Life of the Bellingshausen plate

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[1] The onset of independent Bellingshausen plate movement in the South Pacific is estimated at just after chron C33o. This event closely follows a change in the offset sense on the transform arm of the Late Cretaceous Pacific-Phoenix-Antarctic triple junction and accompanies the creation and/or lengthening, by different mechanisms, of long-offsets on the Pacific-Antarctic ridge at the Udintsev, Tharp, Heezen and V transforms, as the triple junction stepped away from the ridge. At around chron C27, the Bellingshausen plate ceased to move independently and the Pacific-Antarctic ridge inherited the set of long offset transforms. Shortly afterwards, the gravity fabric on the flanks of much of the ridge displays evidence for a spreading rate decrease possibly related to transpression on the long-offset transforms. We speculate on a link between these events and regional tectonic changes around chron C27. *INDEX TERMS:* 1206 Geodesy and Gravity: Crustal movements—interplate (8155); 3040 Marine Geology and Geophysics: Plate tectonics (8150, 8155, 8157, 8158); 8157 Tectonophysics: Plate motions—past (3040); 9310 Information Related to Geographic Region: Antarctica; 9355 Information Related to Geographic Region: Pacific Ocean. **Citation:** Eagles, G., K. Gohl, and R. D. Larter (2004), Life of the Bellingshausen plate, *Geophys. Res. Lett.*, *31*, L07603, doi:10.1029/2003GL019127.

1. Introduction

[2] Antarctica's Amundsen Sea passive margin (Figure 1) formed when New Zealand rifted off it in the mid Cretaceous, leading to inception of the Pacific-Antarctic (PACANT) ridge. The Bellingshausen (BEL) plate [*Stock and Molnar*, 1987] existed on the southern flank of parts of the ridge NE of the Antipodes FZ until around anomaly C27 (~61 Ma, *Cande et al.* [1995]; timescale of *Cande and Kent* [1995]).

[3] The BEL sector of the PACANT ridge, the PACBEL ridge, formed before chron C34y (83 Ma), but has only been reconstructed back to anomaly C33y (73.6 Ma). The inception and pre-C33y history of the BEL plate remain poorly understood [*Stock and Molnar*, 1987; *Larter et al.*, 2002] so it is not known whether the BEL plate originated in a continental or oceanic setting, or how. This uncertainty hampers attempts to understand the late Cretaceous tectonics of Marie Byrd Land [*Luyendyk et al.*, 2003] as well as of microplate formation and growth, and their possible long-term effects.

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2. BEL Plate Boundaries

[4] *Gohl et al.* [1997] demonstrated an extinct convergent zone at the Bellingshausen Gravity Anomaly (BGA; Figure 1). *Larter et al.* [2002] explain the BGA as a BELANT plate boundary. An additional, divergent, boundary with Antarctica may have had both oceanic [*Heinemann et al.*, 1999] and continental [*Larter et al.*, 2002] parts southwest and south of the BEL plate.

[5] The Tharp, Heezen, and Udintsev fracture zones (TFZ, HFZ and UFZ; Figure 1) are some of the Pacific's most prominent tectonic features, and offset post-C33y anomalies in a right-handed sense. *Watts et al.* [1988] show that a left-stepping transform occupied the place of the TFZ and HFZ at chron C34y. *Larter et al.* [2002] show that this transform, gravity anomaly Z (Figure 2), operated between the Pacific-Phoenix (PACPHO) ridge to the NE and PACANT ridge in the SW. The intersection of Z and the PACPHO ridge was the PACPHOANT/PACPHOBEL triple junction (TJ) that approached the PACANT ridge along Z due to the difference in the PACANT and PACPHO ridges' spreading rates. By interpolation, the ridge crests would have met, and the offset on Z reversed, at ~80 Ma.

[6] Consistent with this, Z ceases to have any gravity expression between anomalies C34y and C33o (79.1 Ma), making the TJ hard to trace (Figure 2a). Spreading rate differences place the TJ on the HFZ after chron C32 [*Watts et al.*, 1988]. New models of conjugate magnetic anomaly profiles (Figures 2b and 2c) in the TFZ-HFZ corridor suggest the ridge there never operated in the PACPHO system, but the PACANT/PACBEL system, and that it jumped twice towards the SE between 74 and 70 Ma. These models require the TJ trace to run north of the TFZ-HFZ corridor (Figure 2a), and imply the TFZ formed by jumping of the PACBEL ridge towards the TJ.

[7] FZ V lies NE of the HFZ. *Cande et al.* [1989] show anomaly picks that imply V lengthened after ~64 Ma, after HFZ lengthening; the TJ migrated from the HFZ to V. Fan-like patterns of magnetic anomalies show that the UFZ lengthened due to very asymmetric oblique spreading after chron C33y [*Cande et al.*, 1989].

3. BEL Plate Motion

[8] Finite rotation parameters, from inversion of seafloor spreading data by Joann Stock and others [*Larter et al.*, 2002], describe the BEL plate's kinematics between chrons C33y and C27. New helicopter-aeromagnetic data (RV *Polarstern* 2000/2001; Figure 3) enable us to calculate parameters for C34y and C33o (Figure 4a; Table 1). Visual fitting was done without explicit reference to Stock's parameters, so that the proximity of our Euler poles to Stock's gives confidence in their position.

[9] The new fits (Figure 4a) are compared to fits derived by rotating the PAC data about PACANT poles towards

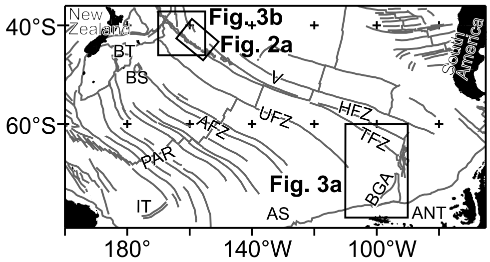

Figure 1. Study area, with features referred to in the text. Abbreviations not used in the text: AFZ: Antipodes FZ, AS: Amundsen Sea, BGA: Bellingshausen Gravity Anomaly, BS: Bollons seamount, BT: Bounty Trough, IT: Iselin Trough, PAR: PACANT Ridge.

BEL data in their C33y position with respect to ANT (Figure 4b) in order to demonstrate an extra pre-C33y plate at the PACANT ridge. In Figure 4b, we use *Larter et al.*'s [2002] FIT rotation (~83 Ma) and a C33o rotation interpolated between it and Stock's C33y rotation. FIT comes from fitting conjugate continental-margin gravity anomalies, and so there is some uncertainty in its date, although *Sutherland* [1999] shows that the anomalies are likely to be only slightly younger than C34y. The anomalies' good fit to one another argues against any significant later deformation. The PACANT reconstructions produce isochron-pick misfits that increase from SW to NE and fail to align FZs. These variations cannot be explained by the age uncertainty in FIT that produces a good azimuthal match to FZs off Campbell Plateau. Misfits yielded with the new rotations are the smaller, by an amount that is larger than the picks' likely navigational uncertainty (<5 km).

[10] Assuming an open, inactive Bounty Trough, the extra plate at the pre-C33y PACANT ridge was BEL. Figure 5 (top, an attempted chron C34y reconstruction with PAC reconstructed to BEL, and BEL fixed in its C33y position with respect to ANT) illustrates this as a large underlap between the Campbell Plateau and Marie Byrd Land gravity anomalies that should coincide at C34y. With BEL fixed in its C33o position with respect to ANT, this underlap is replaced by a modest overlap (Figure 5, bottom) which is most simply interpreted as signifying that BEL plate motion started at or soon after C33o. Although later ages for FIT would tend to enlarge the overlap at C33o, this effect would be cancelled out by having to use a post-C34y BELPAC isochron as well. A southeastwards ridge jump, that excised the Bollons seamount from the Antarctic continental margin just after C33o [*Sutherland*, 1999], is consistent with our estimate of the time of initiation of BELANT extension.

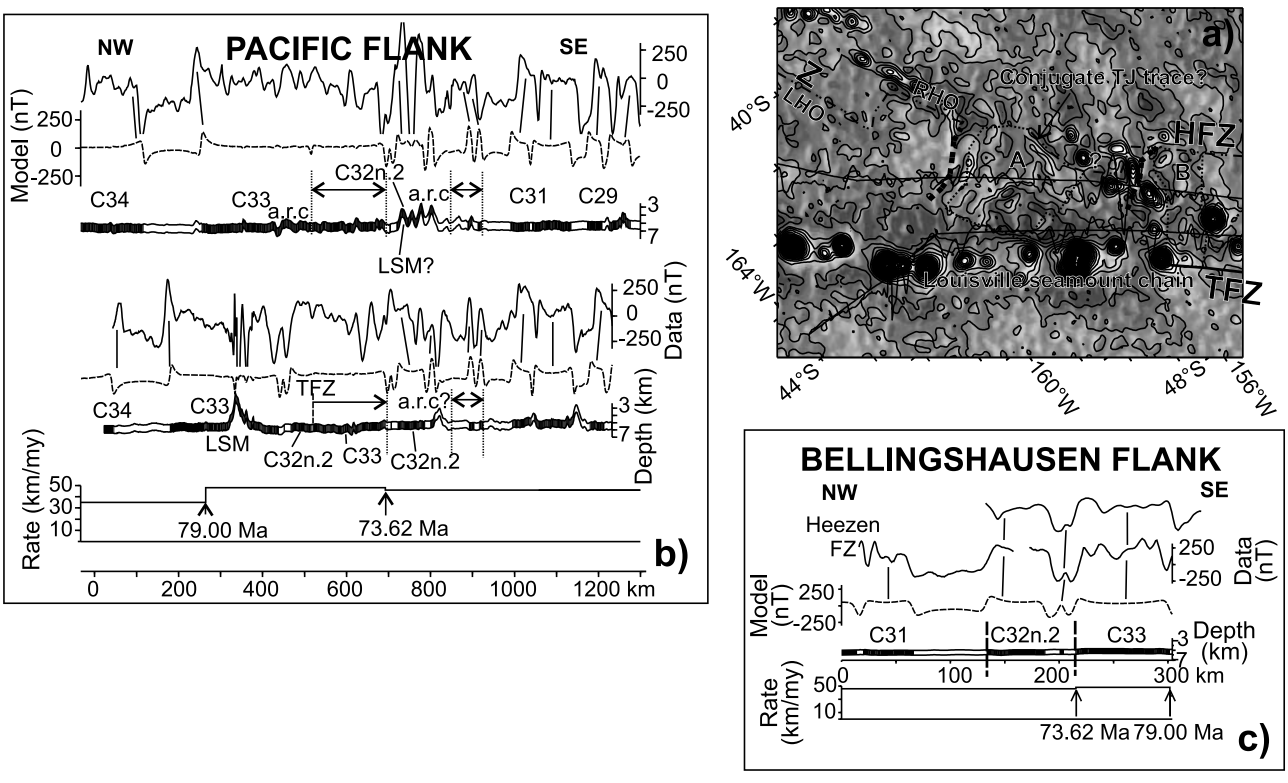

Figure 2. a) Gravity anomalies [*Sandwell and Smith*, 1997]. Z: lineament Z. Thin dot-dash line: TJ trace. LHO, RHO left/right handed offset. Dotted thin line, A, B: compartments transferred by ridge jumps. Thick dashed lines: abandoned ridge crests. Thin solid wiggles: ship-track magnetic data of Figure 2b. b, c) Dashed lines: magnetic model (ridge jumps at 73.6 Ma (175 km to SE) and 70.2 Ma (75 km to SE)). a.r.c: abandoned ridge crest, horizontal arrows: captured crust. Vertical lines: thick dashed: sequence lost, thin dotted: sequence gained, thin dashed: FZ. Predicted bathymetry [*Smith and Sandwell*, 1994] defines 1-km thick source layer. Effective susceptibility 0.065, inclination, declination from IGRF80. Data projected onto 130° (PAC) and 123° (BEL). LSM: Louisville hotspot seamounts (30–20 Ma).

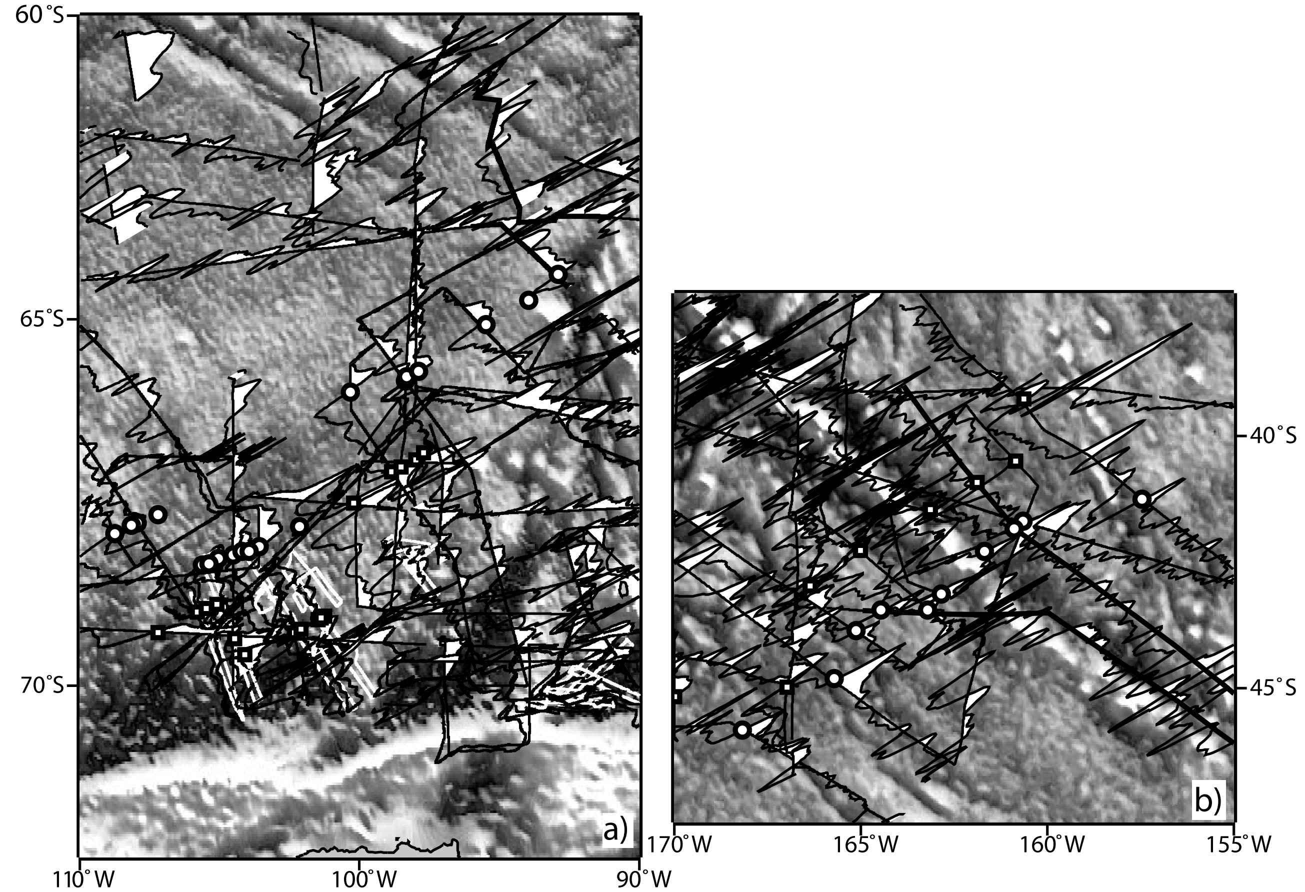

Figure 3. Along-track magnetic anomalies (positive parts filled white) overlaid on gravity anomalies in parts of BEL (a) and PAC (b) plates produced at the PACBEL ridge. Thickened tracks: data in Figure 2. White tracks: helicopter data. Black tracks: ship data (GEODAS compilation). C34y (squares) and C33o (circles) picks from these data and from S. Cande (personal communication, 2000).

[11] The UFZ displays a kink near C33y after which it lengthens [*Larter et al.*, 2002]. These changes occur directly after the first model ridge jump in the TFZ-HFZ corridor, that created a new ~175 km-long offset in the PACBEL ridge at the TFZ. This relationship suggests that PACBEL spreading, and BEL plate motion, were plausibly responsive to the appearance of the long-offset TFZ. The lengthening offset on the PACBEL arm of the TJ that had migrated along Z started to appear at ~80 Ma, just before our estimated onset of BEL plate motion. These observations suggest that not only was BEL plate motion perturbed after the appearance of long offset transforms, but it was also a consequence of it, perhaps via the introduction of new shear stress forces.

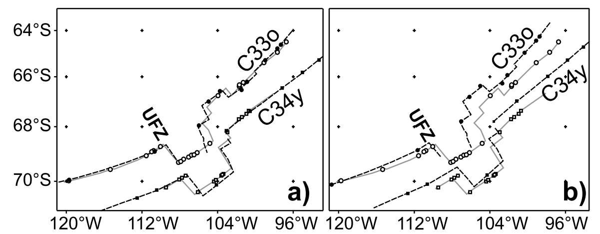

Figure 4. Fits of C34y (squares) and C33o (circles) picks (PAC filled, BEL open) and FZ-isochron figures (PAC dashed, BEL continuous). BEL data in C33y position with respect to ANT (Table 1). a) new parameters, b) PACANT parameters.

4. BEL Plate Extinction

[12] After C33o, the BEL plate had recognisable independent motion that responded to lengthening of transforms in the PACBEL ridge. Transform V was still lengthening when BEL plate motion ceased around chron C27, making it hard to relate extinction of the BEL plate to forces raised at transforms. In contrast, although total shortening at the BGA reached 200 km by chron C27,

Table 1. Finite Rotation Parameters

Lat	Lon	Ang	Age	Chron	Source
Pacific Plate With Respect to Bellingshausen Plate					
70.98	−41.28	62.70	73.60	C33y	Stock et al., unpubl.
70.57	−34.34	72.30	79.08	C33o	This paper
69.43	−34.96	74.84	83.00	C34y	This paper
Pacific Plate With Respect to Antarctic Plate					
66.72	−55.04	53.74	73.62	C33y	Stock et al., unpubl.
65.58	−52.38	63.07	~83.00	FIT	*Larter et al.* [2002]

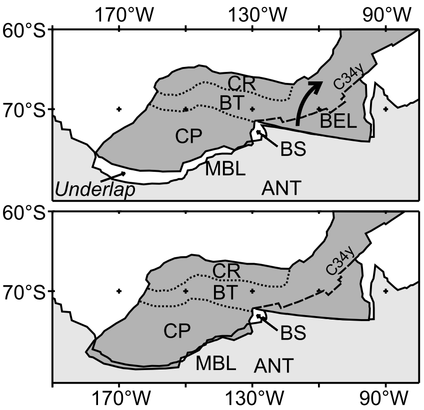

Figure 5. C34y reconstructions, to test for onset of independent BEL movement. BEL is held (top) in its C33y position with respect to ANT, and (bottom) in its C33o position. The PAC plate elements Campbell Plateau (CP), Chatham Rise (CR) and Bounty Trough (BT) are held fixed to BEL in their relative positions at C34y. Black arrow: forwards BELANT motion (schematic). BS: gap occupied by Bollons Seamount (not shown).

Stock's parameters suggest most of it occurred before C30r (~68 Ma), making it plausible that failure to initiate subduction at the BGA may have played a role in BEL plate extinction.

[13] The PACANT ridge inherited the UFZ, TFZ and HFZ unchanged around chron C27. A steady anticlockwise rotation of relative motion vectors after this [*Cande et al.*, 1995] suggests the transforms may have undergone transpression, as an accompanying increase in the amplitudes of the FZs' free-air anomalies may attest. PACANT spreading rates also decreased by 30–50% between chrons C27 and C24, as shown by finite rotation parameters [*Cande et al.*, 1995]. Free-air gravity anomalies show that segmentation of the PACANT ridge SW of the UFZ increased by ~58 Ma (C26) – an observation that may more accurately date the spreading rate decrease, via a change in upwelling pattern [*Phipps Morgan and Parmentier*, 1995], to before C26. The PACANT spreading rate decrease may be a result of increasing transpression on the long-offset transforms inherited from the PACBEL ridge.

5. Discussion

[14] Extinction of the BEL plate was part of a plate tectonic reorganisation of the South Pacific at around C27 that also included changes in the relative motions of Australia, Antarctica and Zealandia. In the geographical midst of these changes is a new East-West Antarctica plate boundary, as seen in the Iselin Trough (Figure 1) [*Marks and Stock*, 1997; *Cande et al.*, 2000]. Above, we noted that this event was closely followed by a reduction in PACANT spreading rates to approximate PACBEL rates.

[15] *Müller et al.* [2000] relate the reorganisation to collision of Neo-Tethyan ridge segments with northern Australia. We speculate alternatively that it is reasonable to expect the long offset UFZ, TFZ, HFZ and FZ V to have continued to exert regional and local effects after BEL plate extinction. Perhaps, therefore, the introduction of long-offset transforms into the PACANT ridge at C27 could have initiated the West Antarctic plate as a replacement for the BEL plate, whose ANT margin needed to lengthen as the PACPHOBEL TJ migrated NE.

6. Summary

[16] Migration of the PACPHOANT TJ caused its PACANT transform arm to change from left-stepping and shortening, to right-stepping and lengthening at ~80 Ma. The TJ then moved away from the PACANT ridge, which developed a number of long-offset transform faults so that its northern tip could stay close to the TJ. These events accompany independent motion of the BEL plate. Shear stress forces across the transforms are a plausible explanation for the plate's independence. About anomaly C27, the PACANT ridge inherited the long offset transforms after BEL plate extinction. Continuing influence of the transforms may explain a subsequent spreading rate reduction and, more speculatively, a regional tectonic rearrangement in which the West Antarctic plate appeared for the first time.

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