3-D MT modeling of the Crustal Region in the Parana Basin's Central Portion

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SUMMARY

A geoelectric model is proposed for the central part of Parana Basin. A major part of that intracratonic basin has one of the most voluminous flood basalt inshore complex up to 2 km thick, covering an area of some 800,000 km^2. The basalt overlies a series of Paleozoic sediments including hydrocarbon source rocks. This paper presents a three-dimensional geoelectric model for the central portion of the basin, based on a data set comprising 231 broadband MT sites with a frequency range spanning 0.001s to 600s, covering an area of 120,000 km². Sites were deployed along 9 profiles running SW-NE, and one NW-SE. Site spacing is compatible to a regional study. The model reveals basin structure through its basement to lower crustal depths. In particular it has revealed a more complex structure for the Ponta Grossa Arch than previously thought. The results emphasize the feasibility of 3-D forward modeling in practice.

INTRODUCTION

High quality broadband single-site MT data was collected along 6 SW-NE profiles, one WNW-ESE and some fill-in sites off-profiles in central Parana Basin by a commercial contractor in the 80's. That study covered an area of 120.000 km² from a larger survey that added up to some 750 MT sites. In order to extend and check the old data we added a new profile to the SE of the study area with 17 sites plus 6 isolated sites, one at each old profile. All new sites were remote referenced. We analyze here 124 MT of the older sites, Fig. 1, to produce a preliminary 3-D model for the region, leaving for another work the integration with the new MT and other data. The results of a 2-D inversion/modeling on the new profile and its nearest old profile was presented elsewhere. The two profiles yield two entirely compatible models. The present data set was previously analyzed in the 80's (Stanley et al., 1985) within a 1D interpretation framework. That interesting paper had restricted its conclusions down to basement depths as for it was more concerned with the significance of the data to hydrocarbon exploration. The authors were able to add new information to the knowledge of the tectonics of Parana Basin. The authors recognized the importance of Ponta Grossa Arch, hereinafter named PGA (Fig. 1), a major uplifted structure within the basin. This work does not repeat the previous work in any of its findings but rather present an entirely new perspective on the same dataset based on a 3-D framework unavailable at the time as well as on more recent data. The authors of the present work and other colleagues have been analyzing a subset of the 450 best sites of the original large data set of 750 MT sites. That has produced a sizeable amount of work (e.g., Carrasquilla et al., 1999; Beamish e Travassos, 1993; Beamish e Travassos, 1992c). The old dataset was always checked against the new data acquired by the authors in order to check its quality. This work concentrates on, but it is not restricted to, the crustal structure in the area of the PGA. The PGA is a large uplift structure of the basement that dips to NW from the eastern edge towards the center of the basin. Its presence has been detected some 150 km from the edge of the basin, deep inside the study area (Fig. 1). Little is known about its crustal structure in spite of the amount of previous works. It is one of the most interesting features in the area of study. The reason MT data is useful to reveal the deep crustal depths at the PGA is due to the fact that resistivity is strongly affected by grain-boundary fluids or solid phases such as graphite if interconnected over distances comparable to the resolving scales of the method. This scale varies from about 100 m at depths of 1000 m to several kilometers in the lower crust (Wannamaker, 2000; Jones, 1992). We were able to recover the effects of multiple tectonic episodes on the resistivity structure. We found that fluids have strong roles in the study area and shed some light on the processes related to thermal regime and deformation.

3-D MODELING

The 2-D inverted models couldn't explain the reason of a good conductor at long periods as seen in the vertical component (see below) nor produced a good cross-line continuity. We then engaged in building up a 3-D model in a trial-and-error exercise. We used a 3-D modeling algorithm (Makie et al., 1993), which is based on the integral forms of Maxwell's equations to perform the forward modeling. The model region was discretized into 80 blocks in the x-direction (N120E) as well as in the y-direction, and 30 blocks along the z-direction. The total dimensions were 400 x 350 x 120 km along x, y, and z, respectively. Both polarizations display fairly good similarities between model and the data for this preliminary model. Figure 2 displays the results for lines 1 and 4 in the form of pseudo-sections. As it can be seen in the figure, we managed to reproduce almost all broad features of our data set. The shallower part of the model displays a good correlation to the previously known geological and other geophysical methods (magnetics and gravimetry) data. We use previous published results (Beamish e Travassos 1992; Stanley et.al. 1982) to help in the interpretation of the resistivity values found in the model. The sediments are associated to the 10-50 ohm.m conductors. The volcanic rocks of the Serra Geral Formation are associated to the 130 ohm.m resistors. We achieved a better fit for many sites after we postulated the existence of vertical resistors (130 ohm.m) close to sites. They represent diabase dikes striking NW that exist in the area (Ferreira et.al., 1996a) as seen in Fig. 1. Of course with an 8-15 km site spacing profile, 50 m wide dikes are not resolved by the dataset but the model do require their existence. By the same token their resistivity cannot be modeled unambiguously: we obtained virtually the same results for other resistivities. The need of postulating dikes in sparse data set like the present one is not a new result. An allowance for the presence of dikes has already been done in a regional-scale closer-spaced MT survey (Beamish & Travassos, 1993). In the present work we didn't find the need to model an anisotropic dike. The electrical basement is 500 ohm.m below all sites.

3-D CRUSTAL MODEL

With the findings of the modeling exercise we can infer some of the crustal structure in the region of the PGA. The deepest geoelectric unit in the 3-D model lies below the resistors of the crust and can be related to the lower crust. It comprises of two geoelectric units: a 20 ohm.m (20-40 km) unit at the southern half and the second is a 130 ohm.m resistor, Figure 3. As it can be seen in Figure 4 the induction arrows in the southern part of the model feel the presence of an eastern crustal conductor at long periods. The resistivity of 130 ohm.m is tipical of a basic/ultrabasic lower crust in cratonic regions (Glover & Vine, 1995), and are compatible with those found for basalt in the studied region. Other works in the region reported a lower crust about the same value (Beamish & Travassos, 1992). On the other hand the existence of highly conductive regions in the lower crust is widely reported in the literature (Glover & Vine, 1995). They have been explained as related to a lowering of electrolytic conduction in pores in favor of interstitial fluid conduction due to increased pressure (Glover & Vine, 1995), or due to graphite or partial melt (Gough 1992).

CONCLUSIONS

In this paper we have interpreted broadband remote-referenced MT data collected at 124 MT sites deployed along 6 SW-NE profiles, one WNW-ESE and some fill-in off-profiles sites. Site spacing was 8-15 km inline and 10-50 km cross-line. This regional study covered an area of 120,000 km². A 2-D inversion followed by 3-D direct modeling and sensitivity analysis has provided new information on the crustal structure of the central portion of Parana Basin. The previous knowledge was mostly restricted to the top of the basement. A study using pure shear extensional models revealed that three main extensional events occurred in Paraná Basin (Quintas et al., 1999). It also located at least two centers of major stress, which could indicate a paleo-structure representing the boundary of two tectonic blocks. And, more important for this study, they should represent the maximum deposition of volcanic rocks and by extension highest concentration of magmatic feeder ducts and sills (Zalán et al., 1986). Those two centers are located 100 km from the SW end (23.8º S, 53.8º W), and within the NW portion of the area (22.3º S, 52.0º W). This is partially corroborated by the real induction vectors (Fig. 4). The first extensional event occurred 440 My and was responsible for the deposition of the Silurian/Devonian sequence. The second event begun 144 My and was responsible for the deposition of the Carboniferous/Permian sequence. The third and last event was responsible for the deposition of the Jurassic/Cretaceous sequence bearing distinct characteristics from the first two (Quintas et al., 1999). A thick conductor associated to the Carboniferous/Permian sequence found in our model is in accordance with the view that the second event was the most intense in Paraná Basin (Quintas et al., 1999). The central portion of the PGA during the Paleozoic, mainly in the Permian, was a low in the basement as suggested by the thickening of the Carboniferous/Permian sediments. The northern portion was a high due to the thinning of the Carboniferous/Permian sediments until they disappear at the Guapiara Lineament. Conversely during the Mesozoic occurred a reversal; the volcanic and post-volcanic sediments thicken from the middle portion towards the edges of the PGA. That thickening appears as a smooth transition indicating that it took place in an almost undisturbed tectonic environment (Northfleet et al., 1969). Our results indicate that the tectonic evolution and the sedimentary deposition in the region were conditioned by the NW structures during the second extensional event that occurred in the basin (Quintas et al., 1999). During the Triassic the crust undergone a thermal uplift in southern Brazil, including the PGA, resulting in a large anticlinal structure (dome) associated to the heating from the mantle (Fúlfaro et.al., 1982). During the Jurassic begins the massive extrusion of volcanic rocks, part of it becoming trapped in the base of the crust. That accumulation is particularly noticeable at the central portion of the PGA, forming a low-resistivity fluid-enriched zone. Less than expected subsidence occurred after the extrusion ceased due to the accumulation of denser material at the base of the crust.

REFERENCES

Beamish, D., Travassos, J.M., 1992c. Magnetotelluric imaging of basalt-covered sedminents, First Break, 10:345-357.

Beamish, D., Travassos, J.M., 1993b. Magnetotelluric studies from two contrasting Brazillian basins: a reassessment of old data. Phys. Earth Planet. Int., 81: 261-276.

Carrasquilla, A., Prata, F., Travassos, J.M., 1999, Three-dimensional magnetotelluric modeling of mariopolis area in parana basin - south of Brazil. Second International Symposium on Three-Dimensional Electromagnetics, Salt Lake City, USA.

Ernesto M., Melfi A.J., Pacca, I.G., Ussami N., 1988b. Significance of the Parana flood volcanism in the disruption of Western Gondwanaland. In: E.M. Piccirillo, and A.J. Melfi (Editors). The Mesozoic flood volcanism of the Parana Basin: petrogenetic and geophysical aspects. São Paulo, Univ. São Paulo, 285-295.

Ferreira, F.J.F.; Blum, M.LB.; Forlim, M.; Soares, P.C.; Rostirolla, S.P., 1996. Superfície Curie da região de Fartura. Anais 39 Cong. Bras. Geologia, SBG, Salvador.

Gough, T.I., 1992. Electromagnetic exploration for fluids in the earth's crust. Earth Sci. Rev., 32: 3-18.

Glover, P.W.J.; Vine, F.J., 1995. Beyond KTB - electrical conductivity of the continental crust. Survey in Geophysics, 16: 5-36.

Jones, A.G., 1992. Electrical conductivity of the continental lower crust. In: D.M. Fountain, R.J. Arculus, and R.W. Kay (Editors), Elsevier, Amsterdam: 81-143.

Mackie, R.L., Madden, T.R., Wannamaker, P.E., 1993, Three-dimensional magnetotelluric modeling using difference equations – Theory and comparisons to integral equation solutions, Geophys., 58, 215-229.

Menezes, P.T.L., Travassos, J.M., 2000. An audiomagnetotelluric survey across an outcropping dike, PAGEOPH, 157: 1857-1872.

Menezes, P.T.; Travassos, J.M., 1995. Geoelectric structure of Ponta Grossa Arch. Preliminary results. Anais do V Simpósio Est. Tectônicos, SBG, Gramado, RS.

Menezes, P.T.; Travassos, J.M., 1996. Outlier detection and robust estimation of MT data: An example of Parana Basin, Brazil. Geociências, 15: 415-424.

Menezes, P.T.L.; Travassos, J.M., 2000. An audiomagnetotelluric survey across an outcropping dike, PAGEOPH, 157: 1857-1872.

Milani, E.J.; Ramos, V.A., 1998. Orogenias paleozóicas no domínio sul-ocidental do Gondwana e os ciclos de subsidência da Bacia do Parana. Revista Brasileira de Geociencias, 28: 473-484.

Quintas, M.C.L.; Mantovani, M.S.M.; Zalán, P.V., 1999. Contribuição ao estudo da evolução mecânica da Bacia do Parana. Rev. Bras. Geociência, 29: 217-226.

Rodi, W., Makie, R.L., 2001, Nonlinear conjugate gradients algorithm for 2-D magnetotelluric inversion, Geophys., 66, 174-187.

Santos, M.V, Saad, A.R, 1982, Mapa estrutural da Bacia do Parana, in Geologia da Bacia do Parana, Paulipetro (CESP/IPT), Annex, São Paulo, Brasil.

Stanley, W.D.; Saad, A.R.; Ohofugi, W., 1982, Regional magnetoteluric surveys in hydrocarbon exploration, Parana Basin, Brazil. Bull. Am. Ass. Petrol. Geol., 69: 346-360.

Travassos, J.M.; Beamish, D., 1988. Magnetotelluric data processing - a case study. Geophys. J. Int., 93: 377-391.

Ussami, N.; Sá, N.C.; Molina, E.C., 1993. Gravity map of Brazil 2. Regional-residual isostatic anomalies and their correlation with major tectonic provinces. J. Geophys. Res., 102: 2199-2208.

Wannamaker, P.E., 2000. Comment on ‘‘The petrologic case for a dry lower crust’’, by B.D. Yardley and J.W. Valley. J. Geophys. Res. 105, 6057– 6064.

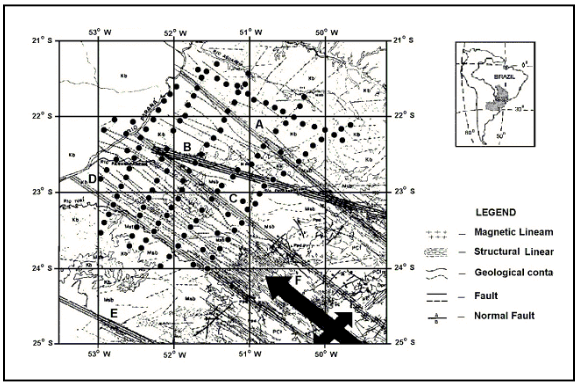

Figure 1: Structural map for the central portion of Parana basin with site locations superimposed

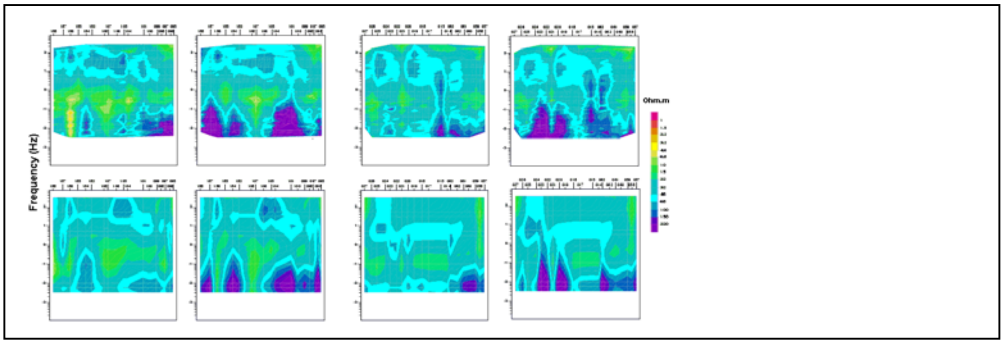

Figure 2. Pseudo-sections of data and model responses. Data is in the top panels, model responses are in lower panels. Left column is XY and YX. The first four panels (A) refer to line 1. The last four panels (B) refer to line 4.

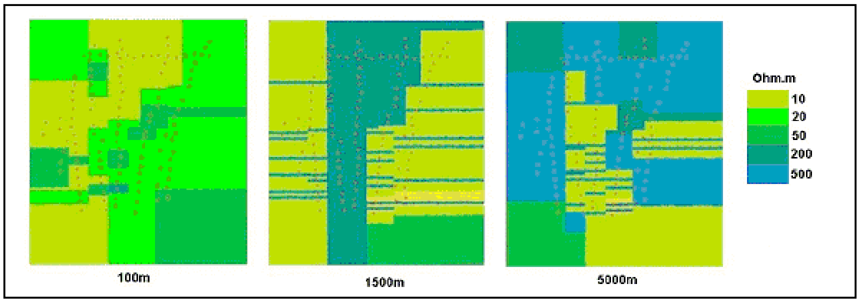

Figure 3. Selected slices from the 3-D model with the MT sites overlaid as red dots. Depths are show below each slice. The first slice (100 m) shows the sediments above the basalt. The second slices 1500 m) show that the basalt layer has a N-S fold at its western half. The third slice (5000 m) shows that the depression has a signature at basement levels.

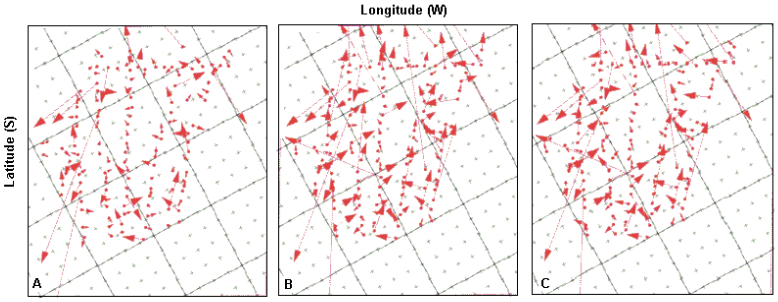

Figure 4. Real induction (reversed) arrows for three periods (100, 200, 300 Hz). Arrows point towards current concentrations.