Interpretation of gravity and magnetic data from western edge of Potiguar basin

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Abstract

This paper presents qualitative and quantitative interpretations of geophysical data in the onshore western part of Potiguar sedimentary basin, NE Ceará. These geophysical data were performed in order to understanding tectonostratigraphy relationships involving these part of Potiguar Basin based on determination of main geophysical lineaments, geometry and depth of sources and the important determinations of geophysical domains. The study area shown structural lineaments partitioning characterized by lineaments in the NE-SW direction, E-W and NW-SE inflexions. The spatial arrangement of geophysical fields is related to the Brasiliano lineaments that occur in the region. Gravity modeling over the profiles shows the geometry of the study area which has a graben feature that may be associated with the accumulation of hydrocarbons such as the Fazenda Belém oil field.

Introduction

The Potiguar basin internal geometry shows a preferencial ENE-WSW direction, showing asymmetric grabens separated by internal basement highs. The structural framework of Potiguar basin is a result of changes that occurred during evolution in rift and drift stages and recent magmatism. (Bertani *et al.,* 1990).

The study area is inserted in the western portion of the Potiguar basin in its portion onshore and within the boundaries of the Ceará state.

The region where is inserted the study area has a positive gravimetric anomaly and a significant magnetic anomaly (Pedrosa *et al*., 2010). This peculiar structure is not well defined and is near Fazenda Belém oil field.

Regional Geological Context

The Potiguar basin is inserted in the Precambrian basement complex of northeastern Brazil named Borborema Province (Almeida *et al*., 1981). This basin is part of a series of small to medium rift basins which form the Northeast Brazilian Rift System and its origin is linked to the South Atlantic opening in the Cretaceous (Matos 1992).

The main stratigraphic units in the study area are, from base to top: 1) the Paleoproterozoic basement represented by supracrustal sequence as mica schist and quartzites of the Santarem Formation into Oros zone; 2) In the southeast of study area outcrop sandstones of the Açu Formation and limestones of the Jandaíra Formation, which are into the Apodi Group; 3) most of the area is covered by sandstones and conglomerates of the Barreiras Formation; e 4) recents sediments associated with alluvial sediments and coastal Aeolian sediments along the entire coast (Cavalcante *et al.,* 2003) (Figure 1). The Jaguaribe lineament or shear zone (JL) was inferred from structural data from Cavalcante et al., (2003). The Ponta Grossa-Fazenda Belem lineament (PGFBL) was determinate by Sousa (2002), who identified strongly deformed sector of Barreiras Formation, which alignement has coincided with Brasiliano shear zones that outcrop in the south of study area.

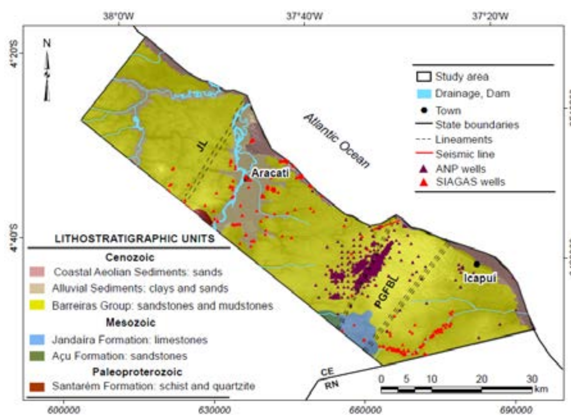

Figure 1: Simplified geological map of the study área. JL: Jaguaribe lineament; PGFBL: Ponta Grossa-Fazenda Belém lineament.(Modified from Cavalcante et al., 2003).

Geophysical datasets

Airborne magnetic data

The aerogeophysical survey provided by the Brazilian Petroleum National Agency (ANP) is named the Potiguar Basin Project. This dataset was undertaken between 1986 and 1987 and covered an area of 44,600 km² with N20°W oriented flight lines and 2.0 and 4.0 km spacing between these lines. The nominal flight height was 500 m and the sampling rate 100 m.

The aeromagnetic data were corrected for diurnal and main component of the geomagnetic field variations IGRF (International Geomagnetic Reference Field). These data were then interpolated into 500 m regular grid by the bi-directional method in order to generate the anomalous field. After this procedure, several filtering techniques were applied to improve the signal/noise relationship and to highlight specific features of the magnetic sources.

Gravity data

The study site has low density terrestrial gravity coverage, with approximately 416 measurement stations, concentrated along major highways, acquired by universities and public agencies in Brazil. In addition to these data 142 new gravity stations were acquired using SCINTREX digital gravimeter model CG-5. The Figure 2 shows the distribution of previous gravity stations and the newly acquired stations, with spacing between stations from 3 to 4 km. The gravity data were interpoled by the kriging method, in 500 m square cell.

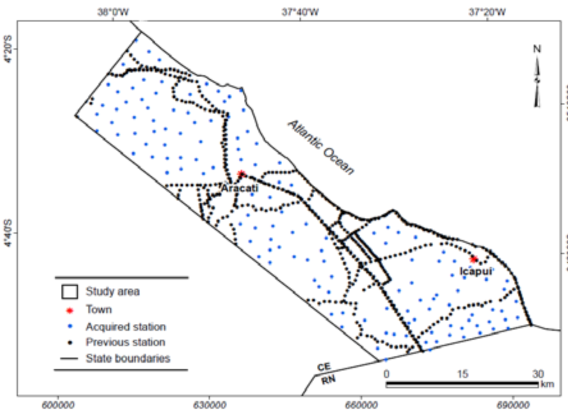

Figure 2: Distribution of previous gravity stations (black dots), as well as the new stations acquired in the study area (blue dots).

Results

Magnetic data analysis

The magnetic signature of the western of Potiguar basin based on several maps of magnetic anomalies, the tilt derivate and analytical signal maps shows lineaments trending NE-SW, NW-SE and E-W (Figure 4). Altogether, 3 magnetic domains could be distinguished (Figure 4). Their limits were defined by the variation of the values of reduce to pole and amplitude of the analytical signal maps:

- FMD (Fortim Magnetic Domain) is located in the west of the study area and is characterized by low magnetic intensity anomalies and some portions lack anomalies in the analytic signal. It has short wavelength anomaly (2 km) with more elongated magnetization in preferred orientation NE-SW (Figure 4). These anomalies could be associated with Jaguaribe shear zone which does not appear in surface, however follow the same trend crossing the continent in the direction of the Atlantic Ocean.
- AMD (Aracati Magnetic Domain) is located in the central portion of the study area. It is associated with high amplitude anomalies of the analytical signal (0.269 nT/m) (Figure 3) with preferred NE-SW lineaments and a significant E-W component (Figure 4). A field reconnaissance was conducted targeting the cause outcropping of such anomalies, however due to significant sedimentary cover, anything that could be related was not found.
- IMD (Icapuí Magnetic Domain) is located in the east of the study area. It has some portions lack anomalies in the analytical signal. In this region outcrop sedimentary rocks of Barreiras Formation, beyond limestones of Jandaíra Fomations and sandstones of Açu Formation.

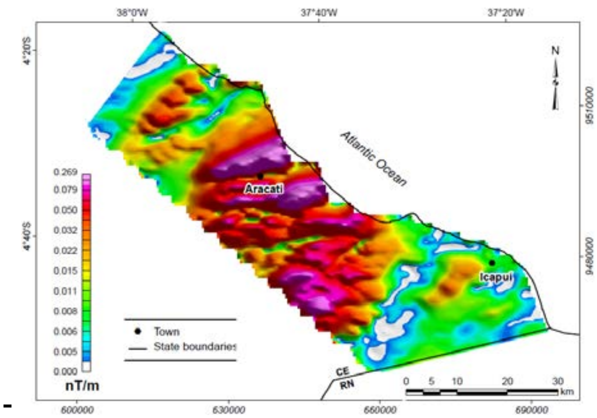

Figure 3: Analytical signal amplitude map.

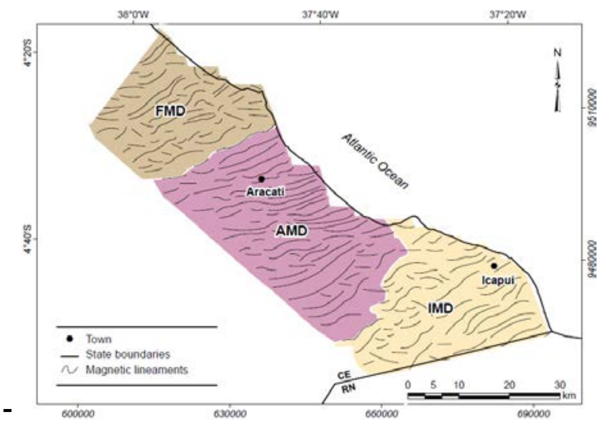

Figure 4: Magnetic domains and magnetic lineaments.

3D Euler deconvolution was performed for semi-quantitative interpretation and estimation of magnetometric residual sources (Thompson, 1982; Reid *et al*., 1990). The index 0 and 3 was chosen due its relationship with linear features and three-dimensional bodies, since it is necessary understand the depth of the contacts and structures, using a 5000 m spatial window and 10% maximum depth tolerance in the index 0 and 15% maximum depth tolerance in the index 3.

The spatial window and maximum depth tolerance parameters were chosen iteratively, by analyzing the results obtained when the parameters changed. Choosing of parameters was based on the number and distribution of Euler solutions as well as on maximum and minimum values, average and standard deviation, in order to obtain representative data and avoid discrepancies.

The figure 5 shows a higher concentration of Euler solutions in the range from 100 m to 1000 m depth. These solutions are aligned along NE-SW and E-W trends, most of which lie in shallow to intermediate depth (500 m). In the east of FMD the Euler solutions shows the deepest sources (over 3000 m) aligned along NE-SW trend and may be associated with JSZ. The IMD is marked by deep sources (3000 m) which represents basement sources.

The figure 6 shows a higher concentration of Euler solutions in the range from 3000 m to 5000 m depth. These solutions are aligned along NE-SW and E-W trends. In the west of study area Euler solutions display the deepest solutions (over 8000 m) and more dispersed clouds while in the east of area Euler solutions display the deepest solutions (over 8000 m) aligned along NE-SW trend.

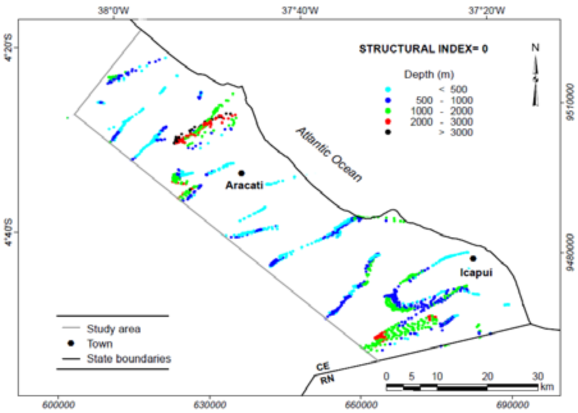

Figure 5: 3D Euler Deconvolution using structural index 0.

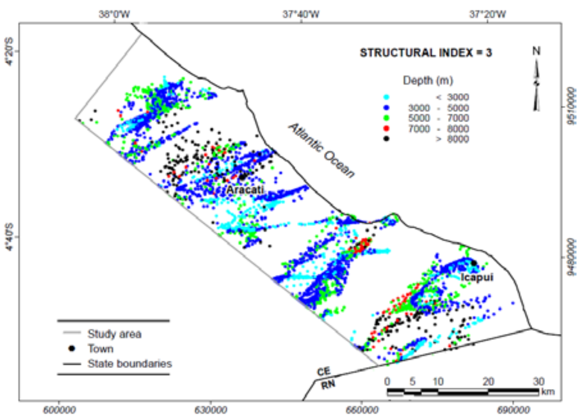

Figure 6: 3D Euler Deconvolution using structural index 3.

Gravity data analysis

The acquired gravity data were corrected for tide effects, instrumental drift and latitude, after which the free air and Bouguer anomalies calculated. After integration with previous stations, the terrain effects were corrected for each station and the complete Bouguer anomaly map of western part of the Potiguar basin was prepared (Figure 7).The regional and residual components of the gravity field were separated by a regional-residual separation filter, which is based on the Gaussian distribution of sources according to depth. The Gaussian function standard deviation of 0.04 rad/km representing cutoff wavelength of approximately 25 km was used.

The regional gravity anomalies display long wavelength (>25 km), ranging from 33 to -9 mGal, from west to east. The residual gravity anomaly map is represented by short to medium wavelength (5 to 25 km) negative and positive anomalies, trending NE-SW, E-W and N-S and ranging from -6.29 to 6.39 mGal. The first vertical derivate of the residual gravity map (Figure 8) outlines the main gravimetric alignments of the western of Potiguar basin. The lineaments have preferred NE-SW trend, while 2nd order lineaments show NW-SE and E-W directions (Figure 9).

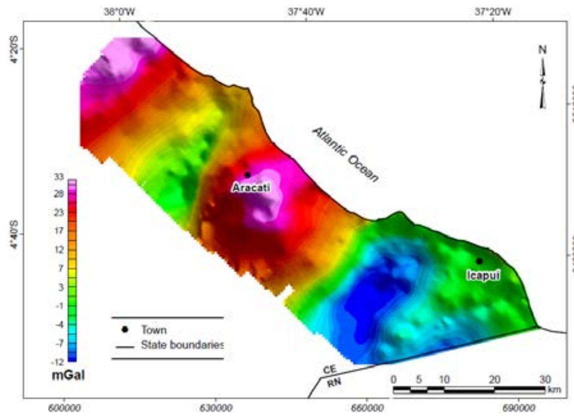

Figure 7: Complete Bouguer anomaly map.

So, 3 gravity domains could be distinguished based on its gravity signatures (Figure 9):

- FGD (Fortim Gravity Domain) is located in the west of the study area and is marked by rough relief, ranging from -6 to 3 mGal, trending NE-SW e NW-SE (Figure 15). This gravity field arrangement is similar to magnetic map in the same region and may be associated with Jaguaribe Zone.
- AGD (Aracati Gravity Domain) is located in the central portion of the study area and is characterized by a significant gravity relief with features trending NE-SW preferres orientation, while 2nd order lineaments shows and E-W directions. This anomaly is associated with higher density in the basement.
- IGD (Icapuí Gravity Domain) is located in the east of the study area and is marked by negative and positive anomalies from -3 to 2.5 mGal with preferred trend NE-SW. In this region outcrop sedimentary rocks of Barreiras Formation, beyond limestones of Jandaíra Fomations and sandstones of Açu Formation.

3D Euler deconvolution was performed for semi-quantitative interpretation and estimation of gravity residual sources (Thompson, 1982; Reid *et al*., 1990). The index 0 was chosen due its relationship with linear and features, since it is necessary understand the depth of the contacts and structures, using a 5000 m spatial window and 15% maximum depth tolerance.

The figure 10 shows a higher concentration of Euler solutions in the range from 500 m to 1000 m depth.). In the east of area the Euler solutions ranging from 500 to 2000m depth aligned along NE-SW trend and may be associated with fault during basin development. In the west of area Euler solutions display more dispersed clouds, however some lineaments are aligned along NE-SW trend and may be associated with JL.

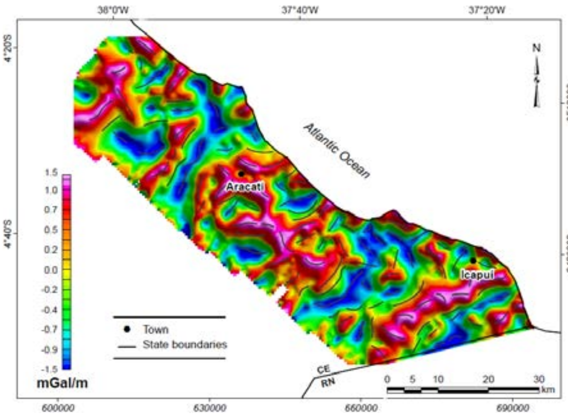

Figure 8: First vertical derivate with major gravimetric lineaments (gray line).

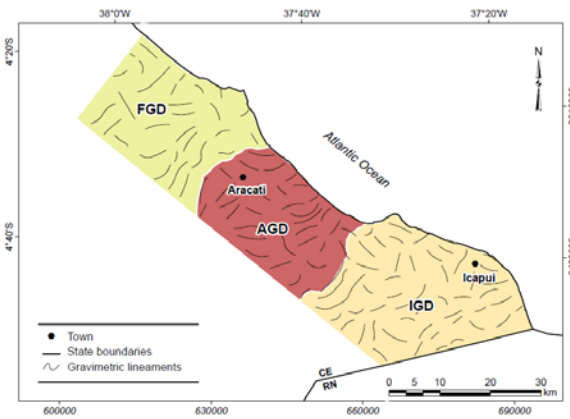

Figure 9: Gravity domains and gravity lineaments.

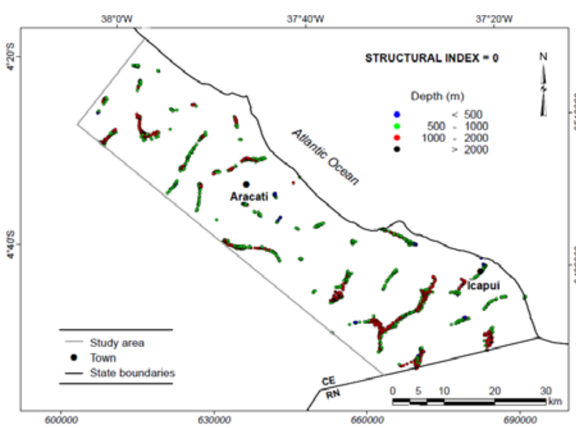

Figure 10: 3D Euler Deconvolution using structural index 0.

2D gravity forward modeling

Three NW-SE trending, approximately 80-km long profiles was determined in the study area to analyze the 2D magnetic and gravity sources, as well as 2D gravity modeling (Figure 12).The initial models were created based on potential methods, previous researches (Sousa, 2002) and 3D and 2D Euler deconvolution (Figure 11). The densities were established based on existing literature to the main litostratigraphic units present in the area (Telford et al., 1990 and Castro, 2011). The sedimentary rocks of Barreiras, Açu, and Jandaíra formations have average densities of 2550 kg/m³, while the supracrustal rocks of Jaguaribe zone have an average density of 2670 kg/m³. The average densities of Jaguaretama Complex gneiss and amphibolites are about 2680 kg/m³. Moreover the volcanic rocks (probably do not outcropping dikes) show higher density of 2685 kg/m³.

The figure 11 shows magnetic and gravity anomalies and Euler solutions for the magnetic and gravity data using structural index from 0 to 1. The regions near the edges of profiles have deeper solutions (3 km) while the central part has shallower solutions (1.5 km), which may explain the presence of sources related to volcanic rocks dikes or structural discontinuities in the basement. It is noteworthy that the extension of the Jaguaribe shear zone (JSZ) (Figure 1) and the Ponta Grossa (PGL) and Fazenda Belém (FBL) lineaments characterized in surface, are well pronounced by the solutions clouds and reach depths over to 3 km. The JSZ coincides in part with the boundary between the geophysical domains FD and the AD, while the PGL marks the boundary between the geophysical domains AD and ID (Figure 12). Note that approximately 55 km from the beginning of the profiles is another lineament interpreted, displaying similar characteristics to JSZ, PGL and FBL with solutions clouds ranging 1.5 to 2 km deep and subvertical dip, such feature may be cited Fazenda Retiro Grande Lineament (FRGL).

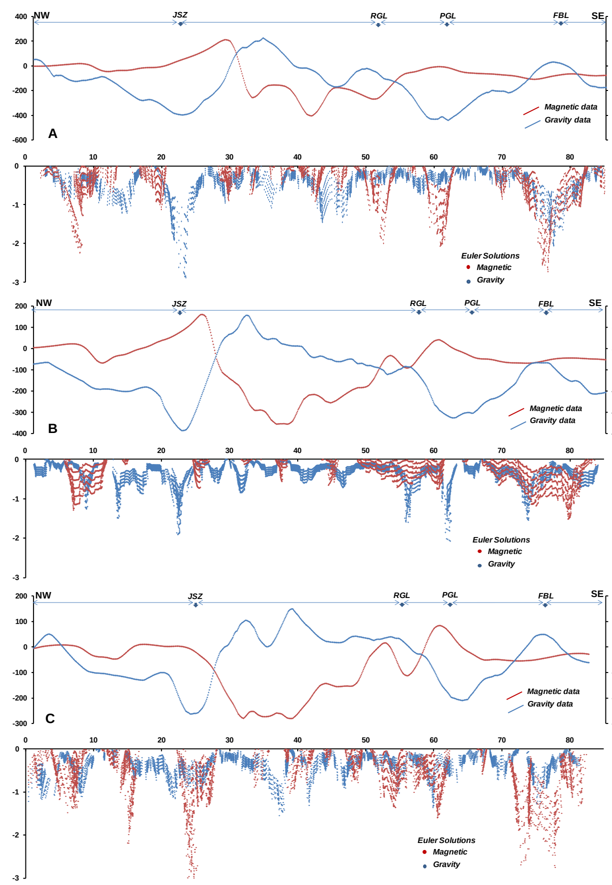

Figure 11: Magnetic and residual gravity anomalies profiles at the top and Euler solutions at the botton. A: section A-A '; B: Section B-B'e C: C-C 'section.

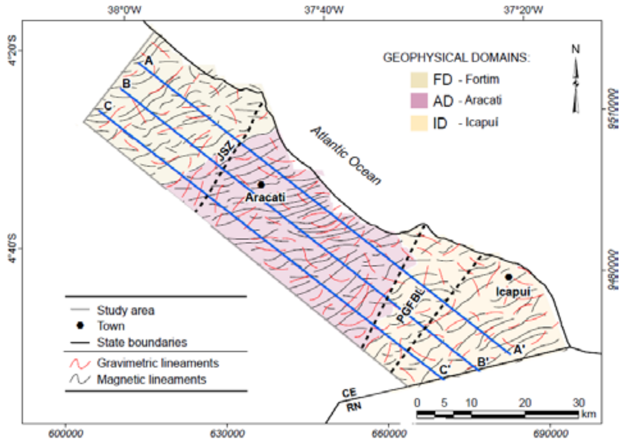

Figure 12: Geophysical domains map with the main structural alignments and geophysical profiles used in the modeling and sources estimative. JSZ: Jaguaribe Shear Zone; PGFBL: Ponta Grossa-Fazenda Belém Lineament.

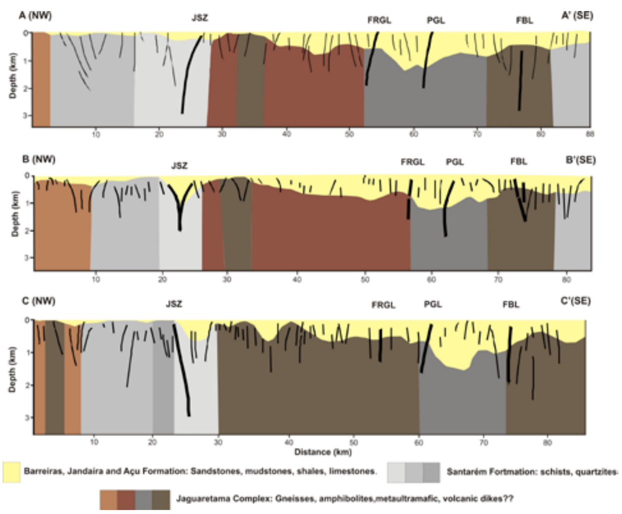

Figure 13: Geological models from profiles: A-A', B-B' and C-C'.

These models show the geometry of western edge of Potiguar basin and the heterogeneity of crystalline basement. Grabenforms structures are identifies in SE profiles area, limited by PGFBL (Figure 13). These models also show that this graben is larger and deeper as its directs to the south of the area.

ZCJ becomes more pronounced in the basement as is directed to the interior of the continent, showing a deeper character, may be associated with more pronounced deformation of supracrustal rocks of Santarém Formation. You can also notice a greater heterogeneity of basement rocks from coast to within continent. The presence of more dense rocks in the basement is strongly accused by the positive anomalies in profiles. These sources were modeled and interpreted as belonging to the rocks of Jaguaretama Complex based on the geological map of the region (Cavalcante *et al*., 2003).

It is likely that in the region occur dikes of volcanic rocks, associated with the recent magmatism Rio Ceará-Mirim trending EW that developed during the opening of the Atlantic Ocean in the lower Cretaceous. These data confirm the results obtained by applying the 3-D Euler deconvolution to the magnetic data (Figure 6) and an increase in density values determined in the 2-D gravity modeling.

The contacts between the basement rocks sequences will give up by discontinuities or interpreted lineaments in estimates of magnetic and gravity data, as well as in gravity models. The shallower alignments located in the SE portion of the profiles are interpreted as faults or discontinuities intrabasin, which may represent reactivation of the main shear zones extending in the study area.

Figure 14 shows in perspective view the three sections modeled and interpreted as well as the extension of the main brazilian shear zones cutting the search area.

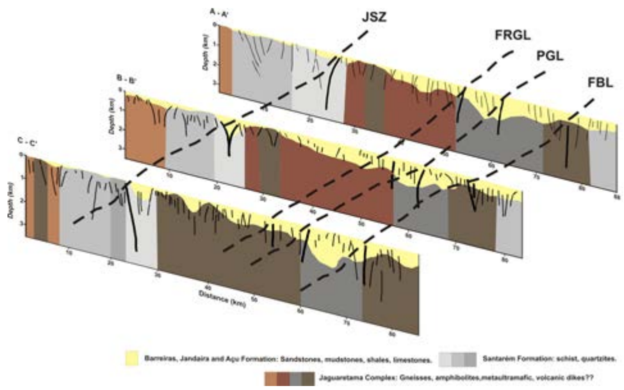

Figure 14: 2,5D Representation of the internal geometry of the western edge of the Potiguar Basin.

Conclusions

The qualitative interpretation of magnetic and gravity data allowed a geophysical separation of three domains which lineaments have preferred NE-SW trend, while 2^{nd} order lineaments show NW-SE and E-W directions. These lineaments are associated with the continuity of the main Brasiliano shear zones. Such lineaments are possibly related with Cenozoic reactivations as Afonso Bezerra faults in the Potiguar Rift (Moura Lima et al., 2011).

The spatial arrangement of geophysical domains is related to the Brasiliano lineaments which occur in the region. JSZ coincides, in part, with the boundaries between Fortim and Aracati geophysical domains, while PGL marks the boundary between Aracati and Icapuí geophysical domains. The FD shows low magnetic intensity anomalies and some portions lack anomalies in the analytic signal, and gravity field is marked by rough relief. The high magnetization anomalous zone is associated with JSZ. The AD is characterized by high amplitude anomalies of the analytical signal and gravity a significant gravity relief with features trending NE-SW preferred orientation, while 2^{nd} order lineaments shows and E-W directions. These anomalies are associates with high density basement features as amphibolites of Jaguaretama Complex and/or volcanic rocks do not outcrop. The ID is characterized by some portions lack anomalies in the analytical signal and a high magnetization anomalous relief, this setting is similar to the gravimetric signature in the same region. These gravity and magnetic anomalies are possibly related with a basement high.

The JSZ is not well marked on the surface, but appears well pronounced on the subsurface as shown in geophysical maps and models. The PGL and FBL present similar characteristics and seem to limit grabenforms structures of western edge of Potiguar basin. Another lineament with expression and depth similar to others presents well marked by 2D Euler deconvolution in northwest of PGL and was named Fazenda Retiro Grande lineament.

The JSZ and heterogeneous basement variation also changes from coast to within continent, denoting a deeper character for ZCJ suggesting more pronounced deformation of supracrustal rocks of Santarém formation. While the greater heterogeneity of basement in the south is interpreted as variation in the densities of the Jaguaretama Complex rocks.

Strong evidence of volcanic dikes associated with Rio Ceará-Mirim magmatism are shown by 3D Euler deconvolution in magnetic and gravity data and in increase of density values determinate by 2D gravity modeling with preferred arrangement E-W.

2D gravity modeling in the three profiles show the geometry of western edge of the Potiguar basin, which has grabenforms features that may be associated with hydrocarbon accumulation already explored in the Fazenda Belem region. The crystalline basement of the entire study region proves to be quite heterogeneous. A perspective view of geological models shows that such graben is wade and deeper in the south of study area.

The shallower alignements located in the SE portion of the profiles are interpreted as faults or discontinuities intrabasin, which may represent reactivations of the main shear zones extending in the study area. These regions are important from the point of view of oil and gas exploration on the western edge of the Potiguar basin, as these features may behave as traps or geological and structural traps.

Acknowledgments

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References

ALMEIDA, *F.F.M.*; *HASUI*, *Y.*; *BRITO NEVES*, *B.B.*; *FUCK*,. R.A., *1981*. Brazilian structural provinces: an introduction. Earth. Science Reviews n° 17, 1-. 29.

BERTANI, R.T., COSTA, I.G. & MATOS, R.M.D., 1990. Evolução tectonosedimentar, estilo estrutural e habitat do petróleo na Bacia Potiguar. In: Gabaglia G.P.R. & Milani, E.J. (eds), Origem e evolução de Bacias Sedimentares. Petrobrás, Rio de Janeiro p. 291-310.

CASTRO, D. L., 2011. Gravity and magnetic joint modeling of the Potiguar Rift Basin (NE Brazil): Basement control during Neocomian extension and deformation. Journal of South American Earth Sciences, 31: p. 186-198.

CAVALCANTE, J.C., VASCONCELOS A.M., MEDEIROS M.D.F., & PAIVA, I.G., 2003. Mapa geológico do estado do Ceará, escala 1:500.000.

MATOS. R. M. D,1992. Deep seismic profiling, basin geometry and tectonic evolution of intracontinental rift basins in Brazil. Tese de Doutorado, Cornell Univ.. U.S.A., 276 p.

MOURA LIMA, E. N., SOUSA, M. O. L., BEZERRA, F. H. R., CASTRO, D. L., DAMASCENA, R. V. C., VIEIRA, M. M., LEGRAND, J. M., 2011. Reativação Cenozoica do Sistema de Falhas de Afonso Bezerra, Bacia Potiguar. Revista de Geociências (UNESP) – São Paulo, v.30, n.1, p. 77 – 93, 2011.

PEDROSA JR, N.C., CASTRO, D.L., MATOS, J.P.L., 2010. Assinaturas magnéticas e gravimétricasdo arcabouço estrutural da Bacia Potiguar emersa, NE do Brasil. Revista Brasileira de Geofísica 28 (2), p. 265e278.

REID, A. B., ALLSOP J. M., GRANSER H., MILLETT A. J., SOMERTON I. W., 1990. Magnetic interpretation in three dimensions using Euler deconvolution. Geophysics, 55: p. 80-91.

SOUSA, D. do CARMO., 2002. Litoestratigrafia e deformação cenozoica na região de Icapuí, Ceará, e implicações para a estruturação de campos de petróleo na borda ocidental da Bacia Potiguar. Tese de Doutorado, UFRN, 222 p.

TELFORD, W.M., GELDART, F.E.M. & SHERIFF, R.E., 1990. Applied Geophysics, Cambridge University Press, USA, 2 (3), p. 62-64.

THOMPSON, D. T., 1982. EULDPH: A new technique for making computer assisted depth estimates from magnetic data. Geophysics, 47: p. 31-37.