Geophysical study of volcanic bodies, Potiguar Basin (RN): preliminary results

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Abstract

The Potiguar Basin is one of the biggest onshore oil producers in Brazil. The geothermal evolution of the basin was partially controlled by magmatic events in the Cenozoic. Based on this information, this work aims to study two volcanic plugs of diabase in São João (RN), using terrestrial magnetic and gravity data. We intend to obtain the 3D geometry of bodies, to increase knowledge of the thermal evolution in the basin as well as the influence on hydrocarbons generation and accumulation. The study also includes measurements of magnetic susceptibilities and densities of intrusive rocks and their metamorphic and sedimentary host rocks.

Previous studies in the area showed that were formed pyrometamorphic rocks, indicating very low pressures and very high temperatures. These results are relevant in petrological terms, and may also have economic implications since a large number of basic bodies intrude rocks with hydrocarbon reservoirs. This is the first study of geophysics done in this area. In this paper, we present the preliminary results obtained with magnetic data in one of the bodies. The magnetic signatures obtained in this first study were revelantes, showing that the method provides results in this application.

Introduction

The study area (5° S and 36° W) is located in the southern boundary of the Potiguar Basin, in the Rio Grande do Norte State, Northeastern Brazil (Figure 1). Intrusive and extrusive rocks derived from magmatic events of mid-Cenozoic are common in this region, affecting both Cretaceous basin and Precambrian basement units. The magmatic events that occur in shape of plugs, flows and sills in this area can be directly associated with tectonic reactivations which can be formed structural traps, as well as related to the accumulation and generation of hydrocarbon (Souza *et al*., 2003).

The terrestrial magnetic data acquisition was carried out in January 2015, along 14 lines, using a pair of magnetometers model ENVI PRO. Altogether 5698 magnetic readings were acquired in a time range between 2 to 4 seconds.

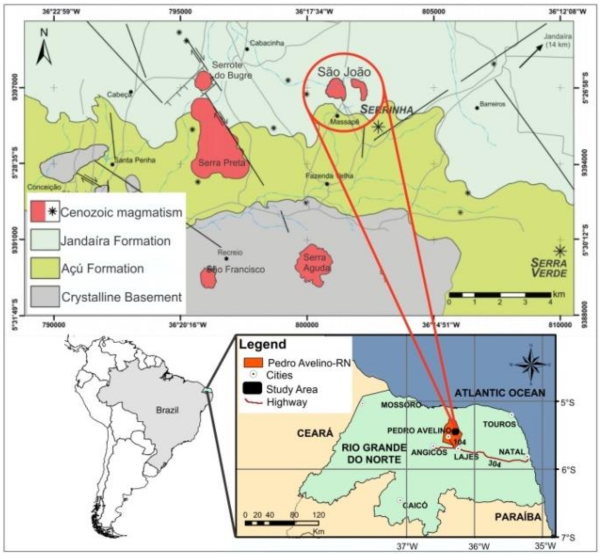

Figure 1. Simplified geological map of the region of Potiguar Basin, showing the location of the São João plugs. Adapted from dos Santos *et al.* (2014).

For navigation during the data collection we used a handheld GPS (Global Positioning System), Garmin Etrex 30. A magnetic susceptibility meter KT-10 v2S was used to measure the magnetic physical properties of the outcropping rocks (Table 1).

Two diabase plugs are partially exposed in São João area (Figure 2). The present study was carried out in the western one, whose surficial dimensions are: 1000 m long and 740 m width. These Paleogene to Neogene basic bodies intruded sandstones, siltstones, shales, limestones in this region. Our aim is mapping this body in surface and depth using magnetic and gravity data. After that, we will map the eastern plug.

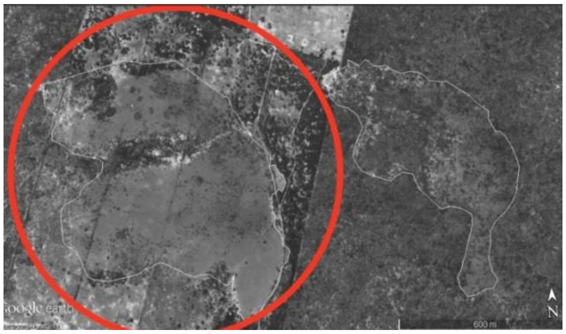

Figure 2. The São João vulcanic intruding carbonate rocks of the Potiguar Basin. The current studied plug is highlighted by the red circle. Image from Google Earth Pro.

Method

The magnetic method is the oldest and most widely used. It depends mainly on the presence of magnetite, pyrrhotite and hematite in the rocks of the surveyed area. The assignment of rock type is ambiguous, since ranges of values of magnetic susceptibilities of different rock types may overlap. Susceptibility may vary considerably, even within the same rock type. In general, sedimentary rocks have the lowest susceptibilities and mafic igneous rocks the highest (Ford, 2005).

The ENVI PRO is a portable, proton-precession magnetometer, was used in WALKMAG mode in this acquisition. It is ideal for applications where high productions, fast reading and high sensitivity are required (ENVI PRO operation manual - Scintrex). The magnetometer's performance is a function of the sensor's orientation with respect to the earth's magnetic field, therefore it was necessary to keep the mark on the sensor faces either magnetic north (or south - Either allowed due to symmetry). We used two devices, one configured as a total-field magnetometer and the other as a base-station, used to correct the diurnal variation. This diurnal drift can cause a variation in order of 50 nT/Hour.

The data were processed using the Geosoft/Oasis Montaj® version 8.1., following the processing flowchart shown in Figure 3.

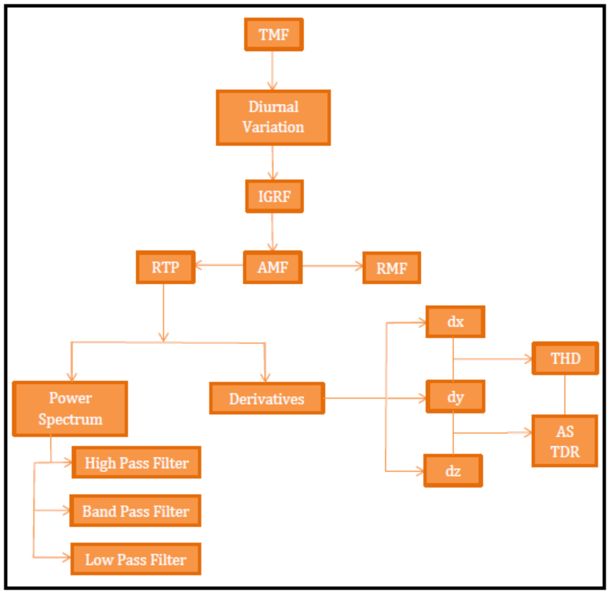

Figure 3. Flow diagram of processing already performed.

Total Magnetic Field (TMF) is obtained in the each station; the raw data are analyzed through a rapid evaluation to remove spikes that might have been produced by non-geologic sources, for example metallic artefacts, electric grids, etc. The removal of diurnal variation of the magnetic data was performed using a base station magnetometer. For IGRF correction, the component of the field magnetic attributed to the Earth's core described mathematically by the International Geomagnetic Reference Field was subtracted from the field data corrected from the diurnal variation, producing the Anomalous Magnetic Field (AMF).

Spectral filters were applied to enhance specific characteristics of the causative bodies. These filters are generated by using the chart values from power spectrum, which shows the variation of the strength of the magnetic signal in accordance with the wave number, where high-frequency signals representing shallow magnetic sources and low frequency signals deep sources (Fendi, 2001). The Earth's magnetic inclination and declination were used to reduce the AMF to the magnetic pole, making the interpretation easier and more reliable.

Derived from horizontal and vertical derivatives of the AMF, the analytic signal amplitude (AS) is a symmetric function bell-shaped, with its maximum exactly on top of each contact, and its width directly related to the depth of the body (Nabighian, 1974). The analytic signal locates the edges of the magnetic bodies independent of geometry or effects of magnetic remanence, an indicator to locate magnetic rocks. The formula used for the calculation is:

$$\mathrm{AS} = \sqrt{\mathrm{Dx}^2 + \mathrm{Dy}^2 + \mathrm{Dz}^2} \qquad (1)$$

The Total Horizontal Derivative (THD) is used to delineate the boundaries of bodies and cause faulty of the main structures, in addition to functioning as a method of regional waste-separation. In this analysis, was used the horizontal gradient of zero order. Given by:

$$\mathrm{THD} = \sqrt{\mathrm{Dx}^2 + \mathrm{Dy}^2} \qquad (2)$$

The Tilt Derivative (TDR) was first proposed by Miller and Singh (1994), provides an automatic-gain-control filter which tends to equalize the response from both weak and strong anomalies (Verduzco *et al*., 2004). The formula for calculation is given by:

$$\mathrm{TDR} = \tan^{-1}\left(\frac{\mathrm{Dz}}{\sqrt{\mathrm{Dx}^2+\mathrm{Dy}^2}}\right) \qquad (3)$$

Results

An anomaly is created when the Earth's magnetic field is disturbed by an object that can be magnetized. Earth's magnetic field typically observed vary from 25,000 nT to 70,000 nT (Telford *et al*., 1990). In the study area, the field strength was 26,255.332 nT, magnetic inclination was -22.06° and declination was -21.19°.

The body contouring extracted from satellite image (Figure 2) is superimposed in the maps to improve the interpretation of the magnetic anomalies.

The intensity of the induced magnetization is directly related to the ambient field by the susceptibility. Magnetic susceptibility data collected (Table 1) were plotted in Figure 4 and are consistent with the expected, since sedimentary and metamorphic rocks have magnetization below basic volcanic. It was found that the volcanic rocks measures have susceptibility around $1.5\text{-}4.9\mathrm{x}10^3$ usgs, low values for these types of rocks, but still higher than the susceptibility values measured in limestone and sedimentary rocks, which were no more than $0.6\mathrm{x}10^3$ usgs.

Table 1. Magnetic susceptibility (MS) of the outcropping rocks. Mean range values extracted from literature (Telford *et al*., 1990).

N°	Rock Type	MS $(10^{-3}\,ucgs)$	Range $(10^{-3}\,ucgs)$
1	Limestone	0.023/0.018	0-3
2	Metamorp.Limestone	0.054/0.481	0-3
3	Limestone	0.105/0.250	0-3
4	Limestone	0.518/0.320	0-3
5	Vulcanic	2.880/2.980	0-80
6	Vulcanic	3.780/3.090	0-80
7	Fine Vulcanic	8.430/3.010	0-80
8	Vulcanic	2.820/3.330	0-80
	Limestone	0.320/0.181	0-3
	Vulcanic	3.480/3.960	0-80
9	Vulcanic	3.130/4.900	0-80
10	Sandstone	0.132/0.108	0-20
11	Vulcanic	1.560/1.590	0-80
	Limestone	0.222/0.166	0-3
12	Vulcanic	4.460/4.130	0-80

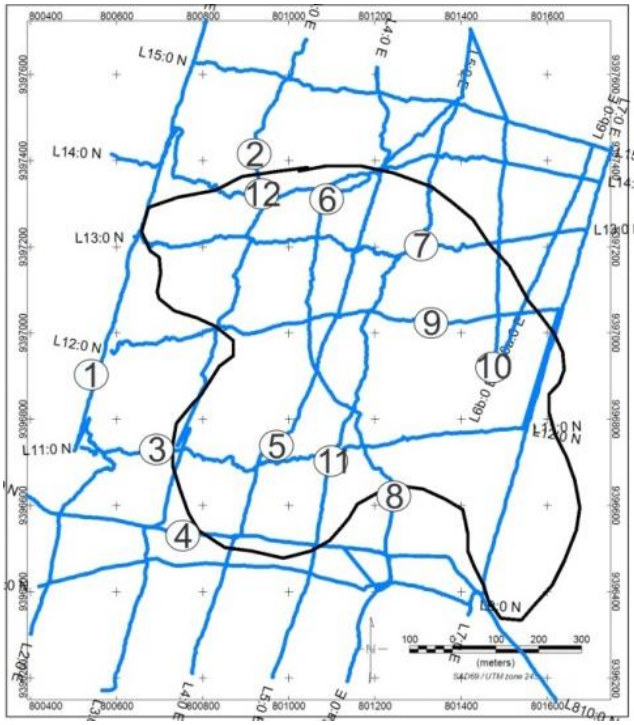

Figure 4. Magnetic data collection lines. Numbered circles are the locations of the magnetic susceptibility measures.

The Anomalous Magnetic Field (AMF), Reduction from magnetic Polo (RTP) and Residual Magnetic Field (RMF) maps show a complex anomalous pattern, however the anomalies match just partially with the plugs superficial contacs (Figure 5).

The derivatives of the magnetic data allow more detailed analysis of the geometry of the causative sources, indicating abrupt changes in slope of the magnetic field, which may be caused by a jump of the average value or the presence of a peak in the data (Portela Filho *et al*., (2003).

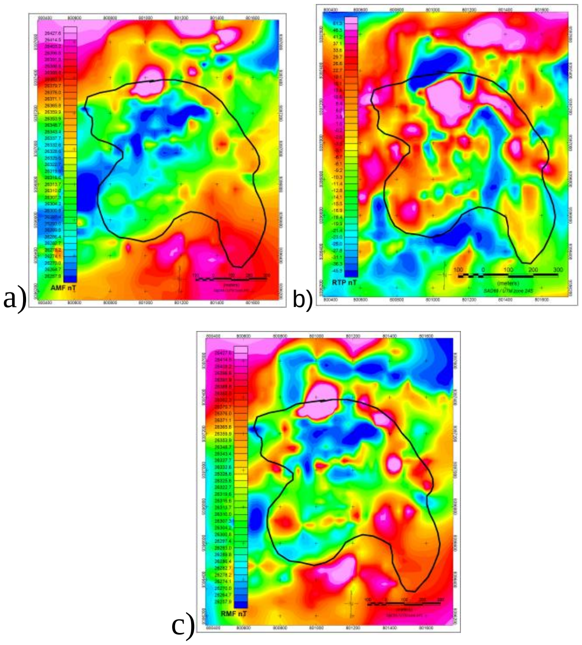

Figure 5. a) Anomalous Magnetic Field (AMF), b) Reduction to magnetic Pole (RTP) and c) Residual Magnetic Field (RMF).

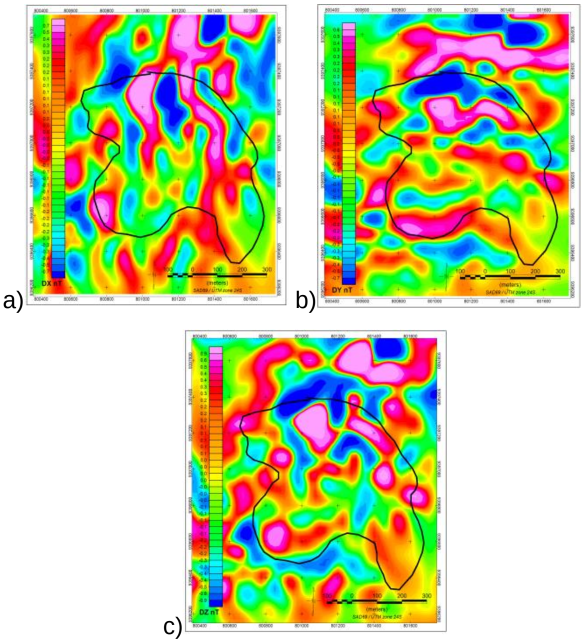

Figure 6. Horizontal derivatives a) DX and b) DY and c) First vertical derivative (DZ) maps.

The horizontal derivatives (DX and DY) and the first vertical derivative (DZ) fit better with the exposed body (Figure 6). In addition, the Tilt Derivative (TDR) and Total Horizontal Derivative (THD) enhance the body contacts, specially a visible high magnetic outline of the lower left border in the Total Horizontal Derivative (THD) (Figure 7). We still need more work on this data processing to better reveal the magnetic behavior of the plug.

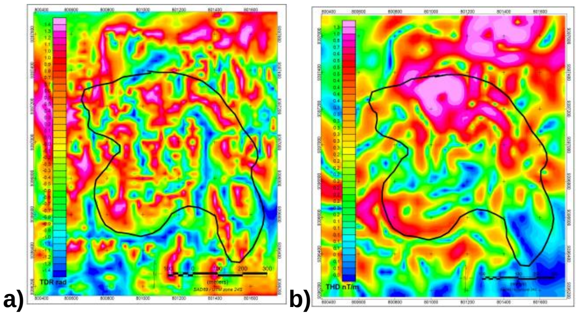

Figure 7. a) Tilt Derivative (TDR) b) Total Horizontal Derivative (THD) maps.

Conclusions

The magnetic signature shows that there are anomalies which do not delineate the body as it is visible in satellite image, but as yet not understood the body's behavior in depth, so need more information arising from other methods such as gravimetric, in order to better define this behavior.

The preliminary results shows that the method has the answer that allows for continue the studies in the area with the gravimetric method as well as 3D modeling of volcanic plugs, and may also use some resistivity method and measurements of densities, data that can be used in the larger goal of increasing knowledge about thermal evolution of the basin as well as the influence on the generation of hydrocarbons.

Acknowledgments

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Figure 8. Magnetic and gravity data acquisition.

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