Alto Tapajos Sedimentary Basin – structural features based on aeromagnetic data.

Marcos de Barros Munis, Brazil Geological Survey (CPRM)
Renato Lopes Silveira, Brazilian Petroleum National Agency (ANP)

Summary

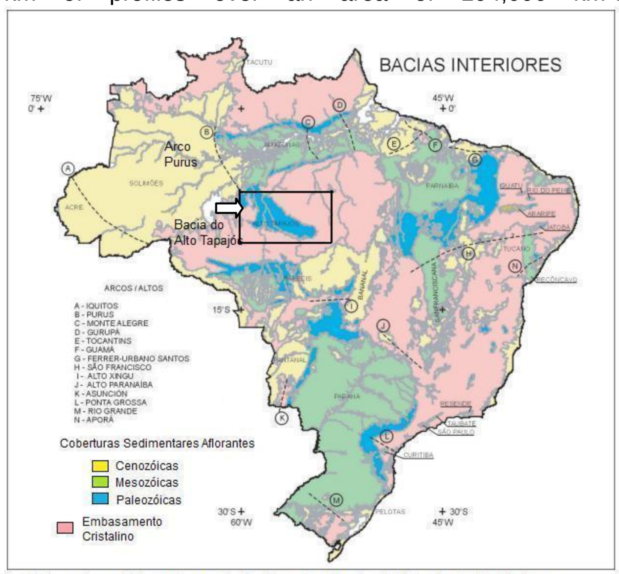
The Upper Tapajos sedimentary basin region has been the subject of some geological surface studies by the Geological Survey of Brazil (CPRM) mainly due to the numerous gold occurrences, as well as iron, manganese, copper, lead and zinc. Since 2008 has been acquired at high-resolution level, the Itaituba, Sucunduri, Tapajós Gold Province, and the Supplement Sucunduri Projects. All of them comprising magnetic and gamma ray spectrometric methods and targeted to mineral exploration. The subsurface studies, however, are scarce and never had been offered blocks in bid rounds sponsored by ANP. This work is a contribution in this aspect, based on the interpretation of available public magnetic data surveyed by Carson Services for Petrobras in 1995 and shows deep Proterozoic rift structures which can be favorable to gas player occurrences.

Introduction

The Upper Tapajos River is formed by the junction of Juruena and Teles Pires rivers, where the state of Mato Grosso borders the states of Amazonas and Pará. The sedimentary basin that occurs in this region extends in NW-SE direction reaching 135,000 km^2 (Reis, 2006), or less, according to several authors, as Bizzi et al. (2003), reaching 105,000 km^2, or even 90,000 km^2 as reported by Hasui et al., (2012). These discrepancies are due to different concepts about what Upper Tapajos sedimentary basin means added to difficulties in mapping a geological dense forested area where the thickness of the weathering reaches tens or even hundreds of meters. Figure 1 is the localization map relative to others on shore basins of Brazil, specially the Solimões and Amazonas basins. Figure 2 is a more detailed area showing the Paleozoic and Proterozoic sequences of Alto Tapajos Basin. Note that this is a very large area comprising 600 x 450 km^2, and the interpretation, a very regional one. As we shall see, the aeromagnetic data show that the deeper parts of the basin filled by Proterozoic sediments exhibit a predominant EW direction, and in the shallows filled by Mesozoic sequence, this direction becomes NW-SE.

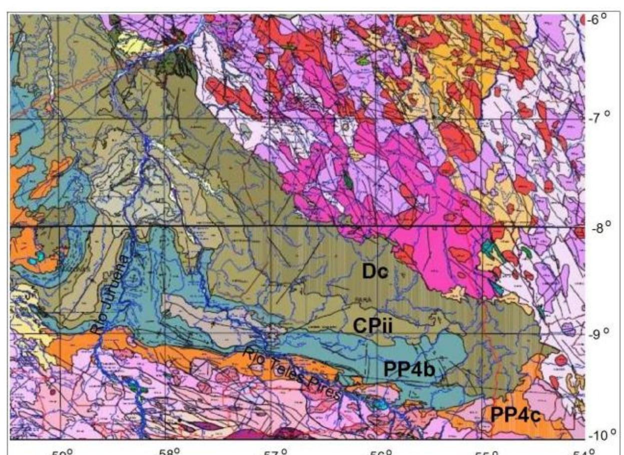
Data Used – Limitations

Considering the current standards of aeromagnetic surveys, the Upper Tapajos Project is a very low resolution one, just a regional reconnaissance survey. It was flown from August to October 1995 and totals 6,452 km of profiles over an area of 104,000 km^2.



Paleozoic and Meso-Cenozoic Sedimentary Basins, in "Geologia, Tectônica e Recursos Minerais do Brasil", (Bizzi et al., 2003) - CPRM.

Figure 1 – Upper Tapajos Basin Location Map.
Source: Silva et al (2003), in Bizzi et al, (2003) – CPRM.



EXPLANATORY NOTE: Dc = Devonian, Capoeira Formation (sandstones, siltstones, mudstones) ; CPii = Carboniferous-Permian, Ipixuna form. (eolian sandstones); PP4b = Paleo Proterozoic, Beneficente Group (conglomerates, sandstones, siltstones, limestones); PP4c = Colider Group (volcano-sedimentary sequence with subvolcanic micrograniites); The remaining area consists of cristallyne basement rocks (gneiss, granites, amphibolites, etc) cut by intrusives.

Figure 2 – Upper Tapajos Geological Map.
Source: The Geological Map of Brazil on the Millionth Scale. - Sheets SB.21 (Tapajos) and SC.21 (Juruena). *http://www.cprm.gov.br.*

The flight line distance is 25 km and the control line is 50 km. The first are in NNW-SSE direction and the second in ENE-WSW direction. The survey was done at 1,060 m barometric height and the magnetometer was a cesium high sensitivity magnetometer MEP 410 from Scintrex, using the optical pumping magnetic-resonance techniques. The navigation used GPS Navstar and the interval of lectures on the ground was 50m. (http://www.cprm.gov.br/aero/4000/aero4000.htm).

The project also included gravimetric acquisition (one of the first in Brazil) but data available for this work still need better treatment to improve the signal to noise ratio. The resolution of an airborne geophysical project is given by the distance between flight lines, being greater the smaller is this distance. For studies in sedimentary basins with hydrocarbon purposes the flight line interval varies from 2,000 to 1,000 m if the goal is the determination of depth to the basement, or less, if sills and dikes are present. Current surveys carried out by CPRM (Geological Survey of Brazil) in areas of crystalline basement uses a flight lines interval of 500 m with flight altitude of 100 m, as Sucunduri and Itaituba Projects in the northern part of the studied area. Older projects as Tapajos 1 and 2 have a flight line interval of 1 km and the southern projects Juruena-Teles Pires 1 and 2 a 2 km interval. These are high quality surveys and considered as high resolution projects but none of them reaches the depocenter of Upper Tapajos Basin or *Graben Cachimbo* as described in the geologic map of Brazil to the millionth. The shape files of these projects are showed in Figure 3.

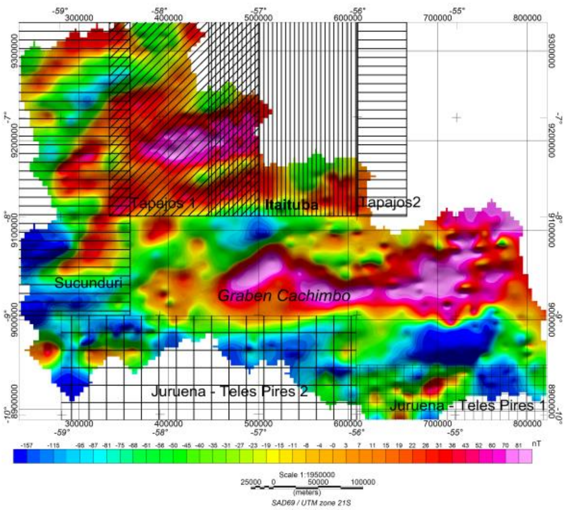


Figure 3 – Upper Tapajos Total Field Magnetic Map IGRF reduced, with shape files of CPRM high resolution surveys.

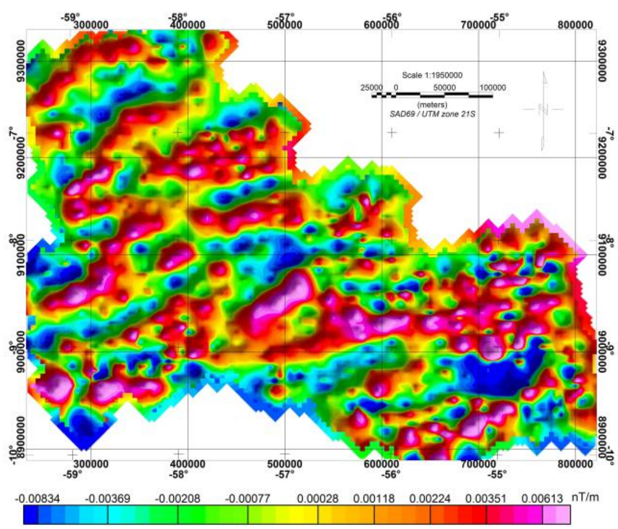


Figure 4 – Upper Tapajos First Vertical Derivative Map of the total magnetic field - IGRF reduced. Shaded View (Inclination = 45^o , Declination 45^o).

Metodology and Results

In so-called potential methods, sources produce signals with increasingly low frequency the larger the distance they are from the sensor. To get some response beyond the simple regional trend it was did a 5 km cell grid and a regrid with 2 km cell grid. Figure 3 shows the total magnetic field IGRF reduced, using a shade relief view with 45^o inclination and 180^o declination under the shape files of CPRM projects cited.

To these data it was applied the first vertical derivative because is just over the geological contacts between rocks with differences in magnetic susceptibility that the magnetic field varies faster. This filter is very sensitive to lack of data and for this reason it was used the original grid with 5 km cell. The result showed under a pseudo illumination view corresponds to Figure 4.

This map shows a better picture of the tectonic behavior of the area with predominance of E-W directions for the main graben, cut by NE-SW or NW-SE faults. The great distance between the positive and negative alignments of anomalies (low frequency) reflects the big interval of flight line acquisition. Another very useful filter in magnetic interpretation is the reduction to the pole. In Figure 3, just over the graben Cachimbo there is a positive anomaly and this is because the region is near the magnetic equator, a very problematic area to use this filter.

At the magnetic equator, geologic bodies with magnetic E-W directions have an induced magnetization with same value but with inverted sign if it were at the pole. If the direction of the magnetic body will turning toward the north, the anomaly increases (decreases in absolute value) to vanish completely. In other words: magnetic bodies aligned in NS magnetic direction are transparent to the method in the magnetic equator. Luckily geology and processing of data provide some solutions to solve the problem. Reducing to the pole is made by using the following equation

$$L(\theta) = N / (D1 \times D2) \quad (1)$$

Where

$N = (\sin(I) - i\cos(I)\cos(D - \theta))^2$

$D1 = (sen^2(I\alpha) + \cos^2(I\alpha \times \cos^2(D - \theta))$

$D2 = (sen^2(I) + \cos^2(I) \times \cos^2(D - \theta))$

With

$i = (-1)^{1/2}$

I = geomagnetic inclination

$I\alpha$ = inclination factor for amplitude correction

D = geomagnetic declination

θ = geologic direction

Figure 5 is the result of the application of this filter using a 70^o amplitude correction factor. This is a very good skill for geologic interpretation as we see a better correlation between the known geology and the geophysical response, with low magnetic anomalies over sedimentary rocks with low magnetic minerals contents.

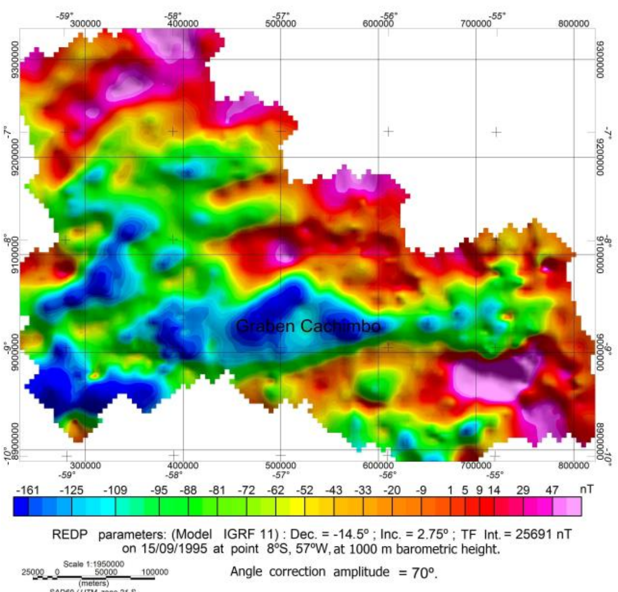


Figure 5 – Upper Tapajos Reduced to the Pole Magnetic Shaded Map (Declination = 315^o ; Inclination = 45^o.

The same map but with a better visualization of the deep tectonic behavior of the graben is shown in a 3D model as seen in Figure 6. The intense blue color corresponds to the main depocenters of Upper Tapajos basin in which predominates Proterozoic sediments. The green colors corresponds to medium depths with predominance of Mesozoic formations and the red colors to crystalline basement or shallow depths sediments sequences. It never hurts to call the attention of border problems that happen in filtered maps using the fast Fourier transform. The big negative anomaly at the SW extreme of the area is just one of them, with no geological significance as can be completed in a quick reference to the total field magnetic map shown in Figure 3.

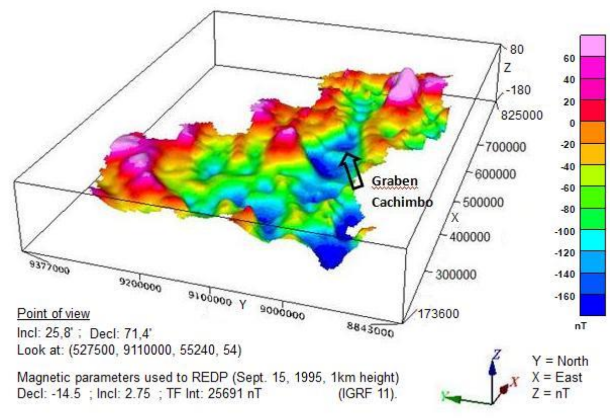


Figure 6 – 3D View of the Upper Tapajos Reduced to the Pole Magnetic Map.
Viewing angle: Dec. = 71.4^o ; Inc. = 25.8^o.

The Euler Deconvolution is a technique that has been successfully applied to determine depths of magnetic sources and aligning of these sources, assisting in mapping of geological trends at subsurface. Euler's equation

$$(x - x_o)\delta f/\delta x + (y - y_o)\delta f/\delta y + (z - z_o)\,)\delta f/\delta z = nf_{(x,y)} \quad (2)$$

Where

x , y, and z are the coordinates of the measured point

x_o, y_o, z_o are the coordinates of the sources (unknown)

"f" and its first partial derivatives refers to f at point x,y

and "n" is a constant depending on the source type.

This equation is true if and only if "f" is a homogeneous function. In the case of reduction to the pole, the filter applied distorts the function and because of this it was applied the total magnetic field function to search for depths of magnetic sources. Figure 7 shows the results obtained for a structural index of 0.2 using a window size of 100 km. Clearly there is a E-W region with deep sources coincident with the Cachimbo Graben mapped by surface geology and reinforced by figures 5 and 6. The main depocenter are better delimited and other minors depocenters, not so well marked occurs at NE and SW of the basin, reaching depths of 10 km or more.

Dealing with low resolution data in which acquisition was made with flight line intervals of 25 km, we can get only information from deep sources producing low frequencies signals. One way to enhance the signal is working with its derivatives as done in equation 2.

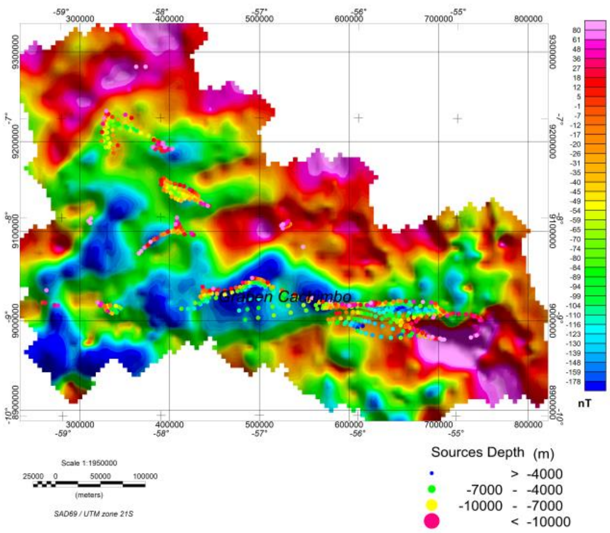


Figure 7 – Magnetic Sources Depth obtained from Euler Deconvolution using structural index 0.2 (fault) and (100 x 100) km window, over the reduced to the pole map.

Others commons techniques using first derivatives are the analytical signal (ASIG), which is the magnitude of the first derivative of the total magnetic field defined by the square root of the sum of the squares of the derivatives in the x, y and z directions

$$ASIG = ((\delta f/\delta x)^2 + (\delta f/\delta y)^2 + (\delta f/\delta z)^2)^{1/2} \qquad (3)$$

An enrichment of equation (3) is the tilt derivative TDR or inclination of ASIG defined as the arctangent of the vertical derivative (VDR) by the horizontal derivative (HDR) as seen in equation (4) which is the same of the ratio of the first derivatives of the vertical and horizontal component (module) of the total magnetic field (Equation 5).

$$TDR = \arctan (VDR / HDR) \qquad (4)$$

$$TDR = (\delta f/\delta z) / ((\delta f/\delta x)^2 + (\delta f/\delta y)^2)^{1/2} \qquad (5)$$

In turn, an enrichment of equation (5) is the total horizontal derivative of the tilt derivative (HD_TDR) given by

$$HD\_TDR = ((\delta(TDR)/\delta x)^2 + (\delta(TDR)/\delta y)^2)^{1/2}$$

this filter is what provides a more representative picture of the tectonic behavior of the basin and a composition with the map reduced to the pole and data from the Euler deconvolution is showed in figure 8. Note that the last two equations (tilt derivative and total horizontal derivative) are indicated for mapping shallow basement structures and mineral exploration targets which means high frequencies anomalies. This is not the case of this project, but the contacts between the sedimentary main sequence and the crystalline basement or shallow sediments are clearly seen in the map.

Conclusions and Recomendations

Aeromagnetic data confirms that the Paleozoic Upper Tapajos sedimentary basin rests on a deep graben of Proterozoic age, which can reaches more than 10 km depth. The main direction of this structure is E-W as highlighted by reduced to the pole data and response from the application of Euler's deconvolution. During the geologic evolution, the occidental part of the graben was affected by transcurrent faults of NE-SW and NW-SE directions giving the currently behavior. Between these faults, some magnetic sinusoidal lineation occur suggesting zones of folds and faults "en echelon". This structural behavior forming areas of tension and relief are good prospects for oil and gas players as occurs in Solimões Basin (Munis, 2009). As the Upper Tapajos Project is a low resolution one, it is recommended a new aero survey with 1 km flight line spacing. It is mandatory an overlap of at last 10 km on surveys of CPRM (Figure 3), to get a good junction and suppression of border problems, a very common and inherent case on geophysical interpretations. As the old low resolution projects, this new suggested, must include magnetic and gravimetric techniques and be held by ANP the government agency tasked to promote geophysical studies to delineate areas with potential for oil and gas production.

Acknowledgement

Acknowledgments must be done to CPRM, the Geological Survey of Brazil, for the permission to do this work and to ANP, the Petroleum National Agency for cession of data in accordance with the current ANP/CPRM agreement for use of geological and geophysical data.

References

Bizzi, L. A., Schobbenhaus, C., Vidotti, R. M., Gonçalves, J. H., 2003, "Geologia, tectônica e recursos minerais do Brasil", CPRM, MME, SMM., 674 p.

Hasui, Y., Carneiro, C. R., Almeida, F. F. M. de, Bartorelli, A., 2012, "Geologia do Brasil", Beca Edições, Petrobrás.

Munis, M. de B., 2009, “Caracterização geomagnética do Gráben Purus e suas implicações na evolução das bacias do Solimões e do Amazonas”, Tese de Doutorado – UFRJ/COPPE/PEC, 102 p.

Reis, N. J., 2006, “O quadro estratigráfico da bacia do Alto Tapajós na região de Apuí, Amazonas – implicações sobre seu status paleozoico”, XLIII Congresso Brasileiro de Geologia, Aracaju. *In M.G. Silva & W. J. S. Franca-Rocha (org.) – Coletânea de trabalhos completos, Salvador, SBG, 2008*, p 655-660.

Silva, A. J. P., Lopes, R. C., Vasconcelos, A. M., Bahia, R. B. C., *in Bizzi et al., 2003 p. 55-86.*

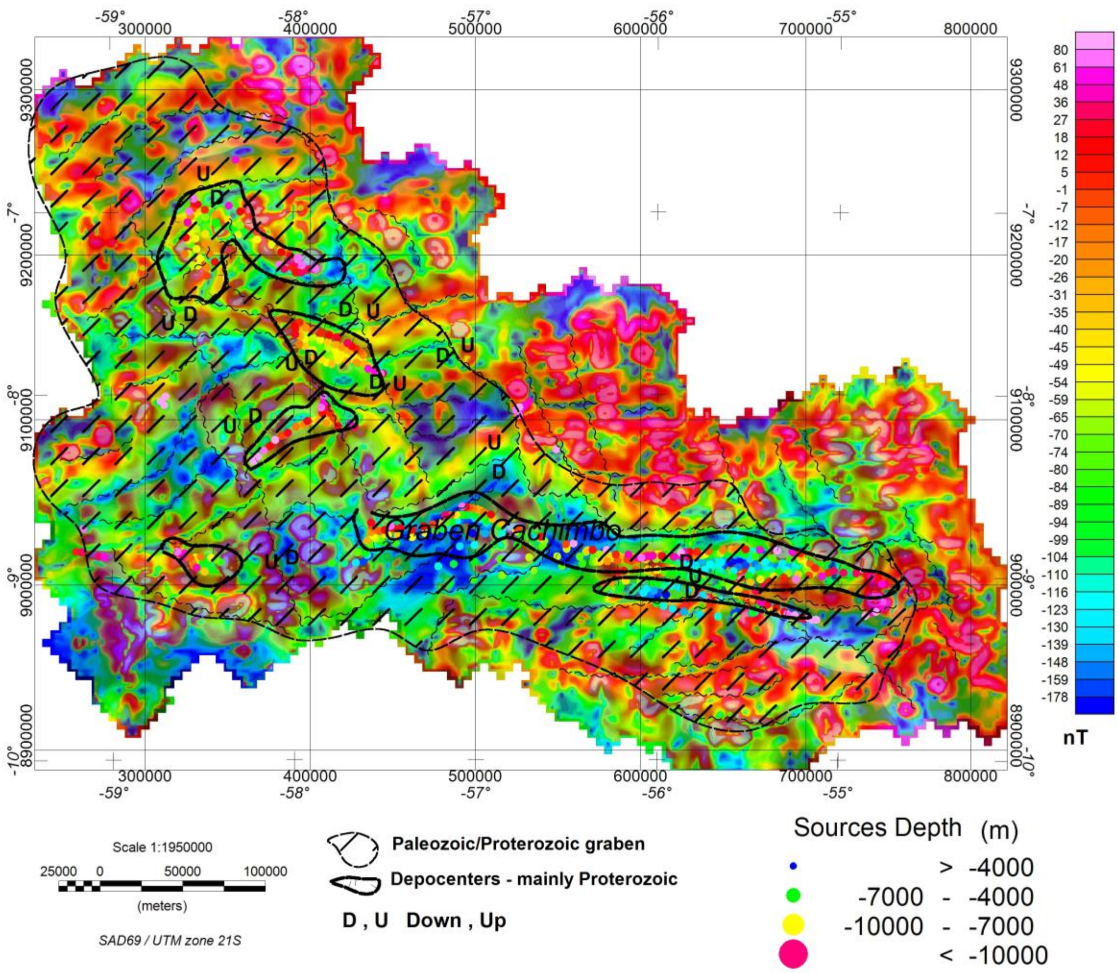


Figure 8 – Interpretation Magnetic Map of subsurface structures of Upper Tapajos Basin over a color composition of the reduced to the pole map and the horizontal tilt derivative map with Euler deconvolution using structural index equal 0.2 (fault) and 100 km size window.