Magnetic study of Saint Paul Fracture Zone, Equatorial Atlantic

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Abstract

The magnetic study of Saint Paul fracture zone is part of the COLMEIA Project (Complex Mantle Exhumation and Intra-transform Accretion), and deals with the magnetic data collected during the oceanographic cruise on January-February of 2013. Firstly, the data was processed and the initial analysis was done, getting an observed magnetic anomalies grid. The second focus was the calculation of simple theoretical models able to simulate an homogeneous crust with constant spreading, and topography and two magnetization possibilities: a constant value or a function of age. Therefore, the processed models represent a simple dynamic. The residuals, i.e., the differences between the observed and theoretical signal, show variations in composition, topography and polarity. Differences between models will be presented and discussed. The interpretation of the residual anomalies, compared with other geophysical and geological data, will be able to partially model the geodynamical processes in the region, specifically in the area of St. Paul's fracture and the St. Peter and St. Paul's Archipelago. The interpretation had already started and this work aims to present the first ideas from the magnetic analysis of COLMEIA cruise.

Introduction

In 2013 the international project COLMEIA begun the study of St. Paul Fracture Zone through an oceanographic cruise where geologic, geophysics, and chemistry data were collected. In this extend abstract the initial analysis of the magnetic data is presented.

One of the main objects in geophysical studies in the oceanic crust is the magnetostratigraphy: The challenge of determining the ocean floor age based on magnetic anomalies. The magnetic rocks that form the ocean floor guarantee the record of geomagnetic field while they cool down, resulting in a linear anomaly pattern parallel to the ridge. However, the typical magnetic profiles, like those observed in Vine and Matthews (1963), were not identifiable at the study area due to the very low magnetic latitude, which compromises the amplitude of the normal and reversely anomalies.

The technique of reduction to the pole is used as a tool to enhance the signal for magnetic surveys at low latitudes (Hansen and Pawlowski, 1989; Luo and Xue, 2009). In spite of that, this work uses another approach, the forward modeling. It was adapted from a study published by Maia et al. (2005) which presents a magnetic modeling of oceanic crust in South Pacific as an independent mean of dating volcanic edifices.

This work proposes three magnetic computed models with a simple dynamic behind them. The parameters were chosen carefully, avoiding a complex model, so an interpretation of the differences between the models and the observed magnetic anomaly grid could be done.

Materials and Methods

Available data The observed data consists in multibeam bathymetry (Maia et al., 2013) and surface magnetic measurements each 10 seconds. The bathymetric grid can be seen in Figure 1 and the magnetic anomalies in Figure 2. IGRF-11 was removed from the Total Magnetic Field for each point.

The ship tracks are mostly oriented EW and NS. Usually, profiles in the spreading direction (EW) are better for the identification of the magnetic anomalies and dating the oceanic crust, while perpendicular seismic arrays (NS) identify more precisely transform fault related structures and the fracture zone.

The minimum distance between the ship and the magnetometer was enough to avoid magnetic influence of the ship metallic mass. The measurements are made with an Overhauser magnetometer with 0.001nT resolution and 0.1nT absolute accuracy. A low-pass filtering and a spike-sorting algorithm were applied to remove acquisition errors from the database. The early data processing and validation was done on board.

An important correction for magnetic land surveys is the diurnal variation. It is not done on offshore campaigns due to the need of keep a static magnetometer near the area, which is obviously not possible. However, the amplitude of diurnal variation is smaller in marine surveys (Jones, 1999) ensuring the data validation. In the oceans, electromagnetic induction tends to reduce diurnal variation amplitude, but it is a variable phenomenon. Flow of electrically conducting seawater produces field changes that depend upon the speed and the direction of the water movement with respect to the magnetic poles and the conductivity structure of the seabed. Recordings from the nearest land magnetic observatory cannot be used to take account of offshore diurnal variation without the risk of large amplitude errors (Parkinson and Jones, 1979; Hill and Mason, 1962). This condition made the use of Brazil and Africa's observatories impracticable.

In practice, an analysis of diurnal variation is made to determine if the critical interval, between 10 a.m. and 3 p.m., define differences with other days' time. If this has occurred the only solution would be to remove those points. Fortunately, comparing the complete grid and the grid without critical time (Figure 3) only few differences were found. This study used all data to make the magnetic survey grid and thus follows the current procedures for processing of marine magnetic data.

After all corrections and analysis, the observed database resulted in accurate anomalies.

Model assumptions This work assumed that magnetic anomalies are dominated by thermoremanent magnetization (TRM). By theoretical magnetic studies, it is known that very dynamic areas with hydrothermal circulation have a remagnetization at most of one third of the natural remanent magnetization (NRM) (Hall et al., 1995). This is due to the magnetic moment of the grain, the dependence of time, related to the size and the temperature. The thermal energy decreases the basalt magnetization exponentially. This is guided by the fundamental process called maghemitization, which consists in the transformation of titanomagnetite to titanomaghemite. For moderate oxidation of single domain size grains, the chemical remanent magnetization (CRM) direction, related to maghemitization on this case, is the same as that of the TRM, so that magnetic stripe anomalies should be unchanged in terms of magnetization direction, only the amplitude will change (Dunlop and Özdemir, 1997). This is the affirmation that validates Vine and Matthews's theory for the present study.

The magnetization model's constant parameters are:

- A layer of 500 m thickness that supports the hypothesis of a young crust, recently magnetized (Ade-Hall et al., 1975).
- Five spreading ridges, including two segments parts of the Mid-Atlantic ridge and three intra-transform segments. They have been delimited by their characteristic morphology (Figure 4).
- A constant spreading rate along each segment, their directions were calculated using a set of rotation poles for South America and Africa plates.
- A homogeneous crust of tholeiitic basalt.

The flowlines were calculated as a function of time, so an age grid was interpolated and defined isochrones every million year. The age at the center of each ridge segment, at the neo-volcanic ridge, is zero. In the Figure 4 it is presented the trace of the active transform faults and the corresponding inactive fracture zones traced visually following the valleys structures roughly parallel to the spreading direction.

The second constructed grid contained the expected magnetic polarities ascribed depending on the age. The polarity time scale uses the range of 35 Ma defined by Cande and Kent (1995). A grid with this information was set and is shown in Figure 5. It indicates the normal and reversal signals of each age strip. The modeling aims to simulate this influence on the magnetic signal.

Models This work compares three models. The distinctions among them are in the Table 1. They were calculated with a project algorithm, an adaptation on the algorithm of Maia et al. (2005), which combine the age, the magnetic polarity and the ocean floor depth grids to calculate the magnetic anomalies formed by the TRM of the oceanic crust.

Table1: Models constructed for this study.

	1	2	3
Magnetization	Equation 1	Equation 1	10 [A/m]
Topography	Observed	Equation 2	Equation 2

$$Mag[A/m] = 10 - 2.1737\sqrt{age[My]} \quad (1)$$

$$Depth[m] = minridge + 350\sqrt{age[My]} \quad (2)$$

Models 1 and 2 consider a decrease of magnetization as a function of age, equation (1). The initial value 10 A/m is an estimative of the magnetization of a zero age basalt crust. Model 3 assumes a constant magnetization equal to the initial value. The dependence of time is a consequence of viscous and chemical remanent magnetizations, as discussed earlier in the model assumptions. The parameter 2.1737 follows the same empirical relation used in Maia et al. (2005).

The first model used the observed bathymetry and the others a depth dependent of time (equation 2). The depth increases with age as the oceanic lithosphere subsides. This particular relation was presented by Parsons and Sclater (1977). The *minridge* is the value of minimum topography at the ridge axis. It was set as 2500 m for the North and South segments, 3000 m for the intra-transform North segment and 3200 m for the central and south segments. These values had been chosen visually from the bathymetry map, Figure 4.

Results and Preliminary Conclusions

The three models represent different possibilities to the magnetic anomalies related to a simple spreading model for the area of the St. Paul fracture zone.

Model 1 (Figure 6) presents high amplitude anomalies around the accretion axes and an approximately parallel distribution of the polarities. The anomalies induced by the boundaries between plates with different polarity and ages are noticeable. Besides, the model does not systematically present a mirror effect between the two flanks of the ridge.

Model 2 (Figure 7) shows magnetic anomalies with small amplitudes. The symmetry between the two flanks of the ridges is not very clear, either.

Comparing models 1 and 2 it is possible to notice significant differences. The observed bathymetry (model 1) presents higher anomaly amplitudes and they are distributed in a larger area. Since the models differ only in the bathymetric input (Table 1) it is possible to associate the differences to the effect of the topography, which is very pronounced in the study area and not always directly related to the normal spreading process.

Model 3 (Figure 8) was formulated to evaluate the effect of the attenuation of the magnetization with time in a theoretical model.

The amplitude anomalies and the alignment of them in model 3 related to the observed anomalies (Figure 2) may alert that the calculated decay may be stronger than the observed in equatorial region. Therefore, a specific model for magnetic decay at equatorial region must be set.

The residual anomalies are the difference between the calculated and the observed grid. Models 1 and 2 were used to calculate the residual anomalies. Results are presented in figures 9, 10 and 11, they show the difference between the calculated magnetic grid (Figures 6 and 7) and the observed anomaly grid (Figure 2).

The residual grid for the model 1 revealed an interesting point:

- The higher anomalies close to the accretion region (Figure 9). It could be explained by the same magnetization decay considered in this study, although, the first million years has faster variations. It is known that the fine grains in quenched pillows, in contact with seawater and warmed through burial beneath later eruptions, oxidize rapidly, certainly within 0.5 Ma (Irving, 1970; Ozima, 1971; Johnson and Atwater, 1977 and Johnson and Pariso, 1993).

The residual for model 2 has very similar anomalies comparing to the residual for model 1, since this models just differs in the input topography. The following characteristics revealed are:

- The negative anomaly caused by St. Peter and St. Paul Archipelago, 29.5°W, and the St. Paul transform fault (Figure 10). It was expected due to the low magnetization from mantle and metamorphic rocks collected during the cruise compared to the tholeiitic basalt used in the models.
- The alteration action on the axes, easily identifiable on the intra-transform segments, as in 27.7°W, this axis has a negative anomaly associated with its north part and a very positive anomaly associated with its south part (Figure 11). A theoretical explanation is that “Shallow fractionation and serpentinization of ultramafic rocks at segment ends control the amplitude variation within segments. The balance between these processes depends on the thermal state among segments” (Ravilly and Dyment, 1998).

Figures

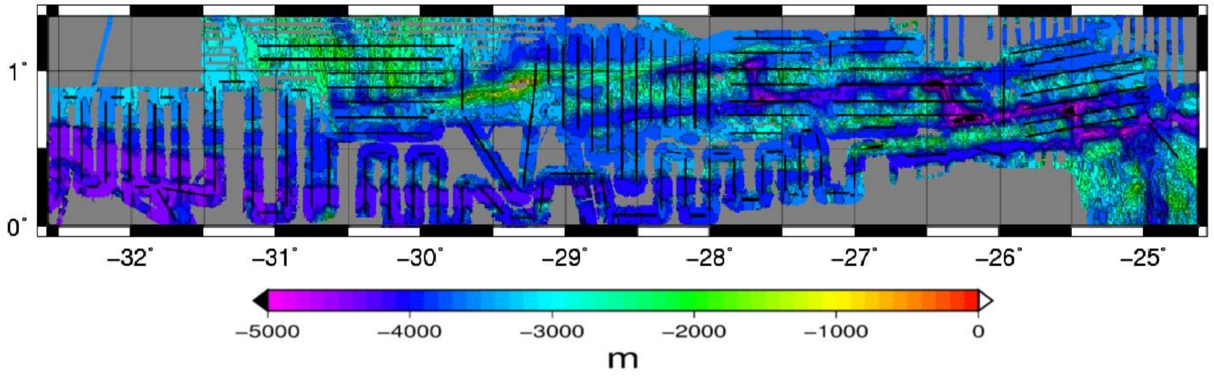

Figure 1: Multibeam bathymetry with track profiles.

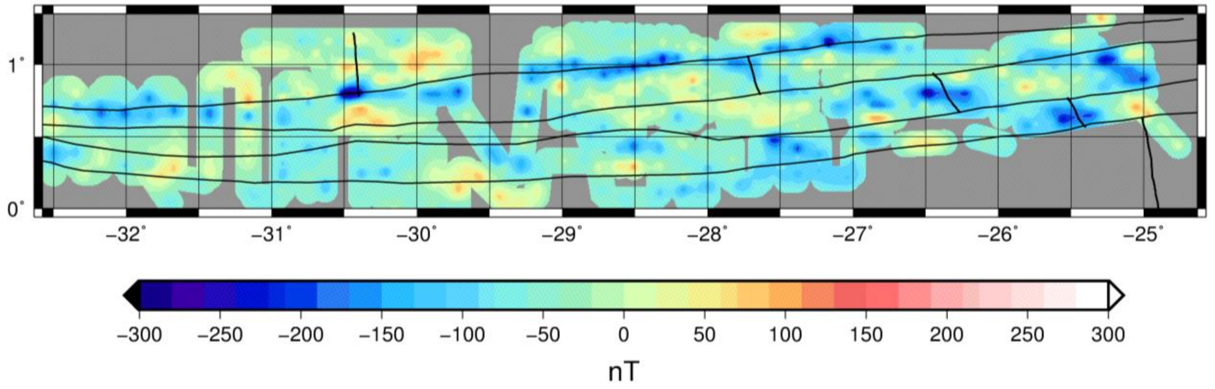

Figure 2: Total field magnetic anomaly map with spreading ridge segments, transform faults and fracture zones in black.

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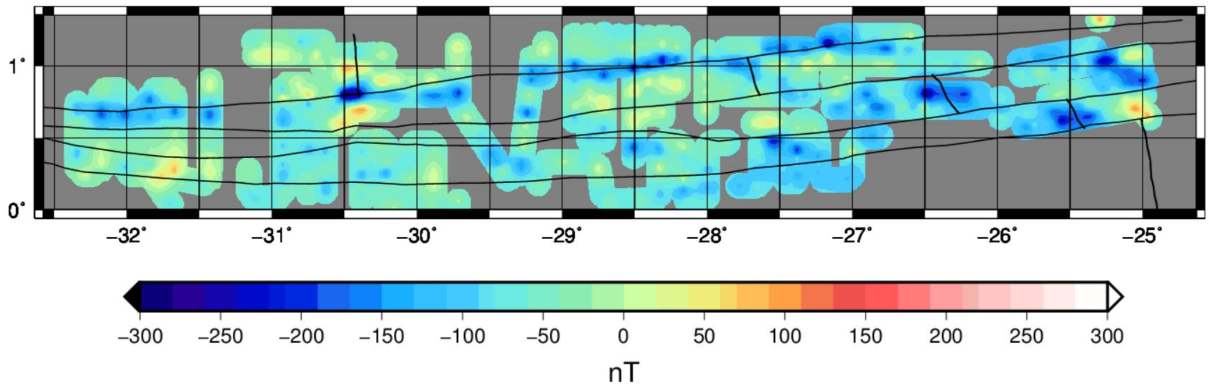

Figure 3: Total field magnetic anomaly map without critical day time with spreading ridge segments, transform faults and fracture zones in black.

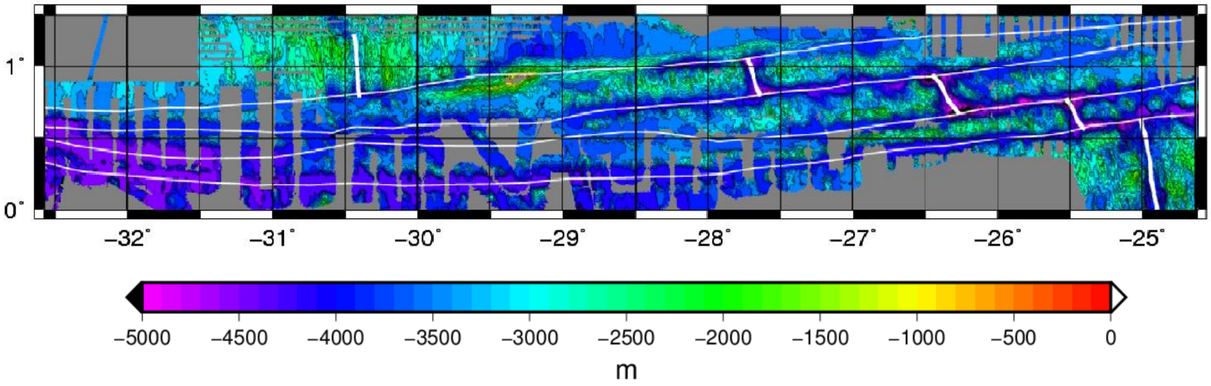

Figure 4: Observed bathymetry with spreading ridge segments (thick white lines), transform faults and fracture zones in white.

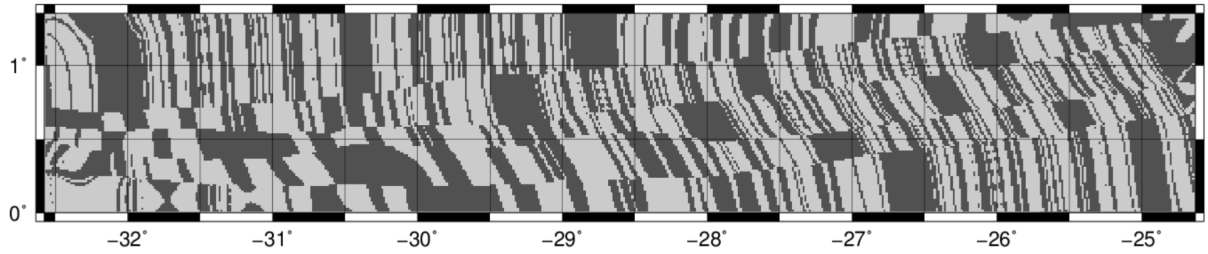

Figure 5: Theoretical polarity. Black represents the normal and the white the reversal signal.

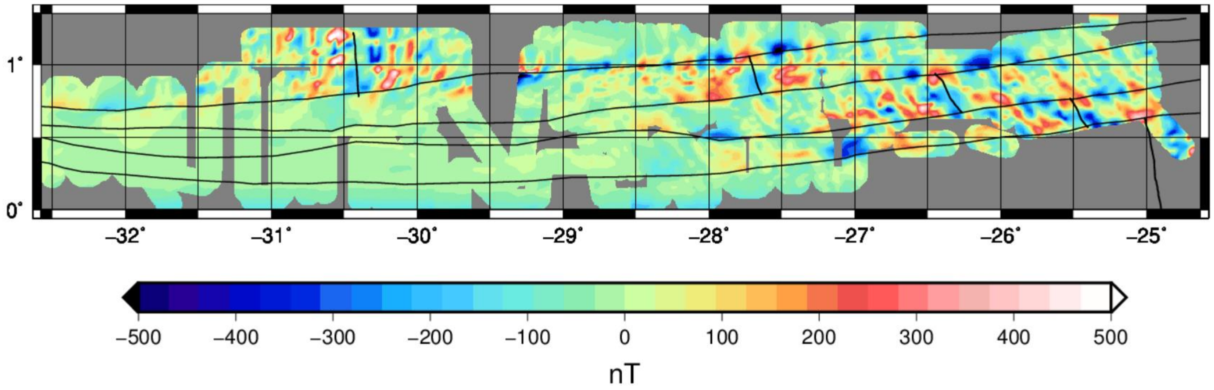

Figure 6: Magnetic results from Model 1.

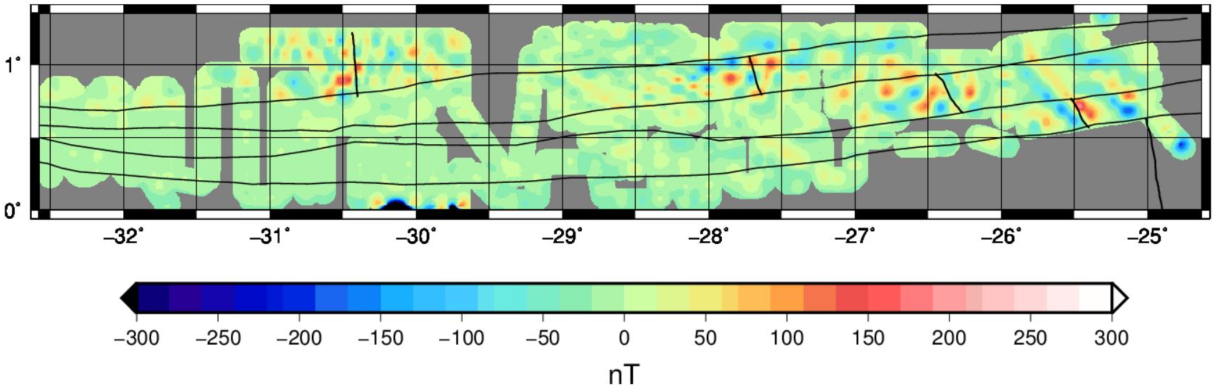

Figure 7: Magnetic results from Model 2.

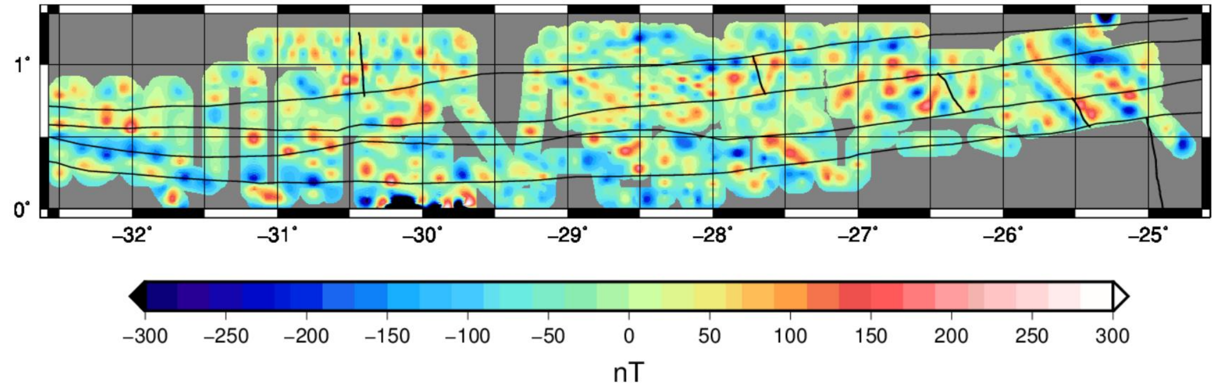

Figure 8: Magnetic results from Model 3.

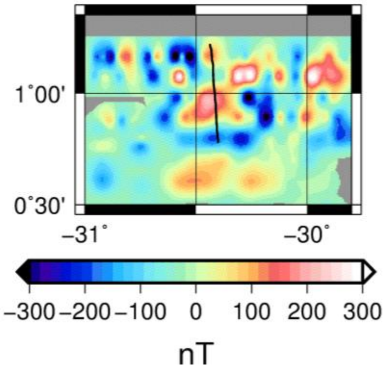

Figure 9: Zoom of the residual anomalies calculated with the model 1 in the Northern Mid-Ocean ridge.

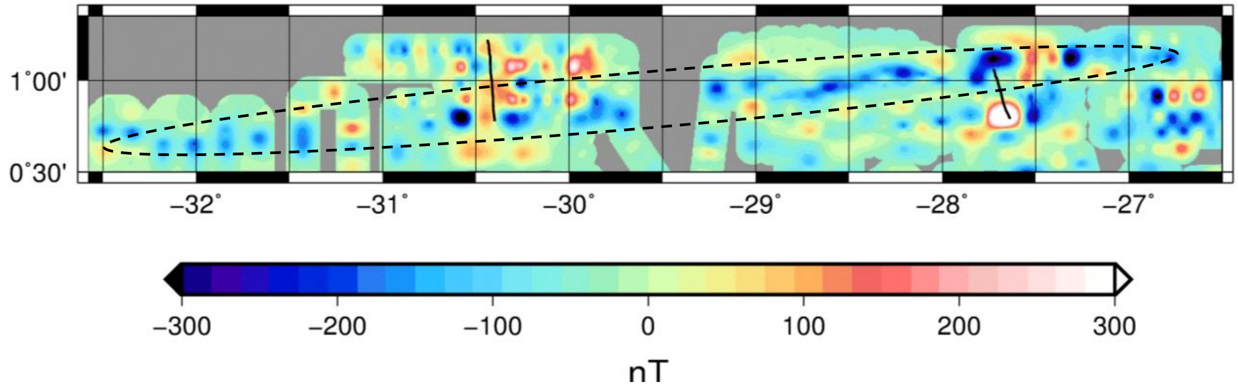

Figure 10: Zoom of the residual anomalies calculated with the model 2 in the St. Paul fracture zone. The linear negative anomaly of the fracture zone is delimited.

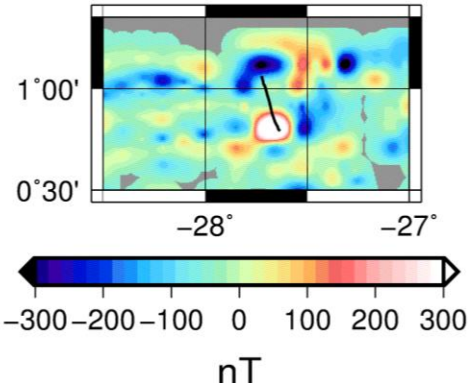

Figure 11: Zoom of the residual anomalies calculated with the model 2 in the Northern inner segment.

Acknowledgments

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