Bird, D. E., and Hall, S. A. [2010] **South Atlantic kinematics and the evolution of Tristan da Cuhna hotspot tracks.** 72nd EAGE Conference & Exhibition.

Introduction

Closing ocean basins along geomagnetic isochrons is an objective way to examine rifted conjugate continental margins prior to seafloor spreading. In the South Atlantic Ocean we incrementally close the basin and examine the conjugate ocean floor edifices produced by the Tristan da Cuhna (TdC) mantle plume. Prior to the breakup of western Gondwana, ca. 130 Ma, the TdC mantle plume produced the eastern South American Parana, and western African Etendeka, flood basalts. As the South Atlantic basin opened, the ridge-centered plume produced seaward extending hotspot tracks: Rio Grande Rise (RGR) on the South American Plate, and Walvis Ridge (WR) on the African Plate. Several ocean floor edifices on the hotspot trends appear to produce lower than expected amplitude free air gravity anomalies, suggesting that they are composed of lower density material.

We relate the positions of RGR and WR through time by: 1) correlating shiptrack magnetic anomaly profiles and identifying geomagnetic isochrons, 2) picking control points at intersections between isochrons and fracture zones and calculating total reconstruction poles, and 3) rotating South American Plate data (viz topography and gravity data, and calculated gravity anomalies derived from regional 3D modeling) relative to African plate data.

Data

Data used in this study are open-file and downloadable from two internet sources: 1) the National Oceanic and Atmospheric Administration's National Geophysical Data Center (NGDC, www.ngdc.noaa.gov), and 2) Scripps Institute of Oceanography, University of California San Diego (scripps.ucsd.edu). Magnetic anomaly profiles (GEODAS Marine Geophysical Trackline Data: gravity, magnetics and bathymetry), TerrainBase global topography (5 arc-minute grid), and Total Sediment Thickness of the World's Oceans & Marginal Seas (5 arc-minute grid) are available from NGDC. Satellite-derived free air gravity anomalies (2 arc-minute grid, Sandwell and Smith 1997) are available from Scripps (Figure 1).

Methods

Magnetic Anomaly Analysis: We have carefully mapped more than 50 distinctive seafloor spreading magnetic anomalies between magnetochrons C5 (9.8 Ma) and M4 (129.8 Ma) (Gradstein et al. 2004) between 15°S and 45°S. We have used this more detailed temporal framework to investigate the relationship between the spreading axis and the position of the Tristan hotspot for the South Atlantic through time. Profile correlations with synthetic seafloor spreading models show excellent agreement and have enabled us to identify a number of additional isochrons throughout the South Atlantic.

Rotation Poles: We have used residualized free air satellite gravity data (Figure 1) to delineate fracture zones (FZs) associated with the Early Cretaceous through Tertiary opening of the South Atlantic. More than 20 flow lines determined from these FZs intersect the magnetic lineations mapped between C5 and M4. The FZs and isochron data have been used to compute stage poles (Bird 2004) from 130 Ma to the present for both the South American and African plates, and the corresponding total reconstruction poles.

Crustal Modeling: To examine variations in crustal density associated with the hot spot trends we have constructed a 3D gravity model of the South Atlantic basin which encompasses a region that extends from 46°S to 10 °S and from 20°E to 60°W. The model comprises four layers: water, sediment, crust, and upper mantle. Variable density sediment and upper mantle layers are incorporated so as to include density changes related to sediment thickness and compaction (Sykes 1966), and upper mantle temperatures (Sclater et al. 1980), respectively. The initial Moho horizon is estimated from isostatic equilibrium calculations (Turcotte and Schubert 2002); however the isostatic effect is scaled away from the Mid-Atlantic Ridge, using a function similar to the variation of heat flow with age of oceanic crust (Sclater et al. 1980), to simulate the active spreading center.

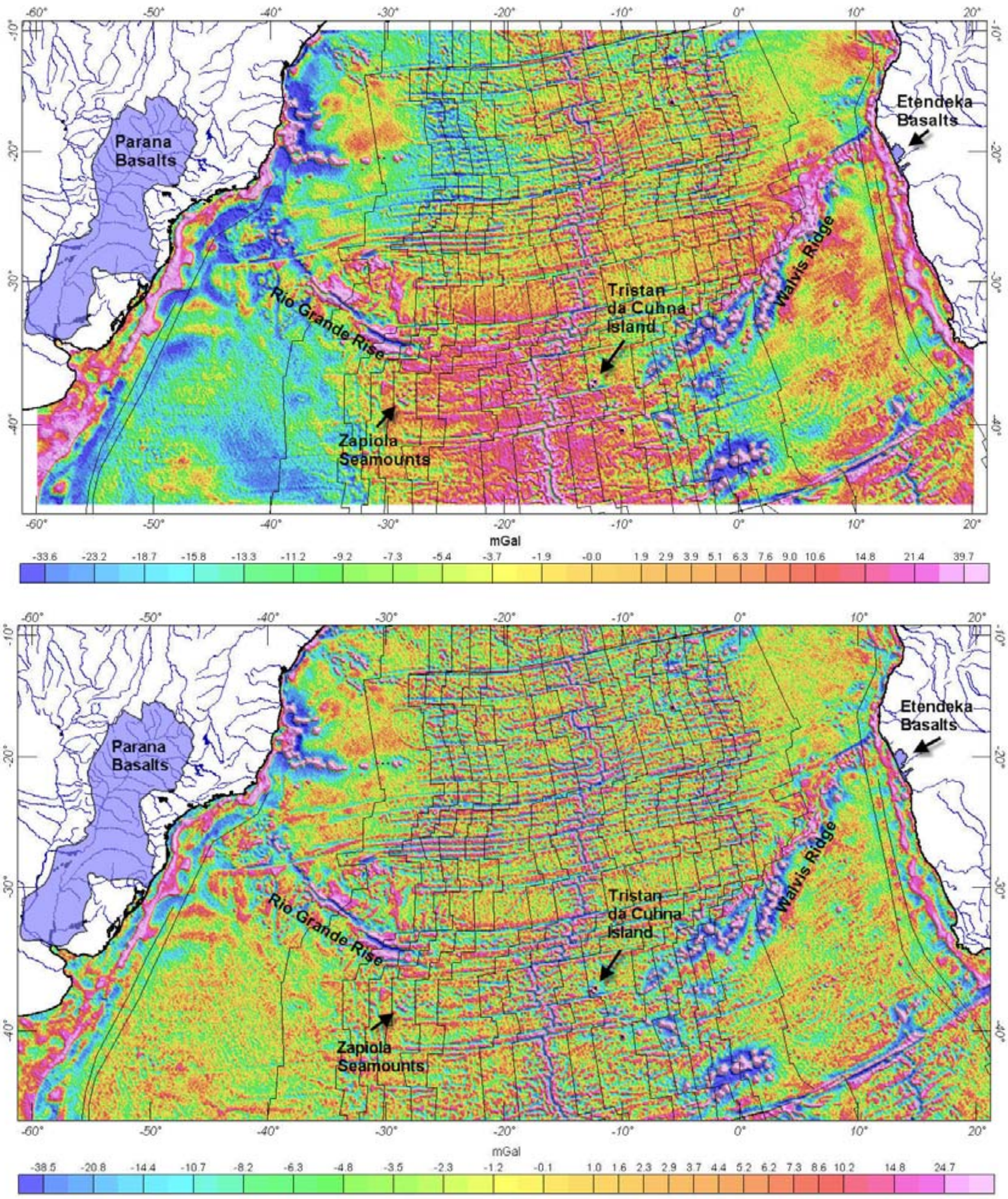

Figure 1. Satellite-derived free air gravity anomalies. Geomagnetic isochrons after (Muller et al. 1997). Bottom: Residual gravity anomalies calculated by subtracting a 48 km upward continued free air grid from the original free air grid.

Results

Between C34 (84 Ma) and C5 seafloor spreading appears to be roughly symmetrical with three separate phases identified: 1) steady spreading of ~30 mm/yr from 9.8 to ~45 Ma, 2) slower (15-18 mm/yr) and more variable spreading from ~45 to ~70 Ma, and 3) an earlier faster spreading (36 mm/yr) from ~70 to 84 Ma. The lack of identifiable features between C34 and M0 makes it difficult to obtain meaningful spreading rates (Hall and Bird 2007). We have used the C34-M0 distances to obtain an average value for pre-C34 spreading of ~27 mm/yr. The noticeably larger C34-M0 distance on the South American side near 32°S, 40°W is attributed to one or more eastward ridge jumps that

occurred between 84 and 124.6 Ma. Spreading rates for M0 to M4 are roughly symmetrical but difficulties in identifying these features in certain parts make spreading rate estimates less reliable.
We have obtained the relative positions of the two plates throughout the spreading history of the South Atlantic by holding the African Plate fixed, and rotating the South American Plate for 16 individual times between 129.8 Ma and 9.8 Ma (Table 1). In this fixed Africa reference frame the hotspot appears to move west-southwest. From ~130 Ma to ~70 Ma, spreading was sufficiently rapid that the hotspot was maintained on or close to the ridge axis by eastward ridge jumps. From ~70 to ~45 Ma the slower spreading allowed the hotspot to remain on the ridge without significant ridge jumps. Comparison of paleolatitudes determined for Walvis Ridge features north of the Meteor FZ with TdC's present location suggests no significant latitudinal motion of the TdC hotspot since ~80Ma. Between 130 Ma and 80 Ma, however, the paleolatitude of hotspot features are roughly 10° more northerly that present day Tristan (Hall and Bird 2007).
Modeling results suggest two possible scenarios for the development of the RGR hotspot track. 1) At ~45 Ma the hotspot crossed beneath the Meteor transform fault, was displaced from the ridge axis, and became isolated beneath the African plate. The subsequent increase in spreading rate resulted in the hotspot remaining beneath the African plate where it has produced that part of the Walvis Ridge track between the Meteor FZ and TdC Island from ~45 Ma and the present. 2) The TdC mantle plume remained ridge-centered until ~30 Ma when it produced the Zapiola seamount complex. The hotspot then crossed beneath the TdC transform fault and became isolated beneath the African plate.
The 3D density inversion results of the crustal layer (Parker 1973) reveal a distribution of low-density areas (Figure 2): along the coasts, the seafloor spreading axis, and along the Rio Grande Rise and Walvis Ridge hotspot trends. Coastal and spreading axis low-density areas are thought to be related to continental crust and high temperature upper mantle respectively. Hotspot track low density areas might be related to variable densities within the volcanic edifices, variations in their crustal thickness, or upper mantle densities beneath them (Bird and Hall 2009).

Chron	**Age (Ma)**	**Longitude**	**Latitude**	**Rotation angle**
C5	9.8	-49.698	72.369	4.338
C6	20.0	-40.769	63.976	7.144
C13	33.3	-31.622	53.142	13.903
C18	38.0	-32.053	55.830	16.548
C21	45.3	-30.722	55.079	19.597
C25	56.7	-30.366	57.713	22.444
C31	67.8	-28.968	54.419	24.872
C34	84.0	-34.248	59.397	33.563
	89.3	-33.583	57.067	37.046
	93.0	-33.713	55.940	38.804
	99.6	-33.894	54.149	41.970
	105.0	-33.969	52.733	44.544
	112.0	-34.119	51.378	47.993
M0	124.6	-32.200	43.388	52.182
M2	127.6	-31.818	43.543	53.376
M4	129.8	-32.963	45.491	54.038

Table 1. Total reconstructions poles of South America relative to Africa. Eleven poles (Hall and Bird 2007) corresponding to geomagnetic isochrons (Gradstein et al. 2004), and five interpolated poles during the Cretaceous Magnetic Quiet Zone between Chrons M0 and C34 (Bird and Hall 2009).

Conclusions

The evolution of the central South Atlantic includes the following elements:

- Seafloor spreading rates varied between 15 and 30 mm/a from 84 Ma to the present.
- Between 124.6 and 84 Ma eastward ridge jumps maintained the TdC hotpot on or close to the spreading axis.
- TdC hot spot was ridge-centered to either ~45 Ma, or ~30 Ma.

- Inverted low density variations over the extent of RGR and WR indicate that they are either more deeply rooted than modeled through isostatic calculations, or that they are composed of lower density rocks than typical oceanic crust.

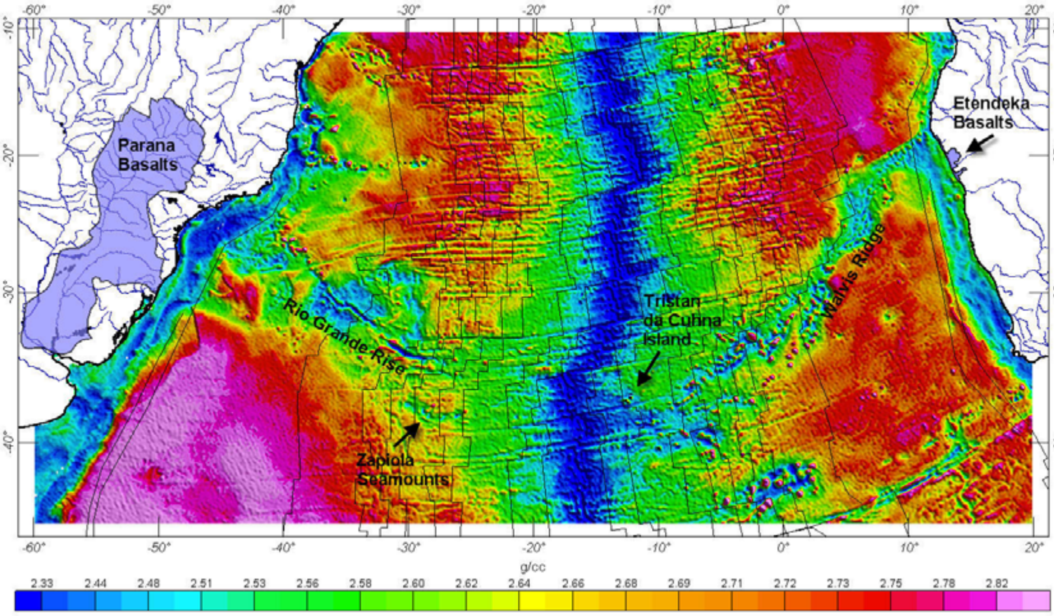

Figure 2. 3D density inversion of the crustal layer results.

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