MT-LMT IMAGING OF TRANSBRASILIANO LINEAMENT AND BASEMENT-COVER RELATIONSHIP IN PARNAÍBA BASIN

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Abstract

A major multi-disciplinary and multi-institutional project has been established to probe the deep structure across the Borborema Province of northeast Brazil. Broadband and long period MT data were recorded at 46 stations, with 10 km spacing along a profile crossing the Parnaíba basin and outcropping basement complex of Borborema province. The MT data were processed using a robust scheme and transfer functions were obtained in the period range of 0.001 – 10,000 sec. Regularized 2D inversion of the data reveals the deep resistivity structure of the Parnaíba basin down to 80 km depth. The sedimentary top crustal section is conductive (<15 ohm.m) while the deep crust and upper mantle are resistive (>100 ohm.m). We found that the major surface lineaments could penetrate into the deep crust, and that there are also two anomalous 10-20 km-wide conductive zones at ~50 km depth which may be related to magmatism on the surface.

Introduction: Regional Setting

The Borborema province, covering an area 450.000 km^2 in northeast Brazil, is a complex association of crustal blocks with differing ages, origin and evolution which were joined together during the late Neoproterozoic-early Phanerozoic Brasiliano orogeny as part of Gondwana supercontinent amalgamation (Almeida et al. 1981). This Province has been the subject of numerous scientific studies (e.g. Brito Neves et al. 2000, Bizzi et al. 2003 and references therein). The limits of the Province are delineated by the São Francisco craton at the southern side, by mid-Cenozoic basins of the coastal and continental margin at the northern and eastern sides and by Phanerozoic deposits of Parnaíba Basin at the western side. The Parnaíba basin, which covers partially the Borborema Province, has also been the subject of several studies (e.g. Cunha 1986, Goes and Feijo 1994, Arora et al. 1999a, 1999b). Both the hydrocarbon potential and its relation with major shear zones like the Transbrasiliano lineament (TBL) make it a target for exploration (e.g. Lima et al 1996, Fontes 1997, Fontes et al. 1997). The TBL (Figure 1), locally called Sobral-Pedro II, is regarded as a continuation of Kandi Lineament that is recognized as a Neoproterozoic suture in Africa (Caby 1989; Castaing et al. 1993, 1994). Over the TBL occur transtensional basins (Parente et al. 2004) and post-orogenic granites, partly covered by Phanerozoic sedimentary rocks of the Parnaíba basin (Zalan 2004). The goal of this paper is to determine the basement-cover relation and the deep-crustal signature of the TBL in the Parnaíba basin using a combined MT-LMT conductivity imaging approach.

Electromagnetic (EM) exploration studies have been carried out in the Parnaíba basin for different reasons. Arora et al. (1998, 1999a, 1999b) reported the presence of a variety of conductivity structures in this basin. Their result was based on the interpretation of magnetovariational (MV) fields and 2D modeling study along an approximately 1500 km long profile with spatially sparse stations (profiles AA' and BB' in figure 1). Their main finding was the Parnaíba basin conductivity anomaly (PBCA). Their result indicated that a conductive unit lies at a depth of 2 to 4 km in the north-central part of the basin. This unit was interpreted as a ‘channel structure’ connecting the Parnaíba and Marajó basins. Meju et al (1999) focused on the tectonic controls of the regional aquifers of Parnaíba basin (profile MM' in Figure 1). They successfully mapped the sediment-basement architecture of the southeastern margin of the basin using high frequency MT and transient EM data. The TBL was imaged as a shallow crustal feature, possibly manifesting as a zone of near-vertical faulting of basement cover rocks. Using a short MT profile data, Oliveira and Fontes (1991) proposed a deep conductive unit which currently is assumed as part of the PBCA. Knowledge of this conductive unit provides information on how local oil bearing geological units were developed and on the tectonics or control mechanism which forms the petroliferous basins. All the previous EM studies targeting the deeper part of the basin have suffered from sparse station interval, short length of the profile or from restricted frequency bandwidth. Thus, deeper parts of the northeastern Brazil still need much attention. It is opportune to use advanced inversion algorithm to model new long period MT data recorded across the basin to image the deep crust and upper mantle in the region for any possible deep structural features, and especially those coincident with the Transbrasiliano lineament.

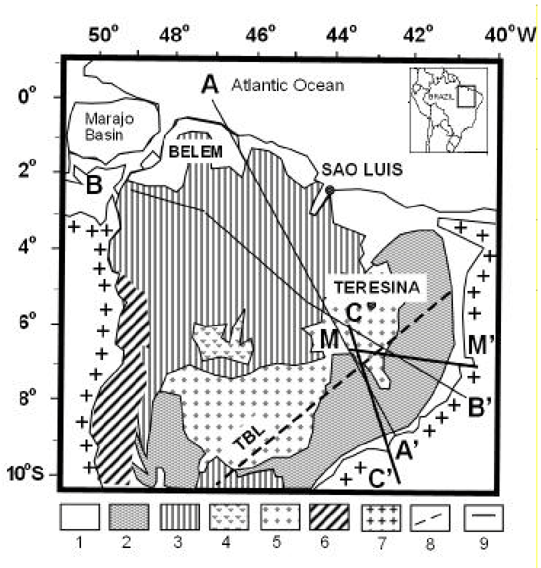

Figure 1. Map showing the regional geology (Simplified from Mesner and Wooldrige 1964, DNPM 1971 and Arora et. al., 1998) and the locations of MT profiles. Note the bowl-shaped Parnaíba basin. (1) Cenozoic, (2) Devonian and Silurian, (3) Cretaceous, (4) Mesozoic volcanics, (5) Permo- Pennsylvanian, (6) Araguaia fold belt,(7) Precambrian, (8) Fault trace, (9) profiles; AA' and BB' Magnetometer profiles of Arora et al (1999a and b), MM' MT profiles of Meju et al (1999) and CC' is the MT AND LMT profile of current study. TBL is the Transbrasiliano lineament.

A major project was launched in 2010 to explore the deep structure of the Borborema Province and was carried out by research teams from the universities of Brasília, Rio Grande do Norte, São Paulo, Campinas, Ceará, Pampa, Instituto Nacional de Pesquisas Espaciais and Observatório Nacional. Overseas collaborators were also involved in the data analysis part. The preliminary results from measurements across the Parnaíba basin (profile CC' in Figure 1) are presented here.

MT Data Acquisition

As part of the project, 46 magnetotelluric (MT) stations were installed with 10 km spacing to record conventional broadband and long-period MT time series (10 to 15 days of data acquisition) at every station. Both the broadband MT (BMT) and the long-period MT (LMT) data are presented in this paper (Figure 2). In the case of LMT, the variation of two horizontal electrical fields (Ex and Ey) and three magnetic fields (Hx, Hy and Hz) were recorded with one second sampling interval using LEMI instruments built by the Lviv Center at the Institute for Space Research, Ukraine. BMT data were acquired in four bands with the Metronix MT ADU07 system using the same configuration. The sampling frequencies are 16384, 4096, 512 and 128Hz, respectively. All measurements were performed on the coordinate axes system that x direction is pointing to magnetic north. Both BMT and LMT data were processed using standard industry software and the EM impedances were obtained in the frequency ranges of 8000 – 0.001 and 0.03 – 0.0008 Hz, respectively.

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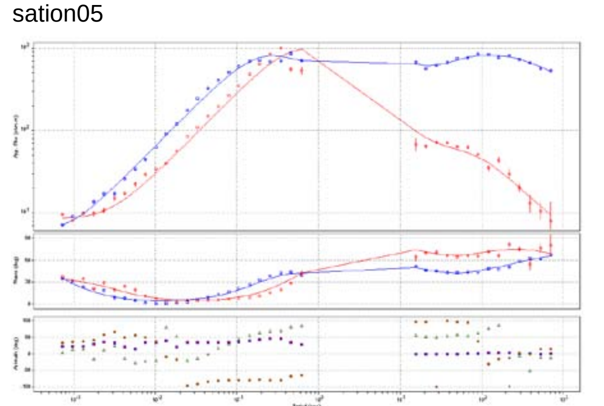

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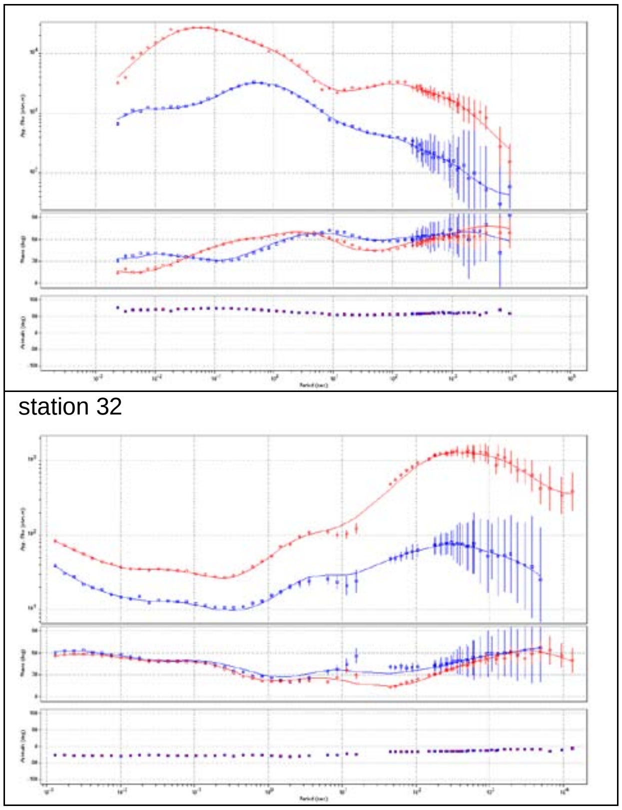

Figure 2. Same example stations; there is a good agreement between BMT (up to ~100 sec) and LMT (after ~30 sec) curves. Blue markers are TE, red ones are TM mode data while continuous lines are smoothed curves obtained from D+ approach (Parker 1980).

The time series data for each station were analyzed as a single station data and magnetic channels (Hx and Hy) were used as reference for the impedance estimation. Coherencies between reference channel (Hx and Hy) and electrical components (Ex and Ey) are generally high (>0.8). It is one of the indicators of the data quality. Additionally, the curves of the apparent resistivity and the phase of the EM impedance show smooth variations with small error bars in much of the frequency range. Note that both the BMT and LMT data were first evaluated separately and then combined as single station once the EDI files are obtained (Figure 2). Both the Swift (1967) and Tipper strikes were consistent as ~25 degrees. Note that the magnetic declination is ~21 degree W in the region. It complies with the direction for the profile and, for the sake of simplicity, x direction was taken as TE mode without any rotation. Any static shift was corrected as in Meju et al. (1999) using transient electromagnetic (TEM) data collected at each station.

2D inverse modeling

The well-known commercial package, WinGLink, was used in this project. The 2D inversion routine is based on the code of Mackie et al (1997). It uses finite difference mesh and network analogy to obtain the responses of the 2D resistivity model. Both TE and TM mode data (apparent resistivity and phase of impedance) were inverted together. A model, consisting of 77x258 cells in x and z direction, respectively, was used in this study. The misfit value (RMS) for the final model was 6.94. The 460-km-long 2D model covers both shallow and deep features of the basin. Figure 3 shows the 2D resistivity inversion model for the profile. Rightmost station is Bor004 at Bahia State and last station is Bor050 in Maranhão State. The comparison of the observed and calculated data is given in Figure 4. Dots represent the data in Figure 4. The data coverage is good and the data constrain most of the model section; a comparison of the observed and model responses indicates that the main features are recovered.

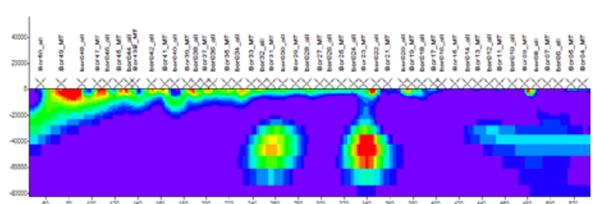

Figure 3 2D model for Parnaíba Basin, depth range 0-80 km left side is Marahao State while right side is Bahia state.

We found that the sedimentary part (<15 ohm.m red color in Figure 3) of the basin may be relatively deeper than defined in previous studies (e.g. Meju et al 1999). Stations Bor04-Bor16 are over the crystalline basement (>100 ohm.m green color in Figure 3) at the border of Piauí and Bahia states. A dipping crystalline border is apparent between stations Bor17 and Bor23. Below stations Bor27, Bor30, Bor33 and Bor42, there appear to be faults reaching down to the crystalline basement. This agrees with the result of seismological studies (Ferreira e Assumpção 1983, Takeya et al. 1989, Ferreira et al. 1998, 2008). Seismogenic faults, reaching the upper crust, with depths of up to 12 km, are in accord with the model. The deeper part of the model (~30-50km depth) appears to host two anomalous conductive zones (red and green color in Figure 3). Although not shown here, when we removed these conductors after 25 km depth, the misfit varied; model RMS was 7.4486, when we remove the left one it increased to 7.4757. The removal of the right one resulted in RMS 7.482. the the removal of both increased RMS to 7.55. We interpret this as confirming the existence of such localized conductors. The localized anomalously high conductivity perhaps points to hot spots and they may be the source of the volcanism active during the Mesozoic.

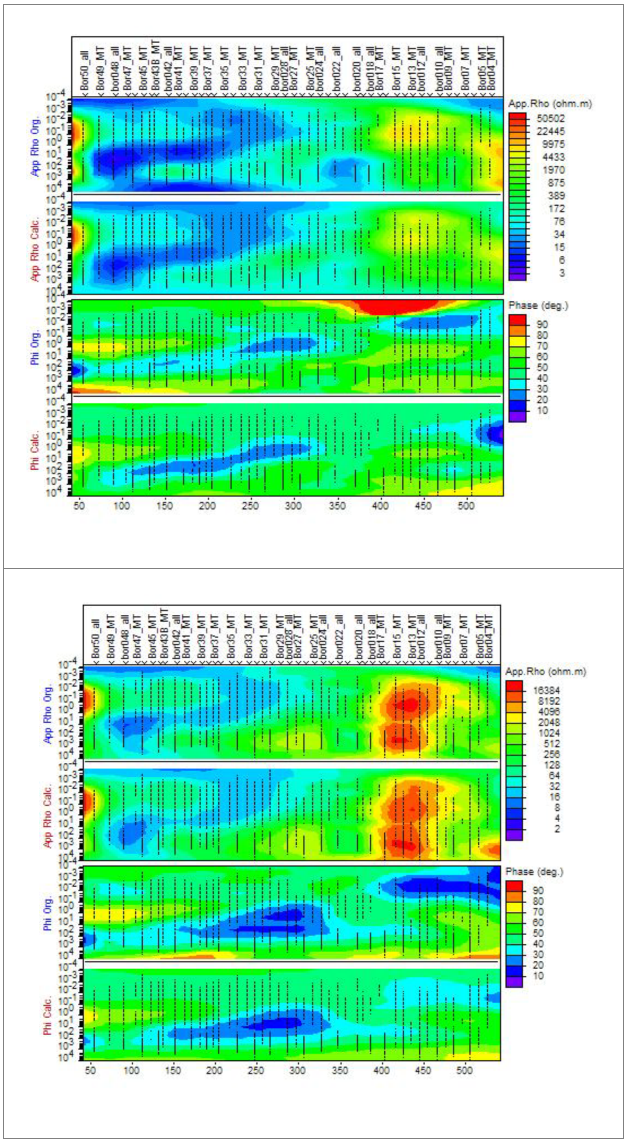

Figure 4 observed and calculated apparent resistivity and phase of impedance for TE (top) and TM (bottom) modes

Conclusion

As part of a major project to probe the deep structure in Borborema province, new tensor MT data have been recorded over the conventional and long period bands. The time series data were processed with a single station robust scheme. 2D inversion of the resulting apparent resistivity and phase data successfully maps major crustal structures: Transbrasiliano lineament which extends deep into the crust and possible magma chambers at ~50 km depth further south which may be the source of volcanism in the basin. The sedimentary top crustal section is conductive (<15 ohm.m) while the deep crust and upper mantle are mostly resistive (>100 ohm.m). It is tectonically significant that major surface lineaments could penetrate into the deep crust and that the conductive zones at ~50 km depth may be related to magmatism on the surface.

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, 17, 1-29.

Arora, B. R., Vitorello, I., Padilha, A. L., Trivedi, N. B., Rigoti, A. & Chamalaun, F. H. 1998. Geological interpretation of the Parnaíba basin magnetovariational anomaly using a 2-D sheet current inversion. Acta. Geod. Geoph. Hung., 33: 167-155.

Arora, B. R., Padilha, A. L., Vitorello, I.,Trivedi, N. B., Fontes, S. L., Rigoti, A. & Chamalaun, F. H. 1999a 2-D geoelectrical model for the Parnaíba Basin conductivity anomaly, North-northeast Brazil and its tectonic implications. Tectonophysics, 302: 57-69

Arora, B. R. Trivedi, N. B. Vitorello, I. Padilha,A. L. Rigoti A. & Chamalaun F. H. 1999b. Overview Of Geomagnetic Deep Soundings (GDS) As Applied In The Parnaíba Basin, North-Northeast Brazil: Revista Brasileira de Geofísica, Vol. 17(1).

Bizzi, L. A., Schobbenhaus, C., Vidotti, R. M., Gonçalves, J.H. (Org.). Geologia, Tectônica e Recursos Minerais do Brasil - Texto, Mapas e SIG. , 2003.

Brito Neves, B. B., Santos, E. J., Van Schmus, W. R. 2000. Tectonic history of the Borborema Province, northeastern Brazil. In Cordani, U.G., Milani, E.J., Thomaz Filho, A., Campos, D.A. (Eds.) Tectonic Evolution of South America. Rio de Janeiro, 31 International Geological Congress, p.151-182.

Caby, R. 1989. Precambrian terrane of Benin-Nigeria and northeast Brazil and late Proterozoic Atlantic fit. - Geol. Soc. Am. Sp. Paper, 230, 145-158.

Castaing, C., Triboulet, C., Feybesse, J. L.& Chevremont, P. 1993. Tectonometamorphic evolution of Ghana, Togo and Benin in the light of the Pan-Africano/Brasiliano Orogeny. Tectonophysics, 218, 323-342.

Castaing, C.; Feybesse, J. L.; Thieblemont, D., Triboulet, C. & Chevremont, P. 1994. Paleogeographical reconstructions of the Pan-African/Brasiliano orogen: closure of an oceanic domain or intracontinental convergence between major blocks ?. Precambrian Research, 69, 327-344p.

Cunha, F.M.B., 1986. Evoluc¸a˜o paleozo´ica da Bacia do Parnaíba e seu arcabouço tectonico, Unpubl. M.Sc. thesis, Univ. Federal, Rio de Janeiro, Rio de Janeiro.

DNPM (Departamento Nacional da Produção Mineral), 1971. Mapa tectônico do Brasil 1:5,000,000.

Fontes, S. L., Meju, M. A., Lima, J. P. R., Carvalho, R. M., La Terra, E. F., Germano, C. R., and Metelo, M., 1997, Geophysical investigation of major structural controls on groundwater distribution, north of Sao Raimundo Nonato, Piaui State: 5th Internat. Congress, Brazil. Geophys. Soc., Expanded Abstracts, 2, 766–769.

Goes, A.M.O., Feijo, F.J., 1994. 'Bacia do Parnaíba. B. Geocience, PETROBRAS 8, 57–67.

Ferreira, J., Assumpção, M.,1983. Sismicidade do Nordeste do Brasil. Revista Brasileira de Geofísica, 1: 67-88.

Ferreira, J.M., Bezerra, F.H.R., Sousa, M.O.L., Do Nascimento, A.F., SÁ, J.M., França,J.S., 2008, The role of Precambrian mylonitic belts and present-day stress field in the coseismic reactivation of the Pernambuco lineament, Brazil. Tectonophysics, 456: 111-126.

Ferreira, J.M., Oliveira, R., Takeya, M., Assumpção, M., 1998. Superposition of local and regional stresses in NE Brazil: evidence from focal mechanisms around the Potiguar marginal basin. Geophysical Journal International, 134: 341-355.

Fontes, S. L. . 1997. Electrical conductivity distribution in the intracratonic Parnaíba basin, NNE Brazil: carbon metagenesis and possible consequences in hydrocarbon generation/destruction. In: Proceedings American Geophysical Union Spring Meeting, V. 1. P. 573.

Lima, J.P.R., Oliveira, M.F.B., Fontes, S.L., Meju, M.A., 1996. Evideˆncia do lineamento Transbrasiliano na bacia do Parnaıba utilizando o metodo magnetotelurico. An. XXXIX Congr. Bras. de Geologia, Salvador, pp. 372–375.

Mackie, R. L., Rieven, S., and Rodi, W., 1997, Users manual and software documentation for two-dimensional inversion of magnetotelluric data: M. I. T. Earth Resources Lab. Report.

Meju, M.A., Fontes, S.L., Oliveira, M.F.B., Lima, J.P.R., Ulugergerli, E.U. and Carrasquilla, A.A., 1999, Regional aquifer mapping using combined VES-TEM- AMT/EMAP methods in the semi-arid eastern margin of Parnaíba Basin, Brazil: Geophysics, 64, no. 2, 337-356.

Mesner, J. C. and Wooldbrige, L.C. 1964, Maranhão Paleozoic basin and Cretaceous coastal basins, North Brazil. Bull. Am. Assoc. Petr. Geol., 48: 1475-1512.

Oliveira, M. F. B. & Fontes, S.L. 1991. Magnetotelúrica na Bacia do Parnaíba, Primeiros resultados. Proc. 2nd International Congress of the Brazilian Geophys. Soc., 1: 294-299, Salvador, BA, Brazil.

Parente, C.V., Silva Filho, W.F., Almeida, A.R., 2004. Bacias do estágio de transição do domínio setentrional da Província Borborema. In Mantesso Neto, V., Bartorelli, A., Carneiro, C.D.R., Brito Neves, B.B. – 2004 – Geologia do Continente Sul-Americano: Evolução da Obra de Fernando Flávio Marques de Almeida. São Paulo, Beca, p.525-536.

Parker, R.L, 1980, The inverse problem of electromagnetic induction: existence and construction of solutions based on incomplete data: J. Geophys. Res., 85, 4421-4428.

Swift, C.M., 1967. A magnetotelluric investigation of electrical conductivity anomaly in the southwestern United States,PhD Thesis Massachusetts Institute of Technology, Cambridge, MA.

Takeya, M., Ferreira, J.M., Pearce, R.G., Assumpção, M., Costa, J.M., Sophia, C.M.,1989. The 1986-88 intraplate earthquake sequence near João Câmara, NE Brazil: evolution of seismicity. Tectonophysics, 167: 117-131.

Zalan, P. V., 2004. Evoluçao Fanerozoica das Bacias Sedimentares Brasileiras In: V. Mantesso Neto, A. Bartorelli, C. D. R. Carneiro, B. B. B. Neves (Organizadores.), Geologia do Continente Sul-Americano: Evoluçao da Obra deFernando Flavio Marques de Almeida. Editora Beca, Sao Paulo, p. 595-612.