Magnetic vector inversion of selected anomalies underneath the sediments of Araripe basin, NE Brazil

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This paper presents a new study of six selected magnetic anomalies underneath and around the Araripe sedimentary basin (NE Brazil) as a complementary tool for improving structural interpretation of the poorly-solved Araripe Basin, northeast Brazil. The basement is little known as the available seismic lines do not cross throughout the basin area as they were carried out only where there are roads. For this reason, airborne magnetic data are important for the general study of the basin. The data used were a compilation of three airborne survey datasets made available by the geological service of Brazil – CPRM. A magnetic vector inversion was performed for each individual anomaly and the results were displayed in a 3D environment for visualization and analysis of the resulting vectors. The results of the inversion yielded varied responses that led to the conclusion that three of the anomalies presented similarities that allowed us to infer that they were related to the same event, while the others presented different characteristics. We concluded that five of the six could be caused by igneous intrusions while the sixth is more complex and appears to have two sources: a fragment of a more magnetic rock of the basement and a younger intrusive body. The depths of the most magnetic groups of vectors of the anomalies' sources are compatible with the current knowledge about the depth of the basement underneath the sedimentary basin.

Introduction

The Araripe Basin, known for its fossiliferous wealth and for the prominent plateau named Chapada do Araripe, covers an area of nearly 9000 km² and 1.500 meters thick, being the largest and the one with the most preserved stratigraphic record of the interior basins of the northeastern region of Brazil, deposited over the Borborema Province crystalline rocks. Its genesis is related with the events associated with the rupture of Gondwana paleocontinent and the opening of the South Atlantic ocean, initiated in the Barremian with lithosferic stretching, which climax would occur during the Aptian (Matos, 1992; Ponte & Ponte Filho 1996, Matos, 2000). The Araripe Basin, is also a focus of interest for having sedimentary formations contemporary to those of the Brazilian offshore oil producing basins. Is consists of a 400-1500 m thick Paleozoic-Middle Cretaceous sedimentary sequence (e.g. Ponte & Appi, 1990; Assine, 2007). The Borborema Province consists of an amalgamation of several tectonostratigraphic terranes of different ages, truncated by several major shear zones (Figure 1). It constitutes a branching system of orogens developed in the global cycle between the fission of Rodinia and the fusion of Western Gondwana, in the Neoproterozoic, with a predominance of paleoproterozoic mobile belts (with Archean seed nuclei) and mesoproterozoic belts, intensely reworked in the Brasiliano cycle (Bizzi et al., 2003).

The study of the basement of Araripe basin's deep structure has advanced recently with the availability of high resolution airborne magnetic survey data but there is still

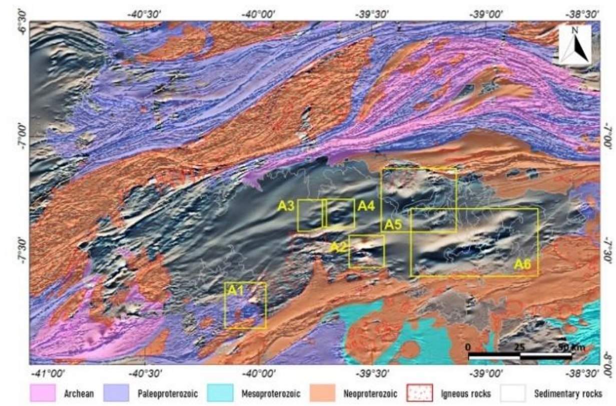

Figure 1 – *Simplified geological map over vertical derivative of TMI shaded map, with the selected anomalies indicated in yellow*

much to be debated due to the complexity and variability of the basement rocks, as well as the scarcity of drill holes and seismic data.

This study presents the results of 3D inverse modelling of six selected magnetic anomalies from sources located underneath and around the Araripe Basin, aiming to complement other endeavors of interpretation of the available data (e.g. Camacho, 2017). The Magnetic Vector Inversion method was selected for this work due to the presence of remanent magnetization that hinders the results of direct susceptibility inversion (Aisengart, 2013).

Method

Three high-resolution airborne survey datasets with 500 m line spacing and flown at 100 m over the terrain, at a sample rate of 10 samples/second, were compiled, re-sampled in 125 x 125 m grids and merged in order to provide full coverage of the Araripe Basin (CPRM 2006, 2010a e 2010b). Fourier-domain filters were applied to the compiled Total Magnetic Intensity (TMI) grids in order to enhance the lower amplitude anomalies underneath the sediments and the linear features that reflect the tectonics of the basement.

Six anomalies were picked to be modeled using the Magnetic Vector Inversion (MVI) method (Ellis et al., 2012, McLeod & Ellis, 2015). This inversion method is preferred for anomalies influenced by remanent magnetization, because it doesn't rely on the assumption that all magnetization is induced by the magnetic field present at the time of the survey, and calculates parameters such as the amplitude, declination and inclination of the magnetization vector. The TMI, topography and flight height grids were windowed for each anomaly and the results of the inversion were displayed in a 3D visualization environment. An isosurface was then created for each inverted set of vectors using the 5% higher values of each amplitude 3D mesh (voxel), and the high amplitude vectors within each voxel were plotted on a stereographic net (Cardozo, N., & Allmendinger, R.W., 2013).

Results

The six anomalies (A1-A6) were selected based on the TMI and Analytic Signal Amplitude (ASA) maps (Figure 2).

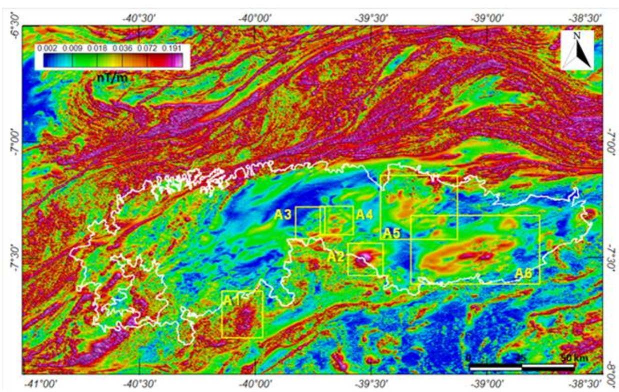

Figure 2 - *Amplitude of the Analytic Signal of the TMI with the location of the selected anomalies indicated in yellow and the border of the Araripe Basin in white*

The A1 anomaly is entirely located in the outcropping basement, A2 is partially located in the basement but also partially covered with sediments, and anomalies A3 to A6 are entirely covered by the basin's sedimentary rocks. The amplitudes of the anomalies reflect this fact, varying from 500 nT (A1), 1000 nT (A2), where the basement is exposed, to 145 nT (A3), 125 nT (A4), 250 nT (A5 and A6), where the basement is underneath the sediments. The Earth magnetic field orientation in the region at the time of the surveys ranged from -22.0º declination and -17.8 declination (2006) to -22.1 declination and -19.8 inclination (2010). Figure 3 displays the stereograms of the highest amplitude magnetization vectors of the six anomalies, indicating that only A2 anomaly magnetization appears to be mostly induced, and A6 is mostly induced, but also with a remanent component.

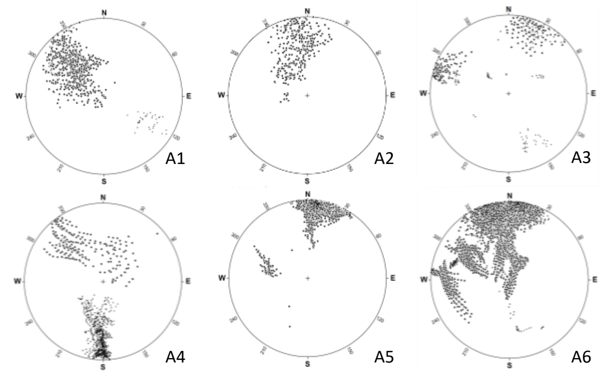

Figure 3 – *Stereoplots of the anomalous magnetic vectors of each anomaly (1% highest values)*

The A1 anomaly, represented in Figure 4, is located in a terrain mapped as intrusive of Tonian age, and consists of a well-defined low. The inversion resulted in a goblet shaped body (isocurve 0.02 S.I.), characteristic of an intrusive body, with magnetization declination pointing -35º, indicating that the border of the possible intrusion is magnetized and possibly it preserved remanent magnetization as it cooled. The high frequency anomalies and the complex pattern of lineaments that that can be observed on the TMI image are a characteristic of the outcropping basement of the Borborema Province and reflect its tectonic history. The depth to the top of the anomalous vectors is approximately 500 m.

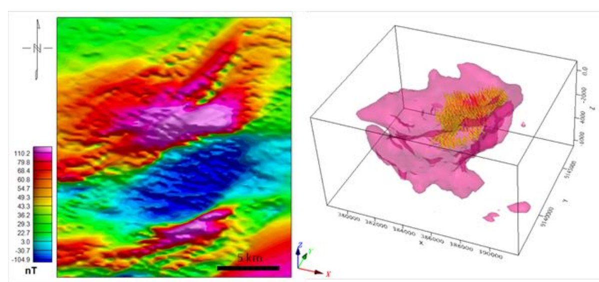

Figure 4 – *A1 anomaly: left: TMI, right: 3D representation of the inverted source body, with the higher amplitude vectors represented as cones. X points East, Y points North.*

Figure 5 displays the A2 anomaly, which is partly covered by sediments, on the NE, and outcropping on the SW. Lineaments parallel to the large shear zones in the region can be observed. The inverted 0.01 S.I. isocurve consists of a more compact, rounded magnetic body, subdivided under the E-W lineament of the TMI image, suggesting faulting during or after the emplacement of the intrusion. The depth of the top of the most anomalous vectors is around 700 m.

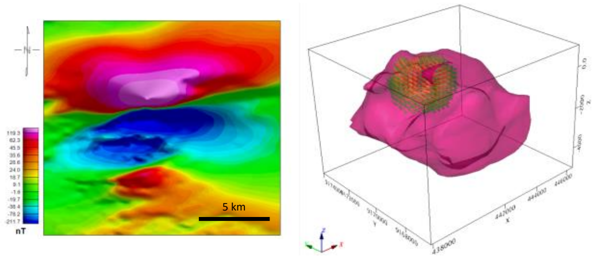

Figure 5 – *A2 anomaly: left: TMI, right: 3D representation of the inverted source body, with the higher amplitude vectors represented as cones. X points East, Y points North.*

Figure 6 displays the A3 anomaly, a round-shaped dipole sitting well underneath the sediments. It is located at the north of the large body of intrusive rocks that outcrop near the mid-portion of the basin. Its shape is rounded and the inversion isosurface (0.003 S.I.) created a ring of bodies compatible with an intrusion with magnetized borders and less magnetic center. The magnetization vectors are distributed in two main groups, none of which in the direction of the Earth magnetic field of the time of the surveys, suggesting remanent magnetization. The depth to the top of the inverted vectors is approximately 2700 m in the north and 700 m on the south of the body.

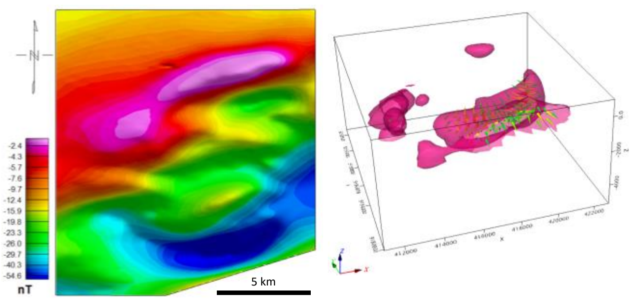

Figure 6 – *A3 anomaly: left: TMI, right: 3D representation of the inverted source body, with the higher amplitude vectors represented as cones. X points East, Y points North.*

Figure 7 represents the A4 anomaly, which generated a somewhat less defined, though bulkier, ring of anomalous magnetization vectors (isosurface: 0.007 S.I.), similarly to the A3 anomaly. Most of its high amplitude vectors point South, in contrast with the other five anomalies. The depth to the top of the anomalous vectors is 2000 m (N) and 900 m (S).

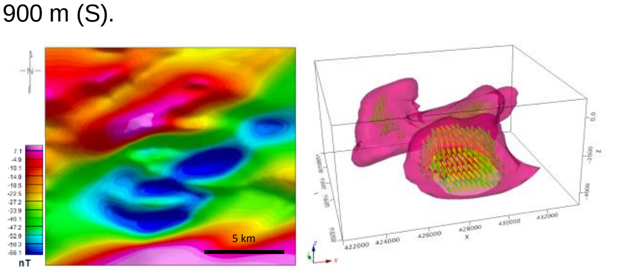

Figure 7 – *A4 anomaly: left: TMI, right: 3D representation of the inverted source body, with the higher amplitude vectors represented as cones. X points East, Y points North.*

Figure 8 shows the A5 anomaly, a larger dipole located on the NW of the basin, mostly in the Cariri valley, where the sandstones that support the plateau are absent and older sediments outcrop. The inversion resulted in a ring of anomalous bodies (isosurface: 0.01 S.I.) in the northern part of the selection and a bulkier body in its southern part, with a few shallower arms under the higher frequency anomalies that can be observed in the TMI image. The higher amplitude magnetization vectors, concentrate in the south of the selection, and point mostly NNE, indicating remanent magnetization in a different direction from the other anomalies. The depth to the top of the anomalous vectors is ~3000 m.

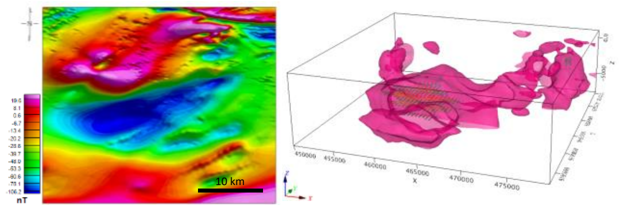

Figure 8 – *A5 anomaly: left: TMI, right: 3D representation of the inverted source body, with the higher amplitude vectors represented as cones. X points East, Y points North.*

Figure 9 displays the A6 anomaly, for which the inversion resulted in an elongated body (isosurface: 0.01 S.I.), with a branch on the NE sector. It differs from the other anomalies in shape and in the fact that the magnetization vectors are more widely spread in the stereoplot.

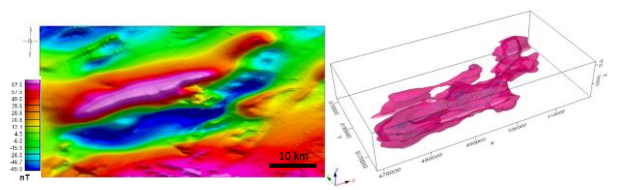

Figure 9 – *A6 anomaly: left: TMI, right: 3D representation of the inverted source body, with the higher amplitude vectors represented as cones. X points East, Y points North.*

The shape of the anomaly and the more scattered vectors suggest that its causative body may be a fragment of a more magnetic rock that was stretched by the tectonic activity observed in the outcropping Neoproterozoic rocks of the basement. The rounded form of the branch in the NE might correspond to a younger intrusive body. The depth to the top of the most anomalous vectors is ~3000 m.

Conclusions

The variety of the magnetic signatures of the studied anomalies signal the complexity and heterogeneity of the basement rocks underneath and around the Araripe basin. From the six anomalies selected for inversion, only A2 displays magnetization in the direction of the Earth magnetic field of the time of the surveys, suggesting that the other causative bodies have remanent magnetization. The shapes of the inverted bodies suggest that there are affinities between some of the anomalies (A1, A3 and A4), while the others belong to different sources. The source of the A2 anomaly appears to be an intrusion crossed by a fault, indicating that there was tectonic activity after the emplacement of its causative body. This fault might be part of the system that caused the uplift of the plateau.

Acknowledgments

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