# Analysis of seafloor depth anomalies arround the south Ascension Island, South Atlantic

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## Abstract

Observed seafloor depths from 12 kHz bathymetry coupled with seafloor spreading magnetic anomalies are used to derive depth anomalies across the Mid-Atlantic ridge axis between 2°S and 18°S. Theoretical seafloor depths are based on the plate cooling model and crustal ages depicted from magnetic anomalies between the zero age to 25 Ma. The magnetic anomalies are symmetric with respect to the ridge axis in the region, but the depth anomalies are quite asymmetric. The east side of the ridge axis is shallower (~ 1,000 meters) than the west side, probably as a result of an upwelling of thermal structure of the lithosphere. This type of thermal anomaly may be caused by a mantle plume located on the African Plate, which could well represent a larger swell linked to St. Helena Island and Fernando Pó-Annobon Volcanic Lineament as well.

## Introduction

According to the plate tectonics model the new oceanic lithosphere is formed at the spreading center along the mid-ocean ridges (e.g., Le Pichon, 1968). Once it is formed the young oceanic lithosphere becomes colder and subsides as it moves away from the spreading center. The cooling of the plate (Parsons and Sclater, 1977) can be described as a function of the age of the oceanic crust, defined from seafloor spreading magnetic type anomalies. This simple model assumes a linear relation between the seafloor depth and the square root of crustal age and, also between the heat flow and the inverse of the square root of crustal age. Sclater et al. (1971) showed an empirical relation between heat flow and seafloor depth and age of the oceanic crust.

The theoretical seafloor depths can be then calculated from the age of the oceanic crust and used to outline oceanic regions that agree or not with the cooling plate model. The seafloor depth anomalies, which mark the difference between the theoretical and observed depths, can be an indicative on lithospheric thermal anomalies associated to hotspots.

Here we examine the depth anomalies between the Ascension and St. Helena Islands (**Figure 1**), which has been argued as a long ridge segment influenced by a ridge centered hotspot (Mello, 1993; Palma, 1998; Bruguier et al., 2003; Minshull et al, 2003). There are topographic and geochemical evidence that support a hotspot location in the region: (a) the existence of an anomalous topographic high at the ridge axis (e.g., Brozena, 1986) and (b) the isotopic spikes in the La/Sm, Nd/Zn and Sr/Nd ratios in basalts dredged around 10°S (e.g., Schilling et al., 1985; Fontignie and Schilling, 1996). But, there are no major geophysical evidences: (a) an anomalous crustal thickness due to intense mantle upwelling and (Minshull et al., 1998) (b) the geographical extension of the hotspot. Thus, this work will focus on the analysis of the seafloor depth anomalies to characterize the existence and extension of thermal anomalies to the south of the Ascension Island.

## Data Set

We used 12 kHz bathymetry data obtained from the National Geophysical Data Center (NGDC). This data set result from measurements performed by different cruises in the last 30 years within the studied region. The age of the oceanic crust was determined from seafloor spreading magnetic type anomalies obtained from aeromagnetic surveys done by the Naval Research Laboratory (NRL) during the Centratlan Project (Brozena, 1986). The geomagnetic time scale of Cande and Kent (1995) was used to match the seafloor magnetic type anomalies to the seafloor age.

The theoretical depth (d) is based on the model of Parsons and Sclater (1977). The depth is calculated assuming that the ridge axis is infinity in the y direction and the temperature of the plate is constant in the same direction. Thus, the depth is calculated by the following equation:

$$d = d_r + \frac{2\rho_a \alpha T_a}{(\rho_a - \rho_w)}\sqrt{\frac{kt}{\pi}}$$

where:

asthenosphere density - $\rho_a = 3.3\ 10^3$ kg m$^{-3}$
water sea density - $\rho_w = 1\ 10^3$ kg m$^{-3}$

thermal expansion coefficient - $\alpha$ = 3 $10^{-5}$ $C^{-1}$
diffusivity - $k$ = $10^{-6}$ $m^2s^{-1}$
temperature of the base of the lithosphere - $T_a$ = 1200°C
water depth - $d_r$ = 2.5 km

Thus,

$$d = 2.5 + 0.33\sqrt{t}$$

where $d$ is km and $t$ in Ma. This equation relates seafloor depth with crustal age.

**Data Interpretation**

**Figure 2** displays the observed seafloor depths gridded and colored contoured. The morphology of the region is characterized by an anomalous axial high at the ridge axis between 8° and 10°S (~ 2,500 m), which is associated to two volcanic edifices to the west. This region is assumed to result of a hotspot ridge centered, somehow linked to the Ascension Island (e.g., Brozena, 1986). A rift valley of about 3,000 – 3,500 m deep is only noted to the north and south along the ridge axis and is limited by the Ascension and Bode Verde Fracture Zones, respectively. Ridge morphology is essentially symmetric with respect to the ridge axis.

The seafloor spreading magnetic type anomalies are shown in **Figure 3a**. They were depicted from magnetic models derived from Mello (1993) and dated according to Cande and Kent (1995). These anomalies are generally symmetric to the ridge axis and quite well defined from zero age to approximately 25 Ma, as shown in **Figure 3b**. Thus, they allowed calculating the theoretical depth anomalies within the studied region (**Figure 4a and 4b)**.

The resulting depth anomalies displayed in **Figure 5** shows a striking asymmetry in depths. The east side of the ridge axis is quite shallower than the west on the order of 1,000 m. This extends beyond the two seamounts on the east side of the ridge with a shape of a larger depth anomaly, probably associated with an off-axis thermal anomaly or hotspot. In fact, this anomaly could well be linked to a further south depth anomaly around the region of St. Helena Island. If it is so, Ascension and St. Helena Island as well as many volcanic edifices within this region, including the ridge axis can be a result of a mantle plume or swell that extends for many kilometers up to the Fernando Pó-Anobom Lineament near the African Margin.

**Conclusions**

The formation of a new oceanic lithosphere is usually modelled as a symmetric process with respect to the spreading axis. But, the thermal structure of the lithosphere underneath the African Plate is probably distinct from the South American Plate around the Ascension and St. Helena Islands. The shallower depth anomalies observed on the east side of the ridge axis between the Ascension and St. Helena Islands is apparently an evidence of an off-ridge axis hotspot located on the African Plate. This hotspot may actually be a mantle plume much larger that extends to the south to St. Helena and to the east to the African Margin. If this is correct then the anomalous geochemistry of the rocks collected in the region are result of a plume type mantle.

Further study on the depths anomalies over a wider region in the South Atlantic seems to be necessary in the light of South Pacific studies on Super Swells (e.g., Adam et al., 2004), which has applied filtering techniques topographic minimization to examine depth anomalies. Geochemical rock analysis of Ascension region and St. Helena should prove a close origin of the mantle source.

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**References**

Adam, C., Vidal, V., Bonneville, A., A Method to characterize seafloor swells with application to the south central Pacific. *Geochemistry Geophysics Geosystems 6:* Art. Nº Q01003, 2005.

Brozena, J. M. Temporal and spatial variability of seafloor spreading processes in the Northern South Atlantic. *J. Geophys. Res.*, 91: 497-510, 1986.

Bruguier, N. J., T. A. Minshull, and J. M. Brozena, Morphology and tectonics of the Mid-Atlantic Ridge, 7°–12°S, *J. Geophys. Res.*, 108 (B2), 2093, 2003.

Cande, S. C., and D. V. Kent, Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic, *J. Geophys. Res.*, 100, 6093– 6095, 1995.

Fontignie, D. and Schilling, J.-G, Mantle heterogeneities beneath the South Atlantic Ridge. *Geophys. J. Ast. Soc.*, 20: 271-284, 1996.

LePichon X., Marine magnetic anomalies, geomagnetic field reversals, and motions of the ocean floor and continents, *J. Geophys. Res.*, 73, 2119– 2136, 1968.

Mello,S.L.M., Marine Geology and Geophysics of the Mid Atlantic Ridge Between Ascension and Sta. Helena Islands, *Master Dissertation*, *Universidade Federal do Rio de Janeiro/IG-Depto de Geologia*_, RJ, 90 pp, 1993.

Minshull, T. A.; Bruguier, N. J.; Brozena, J. M., Ridge-plume interactions or mantle heterogeneity near Ascension Island? *Geology*, 26: 115-118, 1998.

Minshull. T. A., N. J. Bruguier, and J. M. Brozena, Seismic structure of the Mid-Atlantic Ridge, 8-9?S, J. Geophys. Res., 108, 2513, doi:10.1029/2002JB002360, 2003.

Parsons, B., and J. G. Sclater, An analysis of the variation of ocean floor bathymetry and heat flow with age, *J. Geophys. Res.*, 82, 803– 827, 1977.

Schilling, J.-G.; Thompson, G.; Kingsley, R.; Humphris, S. Hotspot-migating ridge interaction in the South Atlantic, *Nature*, 313:187:191, 1985.

Sclater, J.G., Anderson, R.N. and Bell, M.L., Elevation of ridges and evolution of the central eastern Pacific. *Jour. Geophys. Res.*, 76**:** 7888-7915**,** 1971.

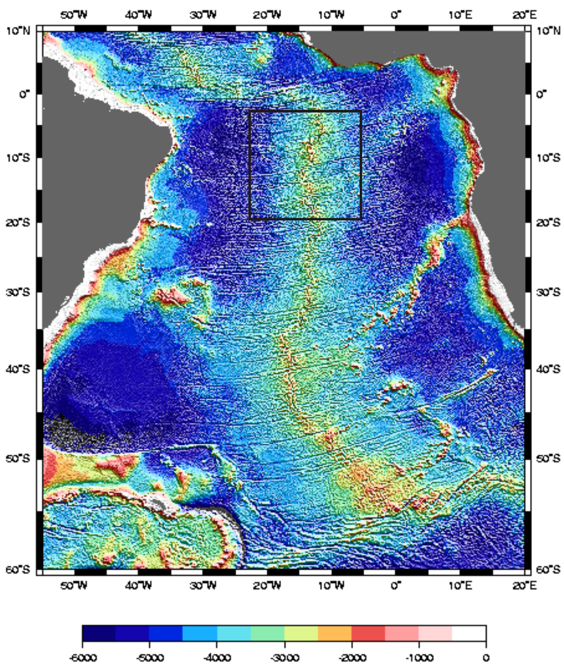



Figure 1 - Study area.

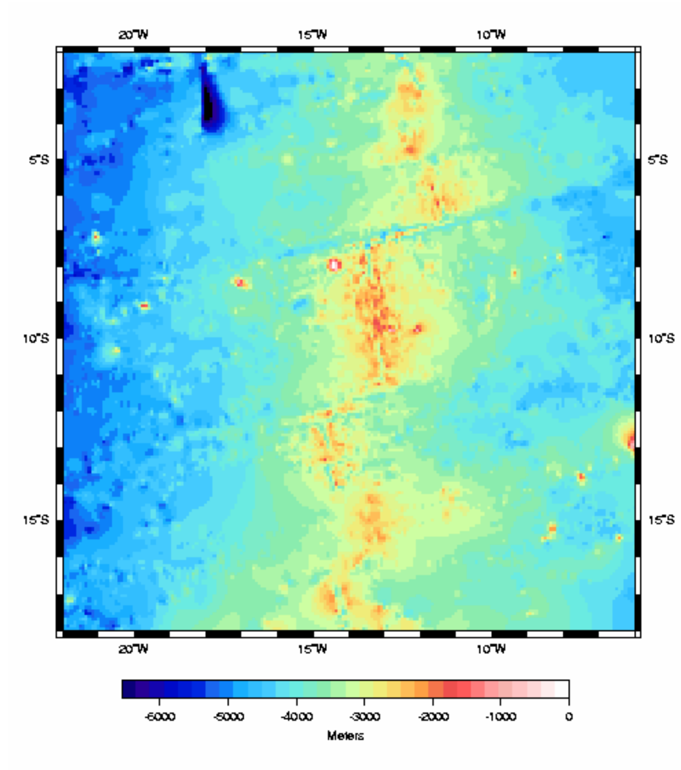
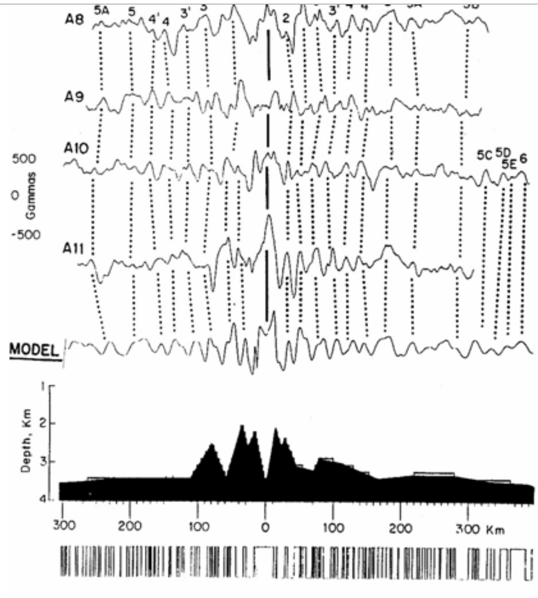
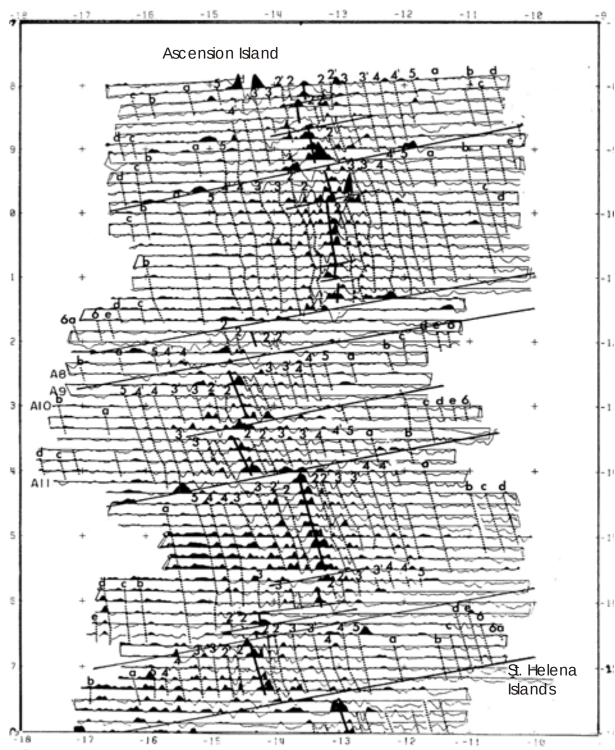



Figure 2 - Observed seafloor depths.

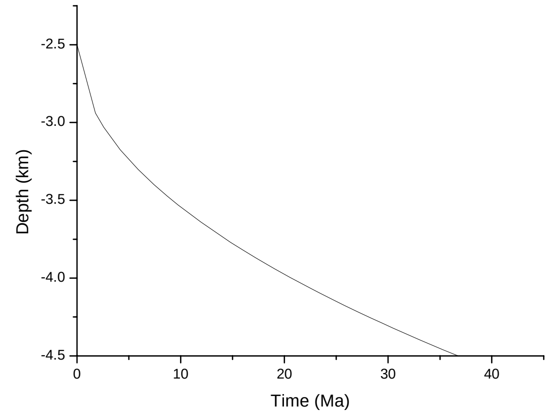



(a)

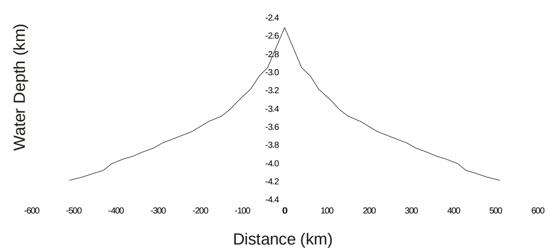



(b)

Figure 3 - (a) Synthetic models applied to observed magnetic profiles across the ridge crest segment between Ascension and St. Helena Islands; (b) Magnetic lineations correlation and major offsets of the magnetic anomalies.




(a)




(b)

Figure 4 – (a) Theoretical depth as a function of age; (b) Theoretical depth as a function of distance from the ridge axis.

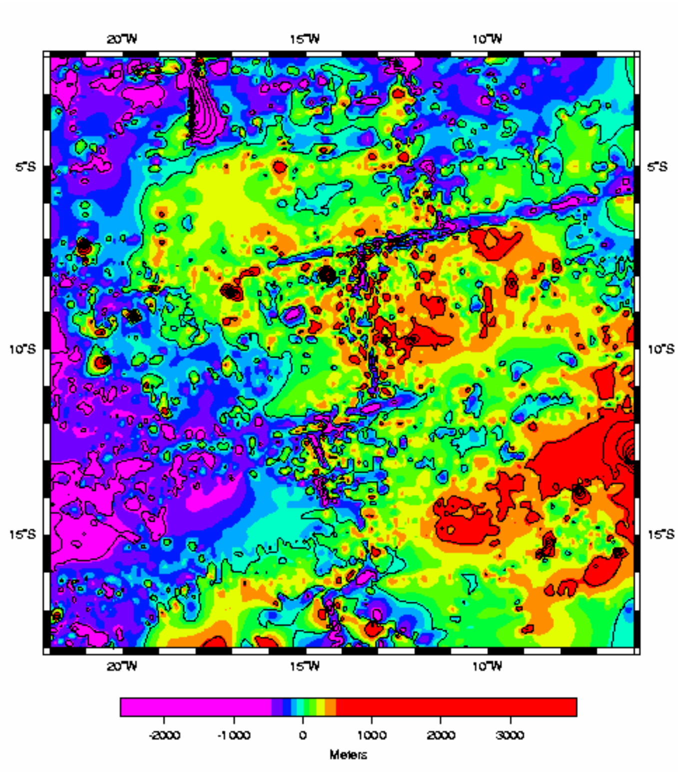



Figure 5 - Resulting depth anomalies.