Response to Comment on "Major Australian-Antarctic Plate Reorganization at Hawaiian-Emperor Bend Time"

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Accurately locating boundaries between continental and oceanic crust is topical in view of locating offshore boundaries relevant to margin formation models, plate kinematics, and frontier resource exploration. Although we disagree with Tikku and Direen's interpretations, the associated controversies reflect an absence of agreed-upon geophysical criteria for distinguishing stretched continental from oceanic crust, and a lack of samples from nonvolcanic margins.

So-called transitional crust along rifted margins often exhibits symmetric magnetic lineations. Prime examples can be found in the Labrador Sea (*1*), on the Newfoundland-Iberia margins (*2*), in the Laxmi Basin in the northwest Indian Ocean (*3*), and on the Great Australian Bight/Wilkes Land conjugate margins. There is no consensus as to the continental or oceanic nature of the crust/mantle underlying such magnetic lineations. Hypothesis 1, promoted by Tikku and Direen (*4*) and others [e.g., (*5*)] suggests that conjugate magnetic lineations are found in extended continental crust in parts of the Great Australian Bight as well as offshore Wilkes land (Antarctica). Hypothesis 2 suggests that the crust is mainly oceanic in nature and represents an end member of slow, relatively amagmatic spreading. In both cases, magnetic lineations may be produced by mantle serpentinization and/or syn-extensional intrusions. However, there is no feasible physical model to explain formation of pairs of symmetric magnetic lineations on conjugate margins over 1000 km long within stretched continental crust.

The Australian-East Antarctic conjugate margins exhibit a transitional zone, up to 120 km wide, that has both a tilted-block basement morphology and sedimentary character akin to stretched continental crust, and symmetric magnetic anomalies (chrons 33o and 34y) as produced by seafloor spreading. Tikku and Direen (*4*) suggest that these magnetic lineations, as well as magnetic anomaly identifications older than chron 20o to 24o along the Sabrina section of the Wilkes Land margin, are not seafloor spreading magnetic anomalies and are thus unable to reveal the relative plate motion between Australia and Antarctica.

Tikku and Direen (*4*) question the validity of magnetic anomaly identifications older than chron 20o to 24o along the Sabrina section of the Wilkes Land margin because they lie on interpreted continental crust (*5*). However, there are considerable acknowledged uncertainties with this interpretation, which is in the "most outboard position," and other unpublished interpretations place the boundary a "considerable distance further inboard" (*5*).

Contention arises concerning the nature of the crust in the continent-ocean transition zone because it does not appear as "normal" ocean crust in seismic reflection profiles. However, very slow spreading rates, oblique angles of spreading, and anomalous underlying mantle conditions (all present in our model of Australian-Antarctic breakup) may also lead to rougher, more faulted oceanic basement associated with serpentenized, exhumed mantle (*6*).

Based on a combination of seismic reflection and multibeam bathymetry data and dredge samples, Beslier *et al.* (*7*) place the boundary between continental and oceanic crust (COB) at the southern limit of the Magnetic Quiet Zone along the Australian margin, which is inboard even from the interpreted position of magnetic anomaly 34y [83 million years ago (Ma)]. Based on recently acquired data on the Antarctic margin, Leitchenkov *et al.* (*8*) locate the COB landward of magnetic anomaly 33, with anomaly 34 located within an area of exhumed mantle. Other independent evidence to support continental breakup around chron 34 is given by Great Australian Bight tectonic subsidence curves (*9*) that show subsidence rates diminishing from approximately 85 to 83 Ma onward, marking continental breakup and thus the transition from continental rifting to seafloor spreading. These interpretations based on recently acquired data support the notion that none of the linear, symmetric magnetic lineations between Australia and East Antarctica are located on continental crust. However, in addition, it is quite reasonable to expect the exact time of breakup to vary along the margin, and not necessarily progressively from one end to the other.

A major problem with previous reconstructions of Australian-Antarctic breakup is the resulting considerable overlap between Tasmania (including the South Tasman Rise) and Cape Adare [e.g., 140 km of overlap at chron 34 (*10*)]. Tikku and Cande (*10*, *11*) previously suggested ~85 km of strike-slip motion or extension in Bass Strait after 79 Ma or Late Cretaceous/Cenozoic extension in Wilkes Land to solve this problem. Tikku and Direen (*4*) now suggest an eastward shift of Australia sometime during the Paleozoic orogenies or the breakup of Pangea to solve the overlap issue, without presenting any supporting evidence. In contrast, our reconstruction solves the Tasmania/Tasman Rise and Cape Adare overlap problem without necessitating any Wilkes Land extension or unlikely motion in Bass Strait.

Tikku and Direen (*4*) suggest that the interpretation of Mesozoic magnetic anomalies to the north of the Bruce Rise (*12*) are speculative because they are noisy and supposedly located on crust that is highly variable in character (*13*). We agree that the magnetic anomalies north of the Bruce Rise are difficult to interpret, and the interpretation of Gaina *et al.* (*12*) is by no means unique, but our reconstructions do not use M anomalies and thus do not depend on this exact interpretation.

Tikku and Direen (*4*) suggest that our new reconstructions result in a poor fit between Broken Ridge and the Kerguelen Plateau. However, the outline of Broken Ridge shown in figure 1B in (*4*) is extremely narrow and results in an unrealistic fit between Broken Ridge and the rifted eastern flank of the northern Kerguelen Plateau and Williams Ridge. The fit resulting from Whittaker *et al.* (*14*) is in fact better, because the gap shown in Tikku and Direen's reconstruction would likely disappear with a more realistic outline of Broken Ridge.

Although the Perth South fracture zone is not as prominent in the gravity data as the Perth (Leeuwin) or Naturaliste fracture zones, the gravity field clearly indicates a tectonic lineament there. Many others have independently interpreted regional tectonic fabrics in this area to indicate northwest–southeast oriented Australian-Antarctic extension [e.g., (*15*)]. Alternatively, if the proposed north-south oriented rifting (*10*) is correct and the Perth and Vincennes fracture zones are conjugates, it is surprising that there is no conjugate on the Antarctic margin to the very prominent Naturaliste fracture zone.

The controversies discussed here reflect that the contributions of mantle temperature and petrology, spreading rate, and the obliquity of spreading to the crustal and mantle characteristics along very slowly and/or obliquely spreading, magma-poor margins are poorly documented. Even though we disagree with Tikku and Direen's interpretations, the debate highlights the need for integrated ocean drilling in the Great Australian Bight.

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