Satellite gravimetry for the Fernando de Noronha Chain, Northeast Brazil, and its bearing on the volcanic seamount structure

Gravimetria de satellite para a Cadeia Fernando de Noronha, Região Nordeste do Brasil, e sua relação com a estrutura de montes submarinos vulcânicos.

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Abstract

The authors present the gravimetric and geomorphologic studies for the Fernando de Noronha Chain, western Equatorial Atlantic Ocean, based on the satellite database TOPEX ver. 14.1, and its bearing on the volcanic seamount structure. The volcanic seamounts are generally of 30 km in base diameter, 10 km of flat-top diameter, and 3000 to 4000 m of relative height. The base diameters and the flat-top diameters show a positive correlation, indicating that the volcanic edifices are voluminous and their top was originally much higher than sea level. The large volcanic edifices tend to have steep slope, of about 25°, and are considered to be constituted by lava flows. The small ones have gentle slope of about 7° and are estimated to be composed of unconsolidated pyroclastic deposits. The southwest foothill of the Sirius Bank and the Guará Bank is covered by thick deposits and they are significantly older than the sediments originated form the continental slope. The flat-top planes of the seamounts are constantly about 50 to 100 m deep and the basement subsidence of the volcano is not observed. The volcanic seamounts show the Bouguer anomaly about 100 mGal lower than the adjacent abyssal plane, indicating that they are composed of the materials less dense than the oceanic crust, such as lava flows and pyroclastic deposits. The large volcanoes have local maximum Bouguer anomaly at the centre, about 80 mGal higher than the border, showing a ring-like structure. It suggests possible presence gabbroic intrusion at the base of the volcanic edifices. The E-W trend of the Fernando de Noronha Chain is widely different from the NW-word absolute motion vector of the South America Plate. Therefore, the Fernando de Noronha Chain is not considered to be a hot-spot track.

Resumo

Os autores apresentam os estudos gravimétricos e geomorfológicos para a Cadeia Fernando de Noronha, região ocidental do Oceano Atlântico Equatorial, com base no banco de dados de satélites TOPEX ver. 14.1, e sua indicação sobre a estrutura dos montes submarinos vulcânicos. Os montes submarinos vulcânicos são geralmente de 30 km de diâmetro da base, 10 km de diâmetro do topo achatado e 3000 a 4000 m de altura relativa. Os diâmetros da base e do topo mostram uma correlação positiva, indicando que os edifícios vulcânicos são volumosos e o topo desses foi originalmente muito mais alto do que o nível do mar. Os edifícios vulcânicos grandes tendem a possuir o talude de alta declividade, de aproximadamente de 25°, e são considerados como constituídos por fluxos de lava. Os pequenos têm o talude de baixa declividade, em torno de 7°, e são estimados como compostos de depósitos piroclásticos. O sopé do Banco Sirius e do Banco Guabá é coberto por depósitos espessos, sendo que, esses são significativamente mais antigos do que os sedimentos originados do talude continental. Os planos do topo achatado dos montes submarinos possuem profundidade constante de 50 a 100 m e, não se observa a subsidência da base dos vulcões. Os montes submarinos vulcânicos apresentam a anomalia Bouguer em torno de 100 mGal mais baixa do que da planície abissal adjacente, indicando que, esses são constituídos por materiais menos densos do que a crosta oceânica, tais como fluxos de lava e depósitos piroclásticos. Os vulcões grandes possuem alta anomalia Bouguer no centro, cerca de 80 mGal maior do que da borda, apresentando uma estrutura anelar. Esta observação sugere possível existência de intrusão gabróica na base do edifício vulcânico. A orientação E-W da Cadeia Fernando de Noronha é muito diferente do vetor do movimento absoluto da Placa Sul-Americana, que é direcionada ao noroeste, portanto geotectonicamente não é considerado como uma cadeia de hot-spot.

Introduction

The Fernando de Noronha Chain (*Cadeia Fernando de Noronha*) is a submarine volcanic sequence with E-W trend along the latitude 4°S in the western margin of the Equatorial Atlantic Ocean. The seamounts are distributed in the area about 490 km long and 110 km wide (Fig. 1). The highest elevations constitute the Fernando de Noronha Island (2) and the Rocas Atoll (6). The volcanic edifice of the Fernando de Noronha Island is 4400 m in relative height, being the third highest Brazilian volcano.

This island is the only locality where the constituent rocks are exposed. It is constituted mainly by strongly silica-undersaturated alkaline basic to ultrabasic rocks, such as alkaline basalt, basanite and nephelinite, which are intruded by phonolite plugs and small monzonite body (Almeida, 1955). They were studied in geochronology (e.g. Rivalenti et al., 2007) and isotopic geology (e.g. Gerlach et al., 1987). The datings (Cordani, 1970; Buikin et al., 2010) indicate that the magmatism took place at about 12 Ma. However, the gravimetric, geomorphologic, and geotectonic studies are scarce.

In recent years, the techniques of satellite gravimetry and predicted bathymetry are in remarkable improvement. The authors have performed the gravimetric analyses for the Fernando de Noronha Chain using the TOPEX ver. 14.1 satellite data. This paper presents the results and discusses its geotectonic genesis.

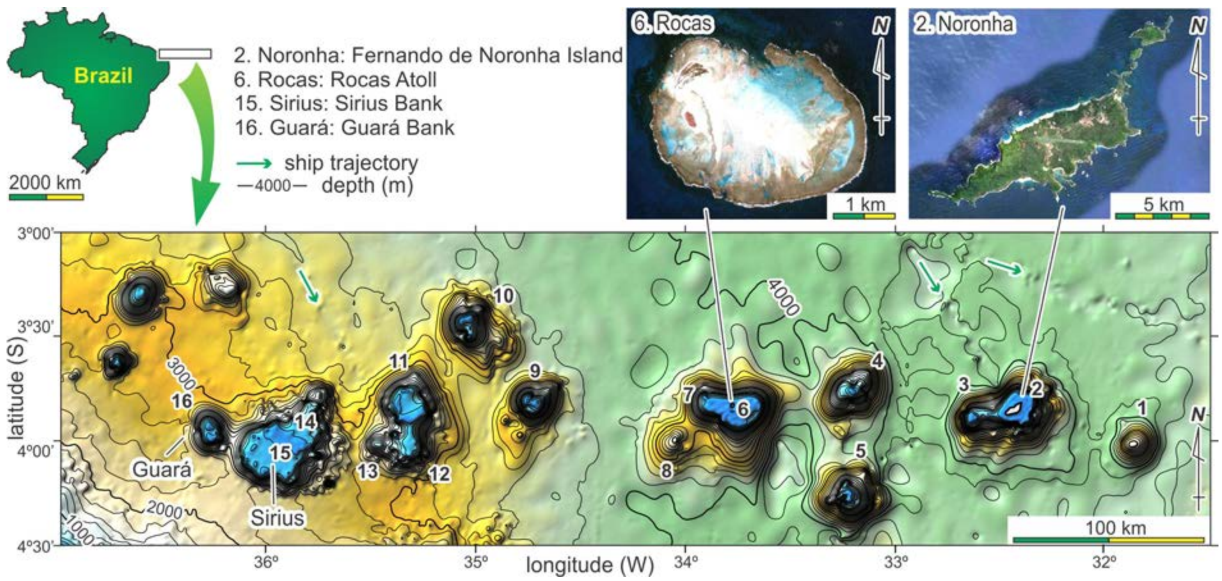

Fig. 1. Predicted bathymetry map for the Fernando de Noronha Chain, Atlantic Ocean of the Northeast Brazil, according to the TOPEX ver. 14.1 database. The satellite images of the Fernando de Noronha Island are originated from Google Earth™.

Research methods

The authors have adopted the free-air anomaly and predicted bathymetry of the TOPEX ver. 14.1. They were elaborated based on the technique of Smith & Sandwell (1997) and are in distribution from the UCSD-SIO. This version has 1.85 km of resolution and it should be at the theoretical limit of the gravimetry.

The free-air data have been submitted to the Bouguer reduction correction based on the water blade thickness of the predicted bathymetry, which has been performed with the help of original software Schwelt ver. 1.0 build 28, adopting continental crust density of 2.65 g/cm, sea water density of 1.01 g/cm, and gravity constant of 6.67259×10^{-11} m^3/s^2kg. The gravimetric maps have been elaborated by Excel™, Surfer™, and CorelDraw™.

Volcanic seamounts

The Fernando de Noronha Chain is constituted by 16 large volcanic edifices. They are almost circular, with general size of 30 km in base diameter, 10 km in the flat-top diameter, and 3000 to 4000 m in relative height. The interval between them is about 30 km.

The flat-top planes are about 50 to 100 m below sea level forming guyots. Their depth is constant and no basement subsidence is observed. The seamounts have a positive correlation between the base diameter and the flat-top diameter (Fig. 2A), suggesting that the volcanic edifices are highly voluminous and their tops were originally higher than sea level.

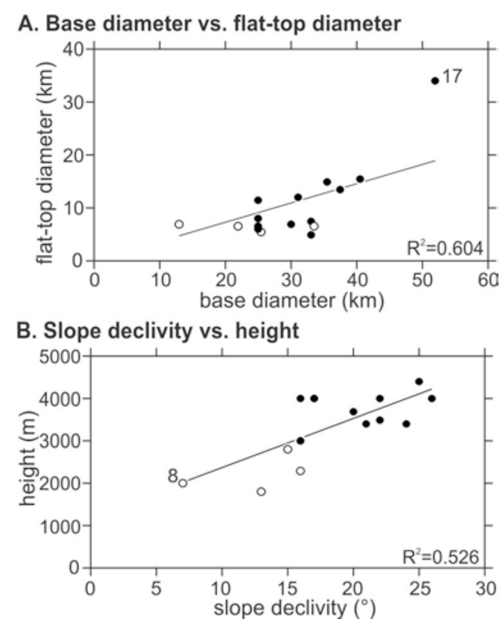

Fig. 2. Diagrams for the comparison of morphologic parameters of the volcanic seamounts of the Fernando de Noronha Chain: A) Base diameter vs. flat-top diameter; B) Slope declivity vs. height.

The slope declivity and volcano height also show positive correlation (Fig. 2B). The large volcanic edifices have steep slope of about 25°, and low ones, gentle slope of 7°. This highly contrasted slope angles could be due to the difference of constituent rock bodies, that is, lava flows or pyroclastic deposits.

The Fernando de Noronha Island is made up of two volcanic edifices, that is, Fernando de Noronha Volcano (2) and the FN-3238-0353 Seamount (3). At the southwest and northeast slops of the Fernando de Noronha Volcano, wide and deep landslide valleys are observed (Fig. 3). Especially, the southwest valley is large, 5 km wide and at least 1000 m deep. The Fernando de Noronha is a large shield volcano of 40.5 km in the base diameter, 15.5 km in the flat-top diameter, and 4400 m in relative height.

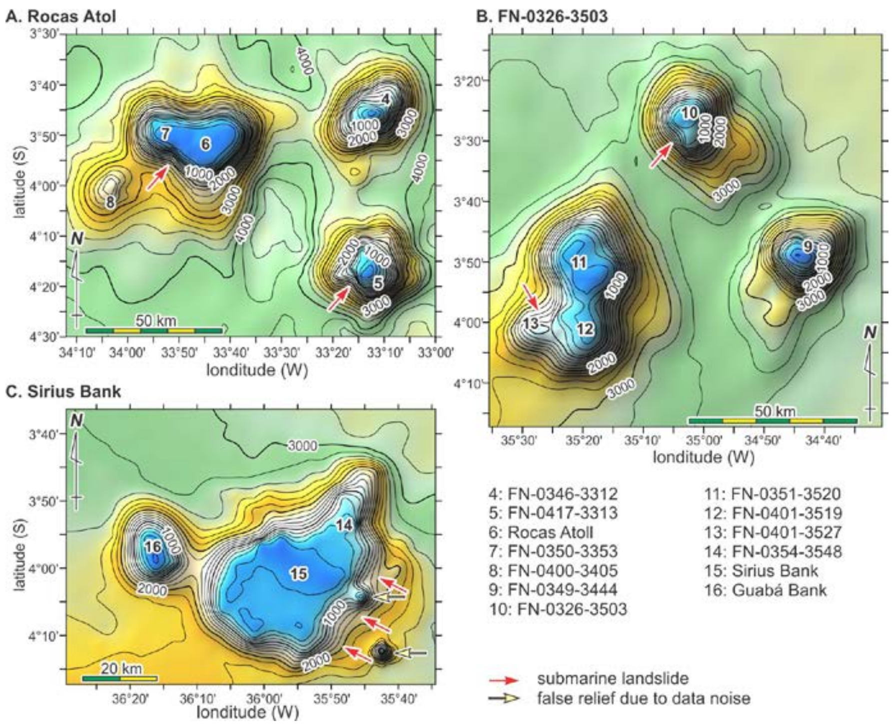

Fig. 3. Detailed predicted bathymetry maps for the areas of: A) Rocas Atoll; B) FN-0326-3503 Seamount; C) Sirius Bank.

The Sirius Bank (15) is the widest volcanic edifice of the Fernando de Noronha Chain, of 52 km in the base diameter, 34 km in the flat-top diameter, and 3000 m in relative height. The shallow flat-top plane very extensive, forming an immense bank. The Seamount FN-0354-3548 (14) and the Guará Bank (16) are smaller volcanic seamounts constituting guyots.

The Sirius Bank (15) and the Guará Bank (16) are situated exceptionally on the foothill of the continental elevation. If they are relatively old volcanoes, thick sedimentary deposits originated from the continental side would burry the volcano foothills. The level difference between the northeast foothill and southwest one of the seamounts, 1300 m, is significantly larger than the regional ones, 600 m (Fig. 4). Therefore, the continental side foothill should be covered by the sedimentary deposits with minimum thickness of 500 m and these volcanoes are significantly older than the deposits.

Gravimetric anomalies

The Fig. 5 shows gravimetric maps of free-air and simple Bouguer anomalies. The free-air map shows a close relation between gravimetric anomaly and depth. On the continental shelf the free-air anomaly is about 40 mGal and on the abyssal plane, about -20 mGal. The free-air anomaly op of the seamounts is of about 200 mGal higher than that of the abyssal plane. Although the flat-top of the seamounts is close to sea level, being almost at the same depth, the free-air anomaly is not homogeneous. The Fernando de Noronha Island (2) and the Rocas Atoll (6) have high free-air anomaly, respectively 240 and 230 mGal. On the other hand, the seamounts FN-0346-3312 (4), FN-0417-3313 (5), FN-0349-3444 (9), FN-0326-3503 (10) are of lower anomaly, respectively 150, 170, 150, and 170 mGal. Large seamounts, as Sirius Bank (15), Guará Bank (16), and Canopus Bank, also have lower anomaly, respectively 180, 140, and 160 mGal.

Between the continental slope and the Sirius Bank (15) there is a low free-air zone. This area occurs on the continental elevation and the low gravity can be attributed to the sedimentary deposits originated from the continental slope. According to the relative anomaly of 50 mGal, the thickness is estimated to be 2500 m.

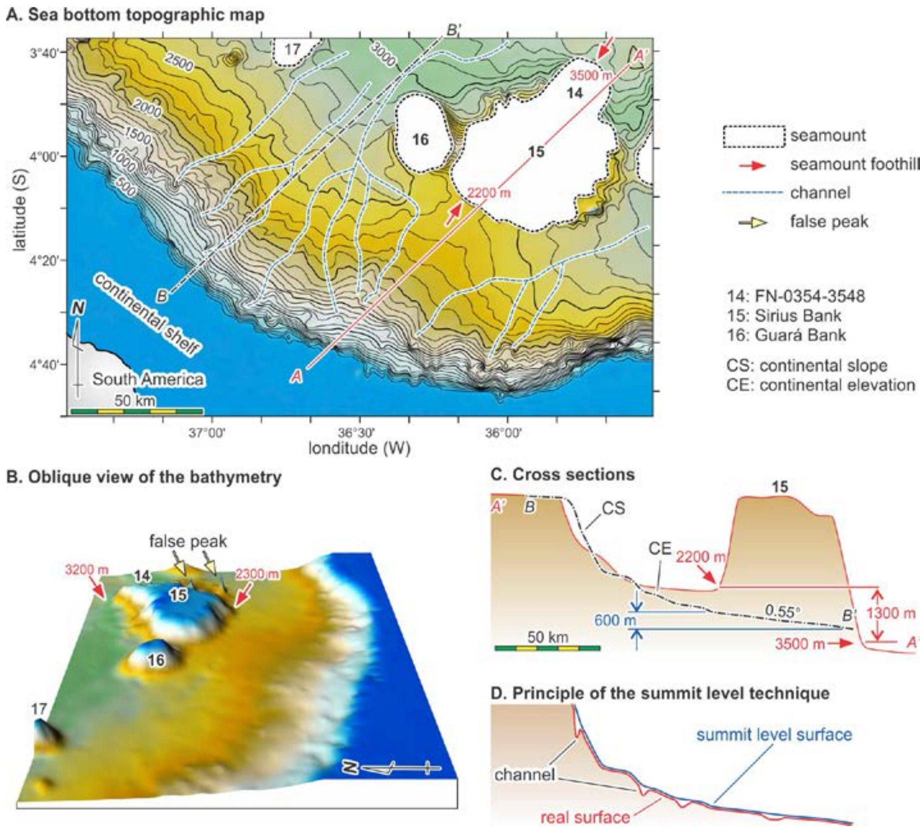

Fig. 4 Submarine morphology around the Sirius Bank (15): A) Ocean bottom topographic map; B) Oblique view; C) Cross sections of the summit level surface based on the mesh interval of 9.4 km; D) Principle of the summit level technique.

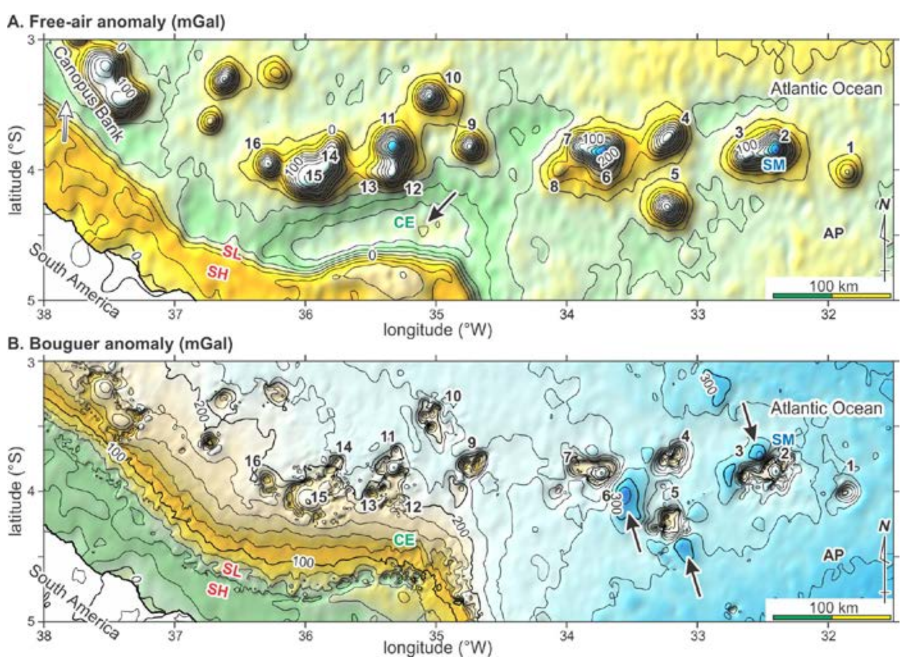

Fig. 5 Gravimetric anomaly maps for the Fernando de Noronha Chain Area based on the satellite data of the TOPEX ver. 14.1: A) Free-are anomaly. B) Simple Bouguer anomaly.

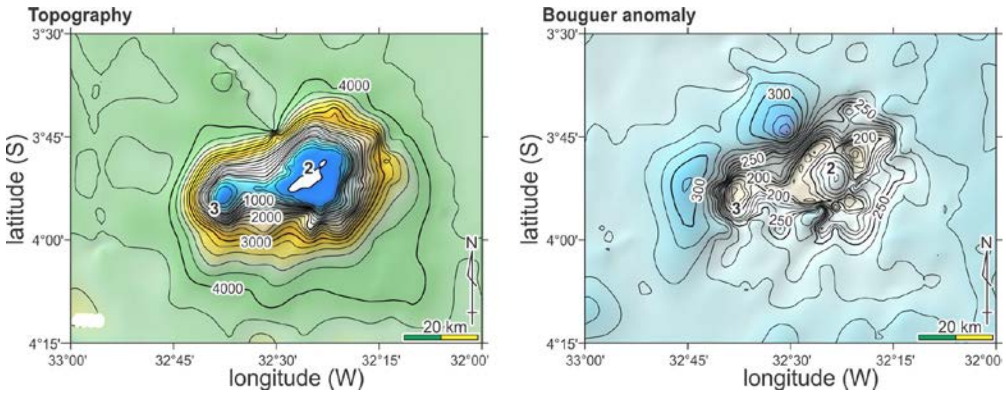

Fig. 6. Predicted bathymetry map (A) and simple Bouguer anomaly map (B) for the volcano of the Fernando de Noronha Island (2) and the Seamount FN-3238-0353 (3).

The Bouguer anomaly map shows low anomaly in the continental shelf, about 20 mGal, and high anomaly in the abyssal plane, about 280 mGal. The volcanic seamounts show Bouguer anomaly about 100 mGal lower than the adjacent abyssal plane. Some large volcanoes have Bouguer anomaly at the centre 60 to 80 mGal higher than the border (Fig. 6). This phenomenon is possibly due to the gabbroic intrusion in the base level of the large volcanic edifices. Close to the Fernando de Noronha Island (2), the Seamount FN-0417-3313 (5), and the Rocas Atoll (7), there are high gravity areas (Fig. 5B, black arrows).

The Fig. 7 presents the relationship between gravimetric anomalies and depth. The geomorphologic and geologic units of the target area are plotted on the specific areas of these diagrams. Close to the sea level, continental shelf (Figure 11, SH) and flat-top of the seamounts (GY) constitute two distinct groups of the shallow zone with the gravimetric anomalies respectively of 0 to 40 mGal and 120 to 240 mGal.

The seamounts (SM) show positive correlation between free-air anomaly and altitude and high-angle negative correlation between Bouguer anomaly and altitude. These observations suggest that the volcanic edifices are sustained not only by rigid oceanic crust but also by isostasy. The data for the abyssal plane presents a negative correlation between the Bouguer anomaly and depth, but the free-air anomaly is constantly about -20 mGal. This fact indicates that the abyssal plane almost is in isostatic equilibrium. The gravimetric anomalies of the continental elevation are about 50 mGal lower than that of the abyssal plane of the same depth. The fact suggests that the maximum thickness of the sedimentary cover is about 2500 m.

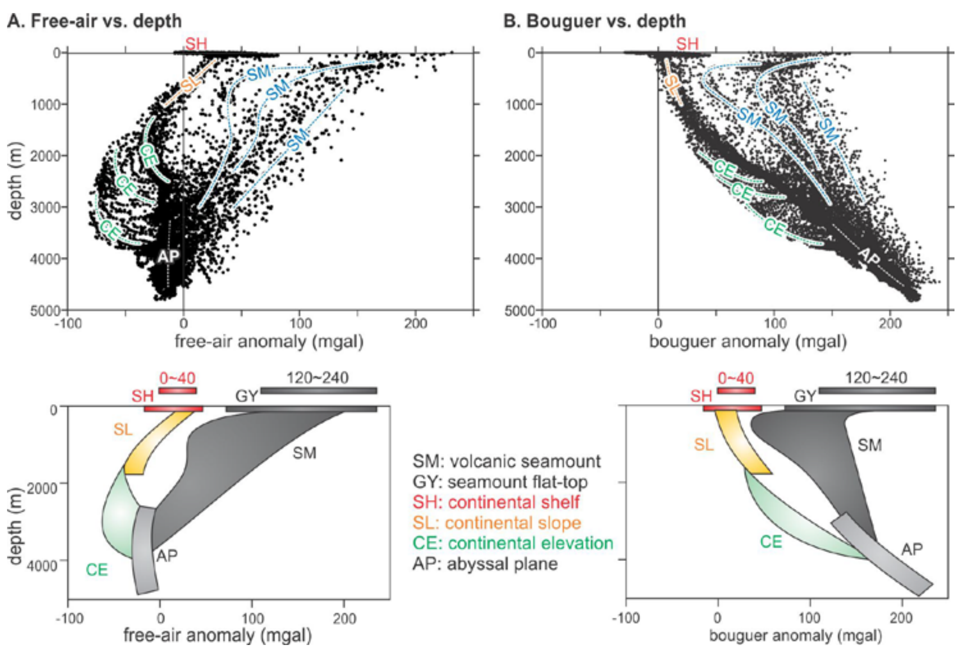

Fig. 7. Relation between the gravimetric anomalies and depth for the Fernando de Noronha Chain and adjacent area, western Equatorial Atlantic Ocean: A) Free-air anomaly; B) Bouguer anomaly.

Geotectonic genesis of the magmatism

The previous papers proposed two different ideas for the genesis of the Fernando de Noronha Chain volcanism: 1) Magmatism along an abyssal fracture zone (e.g. Almeida, 1955); 2) Hot-spot track (e.g. Silveira & Stutzmann, 2002). Recently, an alternative idea of hydrated mantle melting has been proposed (e.g. Skolotnev et al., 2010; Motoki et al., 2012).

The predicted bathymetric map (Fig. 1) shows that the Fernando de Noronha Chain is not linked directly to any systems of active transform faults and abyssal fracture zones of the Atlantic Ocean. In addition, the volcanic chain and the abyssal fracture zones are not exactly parallel, but direction discrepancy of 10°. Transform faults and abyssal fracture zones are cold mantle zones, which is unfavourable for magma generation in normal condition.

The hot-spot track direction is according to the absolute motion of the plate, that is, the plate movement relative to the world-wide hot-spots. If one direction of the magmatic chains is hot-spot track, anther direction is of different geotectonic genesis. O'Connor & Roex (1992) indicate that the absolute motion vector of the South America Plate is about N35°W and the NE-SW trend alignments are of hot-spot tracks. Therefore, the Fernando de Noronha Chain is not considered to be a hot-spot track. For the same reason, the Vitória-Trindade Chain also is not a hot-spot track.

In this moment, no conventional geotectonic model can justify the E-W trend magmatism of the Fernando de Noronha Chain. An alternative idea is horizontal penetration of asthenosphere-origin hot mantle along the abyssal fracture zone from the west to the east (Skolotnev et al., 2010). The abyssal fracture zone should be hydrated due to the serpentinization and the water can help the melting of the hot mantle (Motoki et al., 2012).

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