRACT

In the process of subducted slab capture, a spreading ridge approaches subparallel to a subduction zone following the trailing edge of a downgoing plate. Eventually the downgoing plate is too young and small to subduct, and spreading stops. The spreading ridge stalls many tens of kilometres outboard of the subduction zone. The subducted plate welds to the outboard plate across the dormant spreading center and is captured by it. The captured plate then acquires the motion of the plate it welded to. In the southwest Pacific the Pacific-Phoenix ridge approached the east Gondwana margin as the Phoenix plate subducted beneath New Zealand, the Chatham Rise and Campbell Plateau, the Lord Howe Rise (collectively, Zealandia), and Marie Byrd Land in Cretaceous time. Spreading and subduction shut down here between 110 and 105 Ma, and some sections of the Phoenix plate became welded to (captured by) the Pacific plate. Pacific plate northward motion began in Aptian time, pulling the captured subducted microplates with it. This movement exerted a basal traction on the overlying east Gondwana margin and resulted in extension of Zealandia and Marie Byrd Land. Continued Pacific northward motion rifted Zealandia from Marie Byrd Land at about 85 Ma.

MESOZOIC EVENTS IN EAST GONDWANA

A sudden change in tectonic regime from subduction to extension occurred in New Zealand in mid-Cretaceous time (105 $\pm$ 5 Ma; Bradshaw, 1989). Bradshaw ascribed this change to collision of the Pacific-Phoenix spreading center with the paleosubduction zone along the margin of east Gondwana. Ridge collision was followed by the rifting away during sea-floor spreading of New Zealand, the Chatham Rise and Campbell Plateau, and the Lord Howe Rise (collectively, Zealandia) from east Gondwana shortly before 85 Ma (Lawver et al., 1992; Mayes et al., 1990). A similar sudden change occurred in southwestern North America during late Cenozoic time (Nicholson et al., 1993, 1994; R. Bohannon and T. Parsons, unpublished) and also in the Antarctic Peninsula in Early-Middle Jurassic time (Storey and Alabaster, 1991). I propose that the scenario described by Bradshaw (1989) is correct, but that ridge collision did not occur. Instead, Phoenix microplate slabs underlying Zealandia in the subduction zone were captured by the northward-moving Pacific plate and rifted away overlying Zealandia from east Gondwana.

Extension in New Zealand starting with mid-Cretaceous rifting has been substantial. For the Campbell Plateau it has been estimated at 200 km (Bradshaw, 1991). In the western province of New Zealand, mylonites of the Paparoa metamorphic core complex were uplifted to the surface by 105–100 Ma (Tulloch and Kimbrough, 1989). Extension there closely followed crustal thickening and compression, ending in Early Cretaceous time. Western New Zealand has extensional basins like the Taranaki with 4 km or more of nonmarine sediments of Albian-Cenomanian age and younger (see Bradshaw, 1991). Offshore, the Great South Basin off the southeast South Island of New Zealand is a complex graben structure with more than 7 km of mid-Cretaceous and Tertiary sedimentary rock (Carter, 1988; Cook and Beggs, 1990). Well data there show that subsidence began at 103 Ma or just before (Carter, 1988). Extended structures of Cretaceous age are found on the Lord Howe Rise (Lister et al., 1991; Bentz, 1974), and on the Queensland margin (Symonds et al., 1987). The Bounty Trough between the Campbell Plateau and the Chatham Rise is a Late Cretaceous failed rift that preceded Zealandia–West Antarctica spreading (Carter et al., 1994).

In western Marie Byrd Land of West Antarctica, the migmatites of the Fosdick Mountains are interpreted to have been uplifted during north-south extension from depths of 15 km or more in the period 100–94 Ma (Richard et al., 1994). Paleomagnetic studies suggest that tilting of fault blocks here occurred in the interval 105 to 103 Ma (Luyendyk et al., unpublished), implying that rifting between the Campbell Plateau and western Marie Byrd Land began near this time. Igneous rocks in central Marie Byrd Land have been interpreted to record a sudden change from subduction-related to rift-related magmatism in mid-Cretaceous time (Weaver et al., 1994).

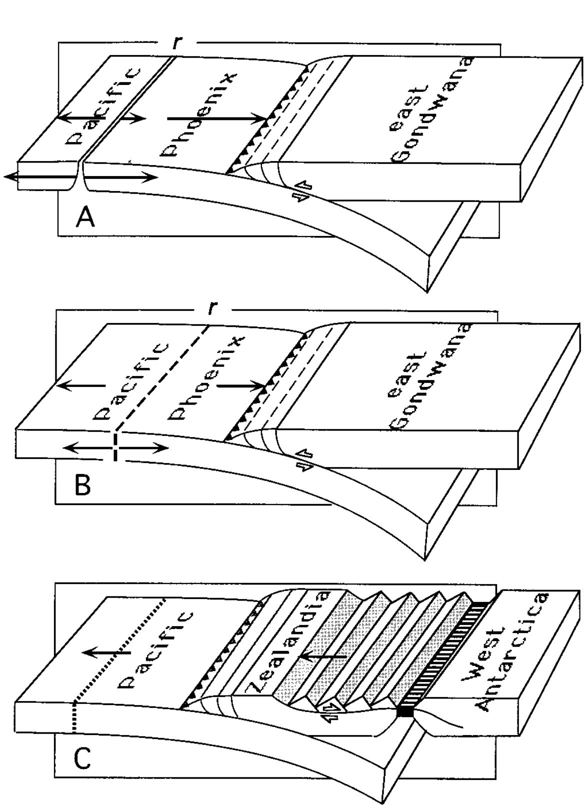

Figure 1. Slab capture model applied to east Gondwana (modified from illustration for California by Craig Nicholson). A: Pacific-Phoenix ridge approaches trench and subduction zone of east Gondwana. Vectors atop plates are relative to east Gondwana or West Antarctica; half-spreading-rate vectors are shown on side. Spreading center approaches subduction zone at rate *r*. B: Spreading and subduction rates decrease as slab pull force decreases. Ridge stops approaching trench when half-rate equals vector of Pacific plate, and retreats slowly from trench as spreading stops. C: Spreading stops and Phoenix plate is captured by Pacific. Basal traction of Phoenix on overlying Zealandia margin extends and rifts it away from West Antarctica, opening new ocean basin.

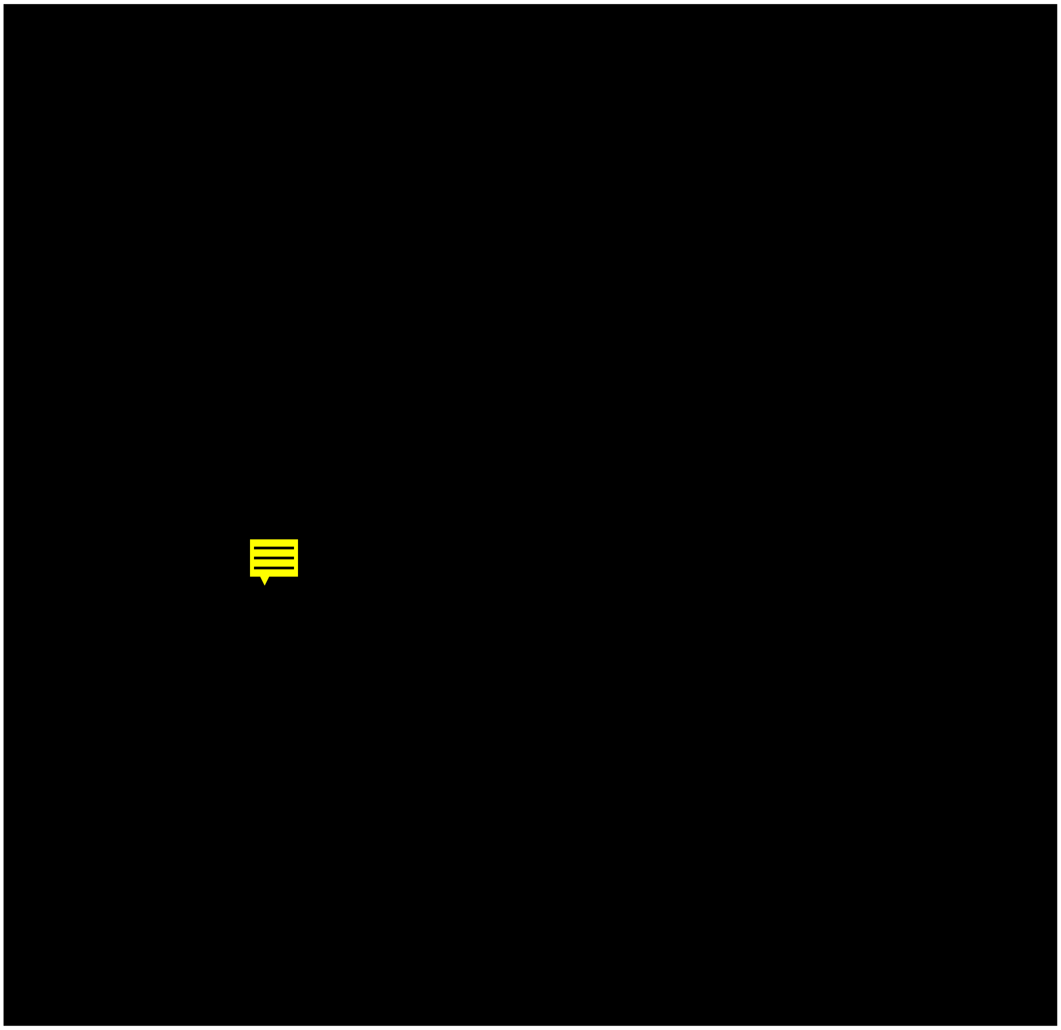

Figure 2. Satellite gravity map of southwest Pacific sector (Sandwell and Smith, 1992). Gray areas are North Island and South Island of New Zealand. Gravity high extending east from South Island is Chatham Rise. Simulated illumination is from north.

SUBDUCTED SLAB CAPTURE

In the subducted slab capture process, a spreading ridge approaches subparallel to a subduction zone following the trailing edge of a downgoing plate (Fig. 1). The age of the subducting plate is decreasing with time. As the young subducting plate approaches the subduction zone it may fragment into microplates outlined by transform faults that intersect the trench. Eventually it may become too small to subduct, and spreading slows and stops. The spreading ridge stalls many tens of kilometres outboard of the subduction zone. The subducted plate welds to the outboard plate across the dormant spreading center and is captured by it. The captured plate then acquires the motion of the plate it welded to. If the outboard plate is converging with the overriding plate, subduction continues, and the welded ridge and captured plate are consumed. However, if the outboard plate is diverging, then rifting and/or strike-slip faulting may occur in the overriding plate. The ridge is not subducted, and there is no "ridge collision" (Nicholson et al., 1993, 1994). Any back-arc spreading could produce a weak zone in the overlying plate and provide a locus for rifting within it.

The slab-capture hypothesis requires supporting observations in order to be fully applied, including an extinct spreading center outboard of the paleosubduction zone and an abrupt change in tectonic regime in the overlying plate. The sudden change observed in east Gondwana (Bradshaw, 1989; Weaver et al., 1994) is the primary clue and is the observation most demanding of an explanation; subduction is quickly replaced by extension. Locating an extinct system of ridges, as was successfully done offshore southwestern North America using marine magnetic anomalies (Atwater and Severinghaus, 1989; Lonsdale, 1991), is more challenging in the southwest Pacific sector. Spreading ended during the Late Cretaceous period of no magnetic reversals, so a symmetric magnetic anomaly pattern cannot be found. Furthermore, except for a reentrant of prerift ocean crust north of the Chatham Rise, all older crust bordering the outboard edge of Zealandia has been consumed by Tertiary subduction and disrupted by back-arc spreading in the Tonga-Kermadec subduction zone.

PACIFIC, PHOENIX, AND ANTARCTIC PLATES IN CRETACEOUS TIME

Recently declassified Geosat altimetry and gravity data reveal important sea-floor features near New Zealand and within the oceanic crust reentrant north of the Chatham Rise (Sandwell and Smith, 1992; Morgan and Sandwell, 1994). A trough aligned with and parallel to the Udintsev Fracture Zone can be clearly traced beyond chron 34, northwest and into the Tonga trench (Figs. 2 and 3); this trough probably marks a fracture zone of a past spreading system. The northwest end of this trace corresponds to the Rapuhia Scarp on the northeast margin of the Hikurangi Plateau (Wood and Davy, 1994). Subtle gravity lineations (buried topography?) that strike northeast normal to the fracture-zone trend can be seen southwest of the inferred fracture zone. Wood and Davy (1994, Fig. 3) mapped northeast-trending buried basement features here from a reconnaissance geophysical survey. The gravity field is rougher southwest of the fracture-zone trace than it is to the northeast; I interpret this as being due to rougher buried topography to the southwest, consistent with slowing of spreading as a section of the Pacific-Phoenix ridge approached the subduction zone. A prominent gravity low follows the north edge of the Chatham Rise, a location where there is no sea-floor trough; this may locate the east Gondwana paleosubduction zone (Wood and Davy, 1994). Another gravity low extends northeast from the east end of the Chatham Rise. This may mark the rift valley of a stalled ridge. Similar gravity signatures are associated with stalled ridges mapped west of the Antarctic Peninsula and in the western Scotia Sea (Sandwell and Smith, 1992). Sea-floor spreading anomaly chron 34 (84 Ma; Kent and Gradstein, 1985) can be found adjacent to the southeast margin of the Chatham Rise (Fig. 3; Cande et al., 1989). Thus, the gravity data may locate a spreading system older than chron 34 north of Zealandia and trending at a low angle into the paleosubduction zone.

The marine magnetic anomaly map of Cande et al. (1989) locates the trace of the Pacific-Farallon-Aluk (the Phoenix plate is renamed Aluk for chron 34 and later time) triple junction; they have marked its location for times prior to chron 34. The northernmost (oldest) point on the triple junction trace is now at lat 25.5°S, long 152.5°W. Extrapolating the spreading rate for the chron 34–33 period back in time, the age of the starting point on this triple junction trace is about 100 Ma. I have extended the Pacific-Phoenix (Aluk) spreading center from this triple junction location to the Chatham Rise perpendicular to the fracture zone trend in the ocean reentrant (Fig. 4). These observations imply that the geometry of the spreading system in mid-Cretaceous time was similar to that of the spreading system in effect at chron 34 time after sea-floor spreading between Zealandia and Antarctica started.

Marine geophysical data from the equatorial and southwestern Pacific also permit the Pacific-Phoenix ridge to be located offshore east Gondwana in mid-Cretaceous time (Fig. 4). Joseph et al. (1993) proposed (following Larson, 1976; Winterer et al., 1974) that at or soon after M0 time (ca. 119–118 Ma; Kent and Gradstein, 1985), the Pacific-Phoenix ridge jumped 10° south from a location at the Nova-Canton Trough. Larson et al. (1992) placed the ridge between 25° and 35°S prior to the jump, so afterward the ridge was as far south as 45°S. Using the East Antarctica Apparent Polar Wander Path of DiVenere et al. (1994), the Chatham

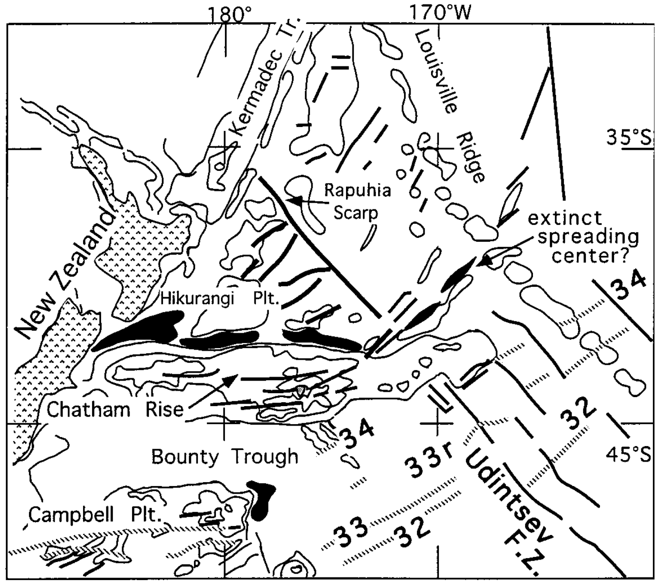

Figure 3. Interpretation of Figure 2. Pre–chron 34 fracture zone extends northwest from east end of Chatham Rise. Gravity lineations perpendicular to fracture-zone trend are seen east of North Island of New Zealand. Gravity low along north edge of Chatham Rise marks paleosubduction zone; low trending northeast from east end of Chatham Rise may mark rift valley of stalled spreading center. Contours mark gravity highs; lows are shaded areas or dark lines; thicker black lines are positive lineations shown in Figure 4. Magnetic anomalies (striped) are from Cande et al. (1989).

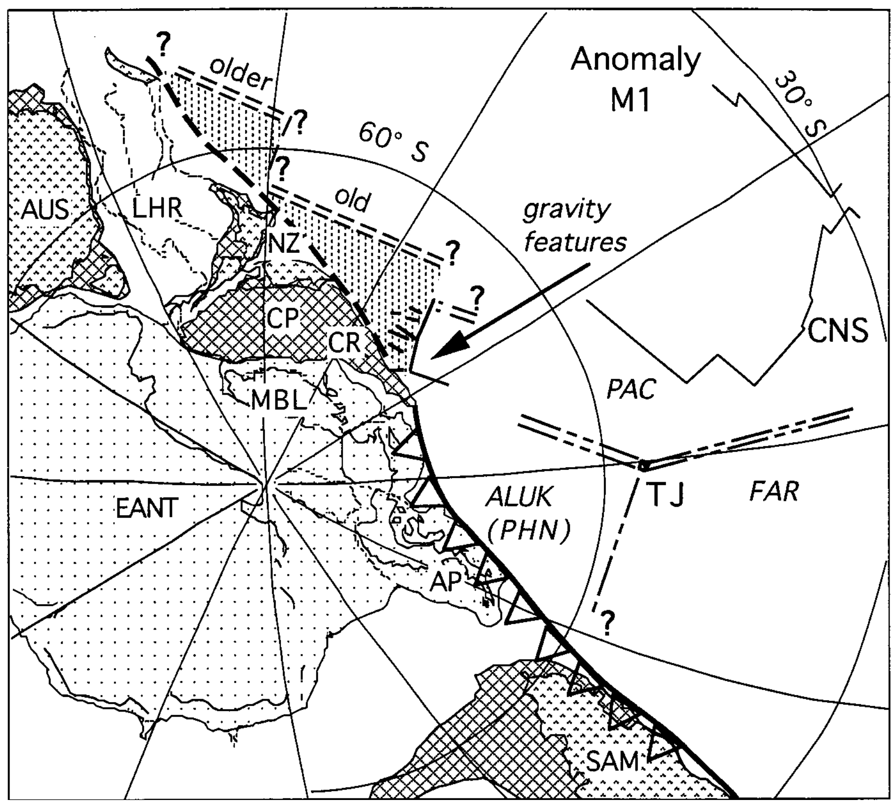

Figure 4. Estimated reconstruction in southwest Pacific for Late Cretaceous time (100 Ma; Lawver et al., 1992) showing proposed locations of spreading centers and subduction zones. CNS is boundary of Cretaceous normal superchron at location of Pacific-Phoenix ridge after its jump to south soon after M0 time (proposed by Joseph et al., 1993). Pacific (PAC)-Phoenix (PHN, Aluk)-Farallon (FAR) triple junction is at old end of triple junction trace (TJ) mapped by Cande et al. (1989), but ridge configurations are conjectural. North of Chatham Rise (CR), spreading features are interpreted from satellite gravity (Figs. 2 and 3). Extinct spreading center (Fig. 3) is shown in its location just prior to Zealandia-Antarctica spreading. At 100 Ma it is proposed to be located to north (double dashed lines). Extinct system of microplate spreading is hypothesized west of there (gray pattern marks captured crust); extinct spreading centers are older to west. Dashed line is extinct Phoenix–east Gondwana subduction zone and solid line is active subduction zone that is mostly dextral-transpressional in West Antarctica. AUS—Australia; LHR—Lord Howe Rise; NZ—New Zealand; CP— Campbell Plateau; MBL—Marie Byrd Land; EANT—East Antarctica; AP— Antarctic Peninsula; SAM—South America.

Rise paleosubduction zone of east Gondwana was near 70°S at this time and moving northward.

Paleomagnetic data indicate that in Early Cretaceous time the Pacific plate was moving southward (Larson et al., 1992). Therefore, the Pacific-Phoenix spreading center was moving southward from the Pacific plate during this period and closing with the east Gondwana subduction zone.

Capture of subducted Phoenix microplates by the Pacific plate occurred when sections of the Pacific-Phoenix spreading center died. In Aptian time the Pacific plate reversed and started to move slowly northward (Larson et al., 1992), pulling the captured microplates with it. This resulted in traction on the overlying Gondwana plate margin and caused extension within it. The rate of Pacific plate northward motion accelerated dramatically during Late Cretaceous time. Its northward rate ultimately reached more than 100 km/m.y. just prior to the time sea-floor spreading started between Zealandia and West Antarctica (Larson et al., 1992). This could have increased shear on the overlying margin leading to ultimate failure and sea-floor spreading. The time lag between the beginning of extension and sea-floor spreading is explained if at the time of capture, the spreading center east of the Udintsev fracture zone was offset left (north) a large distance and subsequently migrated southeast to reach the tip of the Chatham Rise before 84 Ma (Fig. 4).

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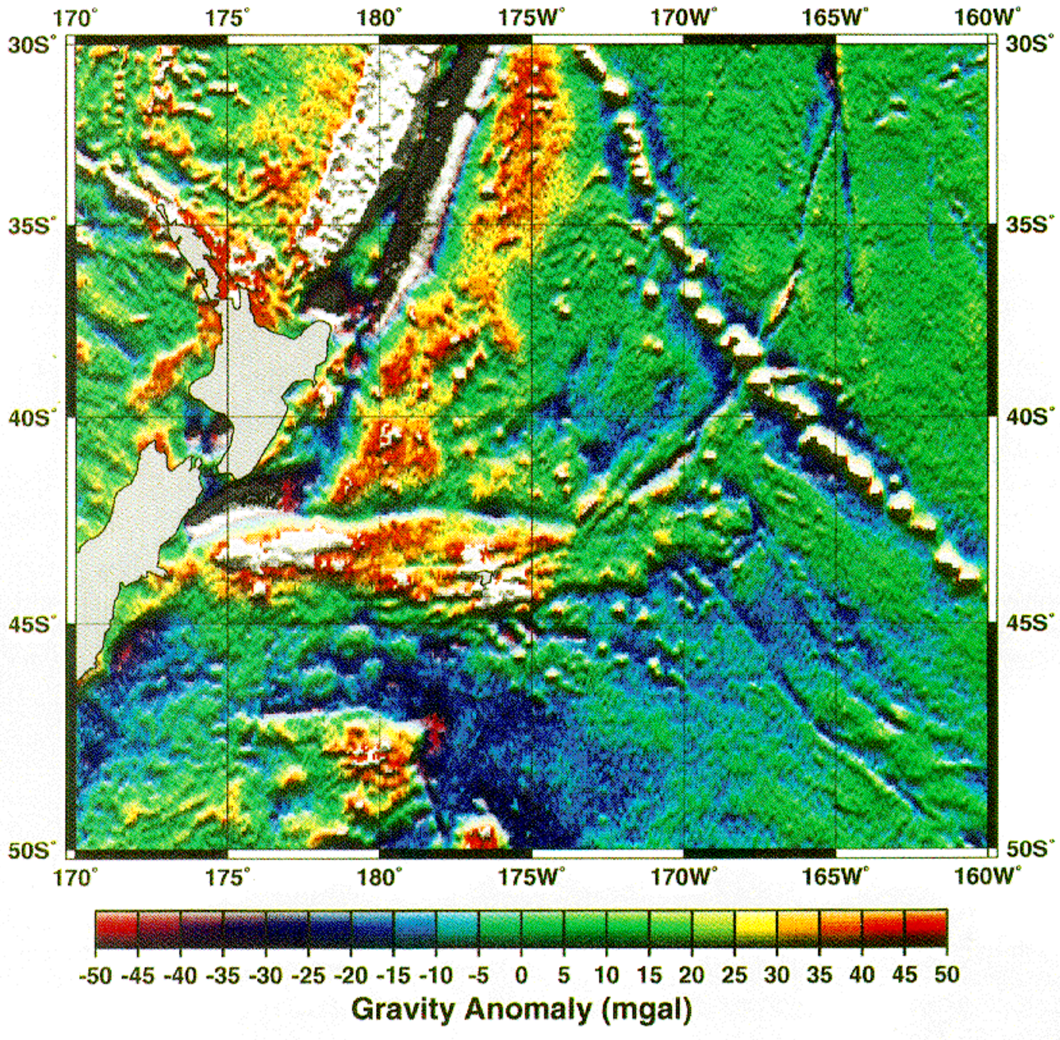
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