Electromagnetic and Seismic characterization of São Francisco Basin, Brazil

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Abstract

The magnetotelluric (MT) method has been widely used in studies of terrestrial and marine Brazilian basins. A major problem in oil exploration is precisely locating basement fracture-zones and heterogeneous carbonate reservoirs underneath thick overburden. Fractures in granitic zones, massive carbonates rocks can be detectable by EM methods, since it is geologically expected that this rock may form regional unconformity-related conductive horizons. In the present study we analyzed several MT soundings from the central region of São Francisco Basin in northwest portion of the state of Bahia near the region called Remanso do Fogo in Brazil. We obtained EM attributes from various geological formations of Sao Francisco basin. The main thrust was to obtain depth-converted EM attributes of fractured carbonate rocks and to map the resistivity structure of well-known portions of the basins. It is shown that the stratigraphic groups characterized in seismic reflection images are in agreement with structural features revealed by MT conductivity imaging.

Introduction

The range of applications for the MT technique is very large; in oil and gas research, for instance, the MT method have been used for several decades in land surveys to contribute to the efficiency of seismic methods, specially where the seismic signal is attenuated by geological structures.

In Brazil, there is now renewed interest in the study of intracratonic basins which include Parecis, Parnaíba and São Francisco basins. This paper presents a revisitation to a MT survey conducted in Sao Francisco basin, by Porsani and Fontes, which generated only 1-D model interpretations.

The intracratonic basin of Sao Francisco is dominantly composed of Neoproterozoic clastic and carbonates rocks of the Bambui Group. These are overlain by the sedimentary rocks of Santa Fe Group (Carboniferous-Permian), Areado (Valanginian to Albian) and Urucuia-Mata da Corda (Cenomanian to Maastrichtian).

The MT survey was conducted in the northwest portion of Bahia State, along a 87 km transect with sounding station spacing varying between 5 and 10 km. Forty-three MT soundings were undertaken along eight profiles in the central portion of the São Francisco basin. The MT frequency ranged between 10^{-2} - 10^{2} Hz (figure 1). The survey was conducted as a follow-up study by Porsani and Fontes (2001), with additional soundings in subsequent years along seismic reflections lines by PETROBRAS. Although the MT data are of a different vintage to modern acquisitions, they will suffice for evaluating the usefulness of MT in carbonate and basement exploration in this basin.

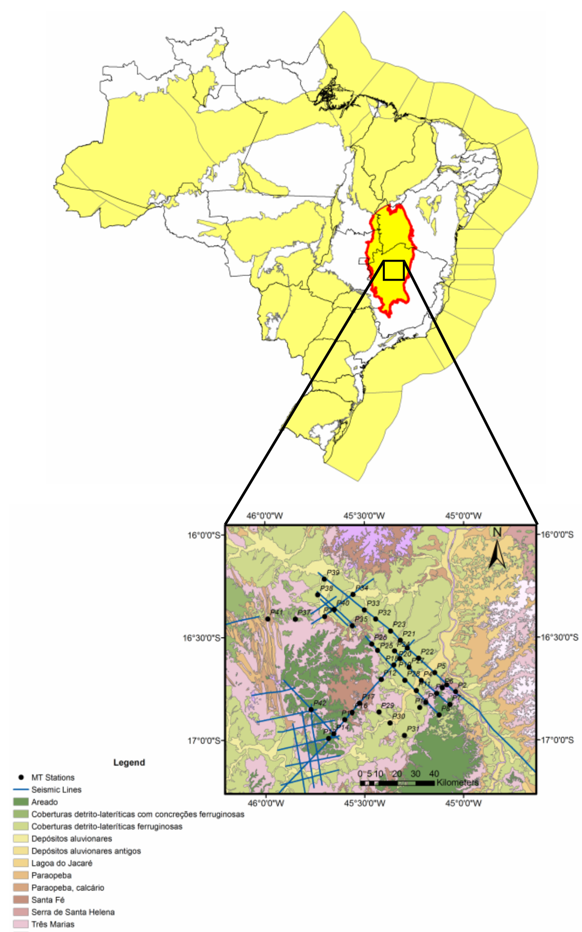

Figure 1: MT site locations (full circles) along seismic lines.

Methodology

The magnetotelluric method (MT) is a geophysical technique used to determine the distribution of electrical conductivity in the subsurface of the earth. The main sources of the signals used by the method are variations of natural electromagnetic fields that diffuse on Earth. These variations mean that the electromagnetic fields penetrate the soil and induce currents inside the Earth. Measurements are made in the time domain and transformed into the frequency domain, where relations involving the amplitude and phase for a given frequency between the electric and magnetic fields are indicative of the conductivity distribution in the subsurface.
For this study, we constrained the 2D inversion with information acquired from well logs. Some cells were filled with values extracted from the resistivity log. We adopted the resistivity well-log for borehole 1-RF1-MG as the ground-truth.
To establish the names of the geological formations associated with geoelectrical horizons, we carried out a comparison between the model MT1 obtained from 2D inversion and the logs profiles from well 1RF-0001-MG. The process of comparison is only qualitative, and the criteria used relates to the tendency of the curve relative to MT profile of the well.

Data Processing

The data processing from Sao Francisco was performed using the procedure described by Gamble et al. (1979). The estimate of errors is based on Pedersen (1982). The resistivity curves were analyzed by Porsani (1993), which shows that the curves presented effect of static drift. For this study, it was not available the time series of MT data conducted in the survey. Thus only could be analyzed the resistivity curves and phase, preventing the application of techniques of decomposition of the impedance tensor of Groom & Bailey (1989), to remove heterogeneity, and robust processing techniques from Egbert (2000).

MT Imaging

The MT 2D smooth model inversion routine used here was developed by Rodi and Mackie (2001). This routine finds regularized solutions (Tikhonov Regularization) to the two-dimensional inverse problem for magnetotelluric data using the method of nonlinear conjugate gradients. The forward model simulations are computed using finite difference equations generated by network analogs to Maxwell's equations. The program inverts for a user-defined 2D mesh of resistivity blocks, extending laterally and downwards beyond the central detailed zone, and incorporating topography.
To produce the 2D inversion model we created a finite-difference mesh with a halfspace of 100 ohm.m.
Figure 2 shows the 2D model MT1 near the borehole 1-RF1-MG after inversion. In figure 3 we present the seismic section coincidently with profile MT1. Both sections are 96 km long. Important features are mapped, and our resistivity geoelectric horizons coincide in depth with the boundaries between key stratigraphic groups as mapped by seismic reflection method. Figure 4 shows profiles MT1, MT2, MT3 and MT6 together.
The uppermost resistivity marker appears to coincide with the Lagoa de Jacaré Formation in Bambui Group. The lowermost resistivity marker appears to coincide with the Sete Lagoas Formation. Between the boundaries of these two resistivities markers we can see two remarkable conductive geoelectric horizons that coincide with boundaries of Serra de Santa Helena Formation, also from Bambui Group.

Conclusions

The inversion models show the comportment of Bambui Group and its main formations. We can see that in the three adjacent and parallel profiles, MT2, MT3 and MT6 the Lagoa de Jacaré Formation is still marked at depths of about 300 – 500m, but it is not continuous in all stations. It shows a lateral change in the resistivity value of the layer in question, but that does not necessarily means a discontinuity in the geological formation.

In the 2-D inversion model, the carbonate rocks are characterized by more resistive geoelectrical horizons, while the shales and sandstones have more conductive horizons. The 2D inversion marked very well the presence of these rocks in all profiles. All of these horizons identified by MT occur at depths similar to the well.

The results of the integrated study of 2D inversion for the 43 MT soundings, together with information about the stratigraphic column and resistivity log, allowed us to estimate that the geoelectrical basement of the basin in its central portion varies from 5.0 to 6.0 km depth.

The excellent quality of the results, particularly in identifying the base of the Lagoa do Jacaré Formation, considered as both a source and reservoir rock in the basin (Braun et al., 1990), as well as the location of the basement high, puts the magnetotelluric method as a relevant tool and complementary to other geophysical methods.

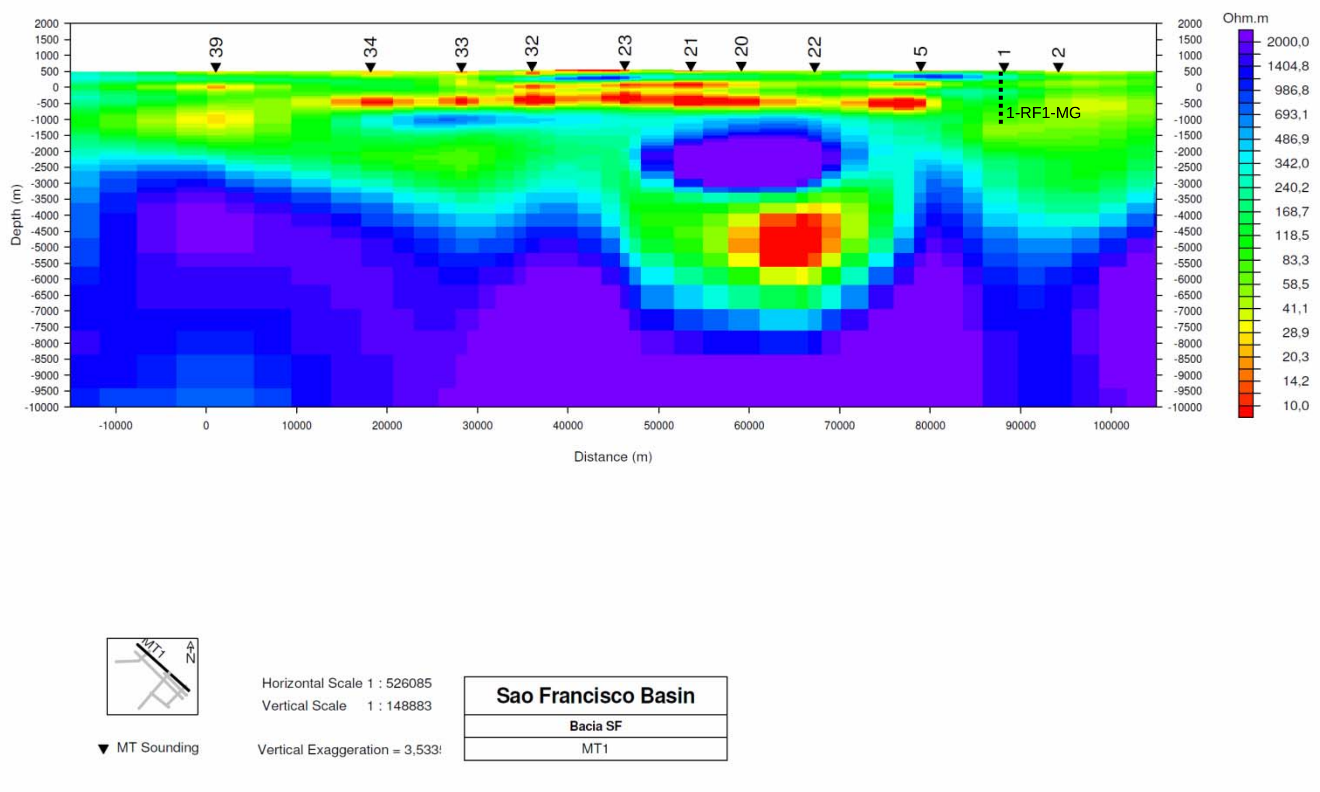

Figure 2: 2D inversion model profile MT1 achieved by constrained inversion using well data. Position of well 1RF-0001-MG is also shown.

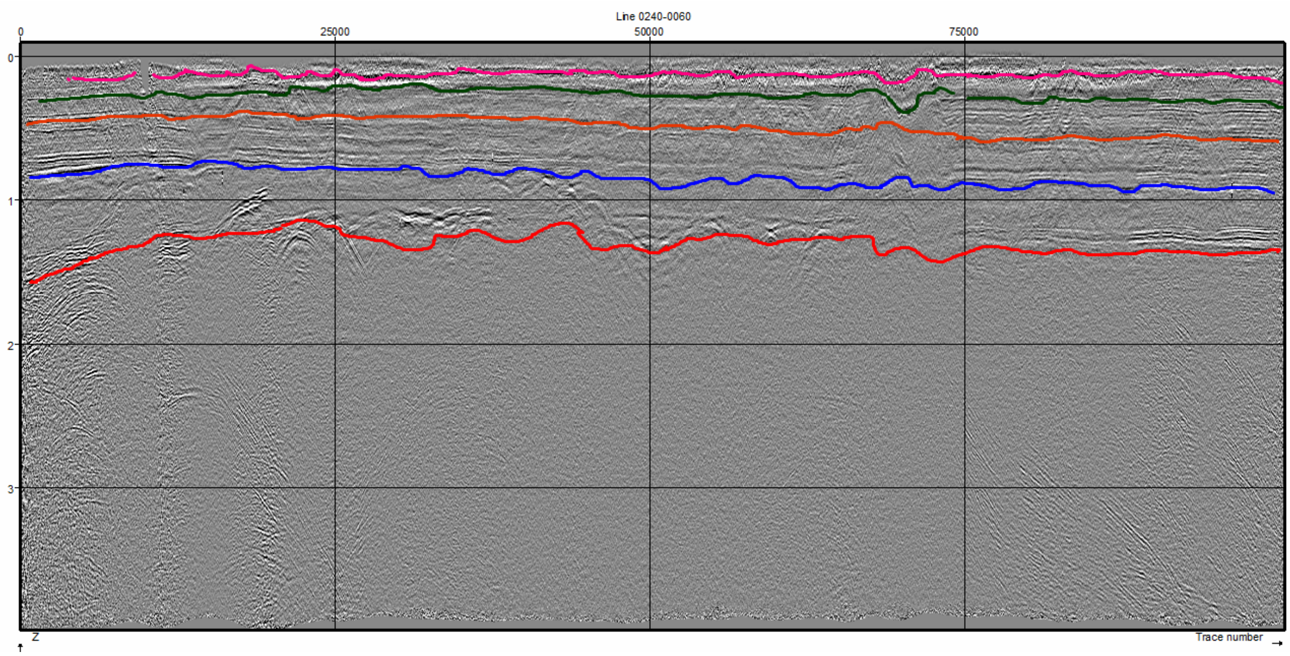

Figure 3: Seismic line 0240-0060 (in seconds) coincident with the MT1 profile. The colorful horizons indicate the interpretation of main seismic reflections.

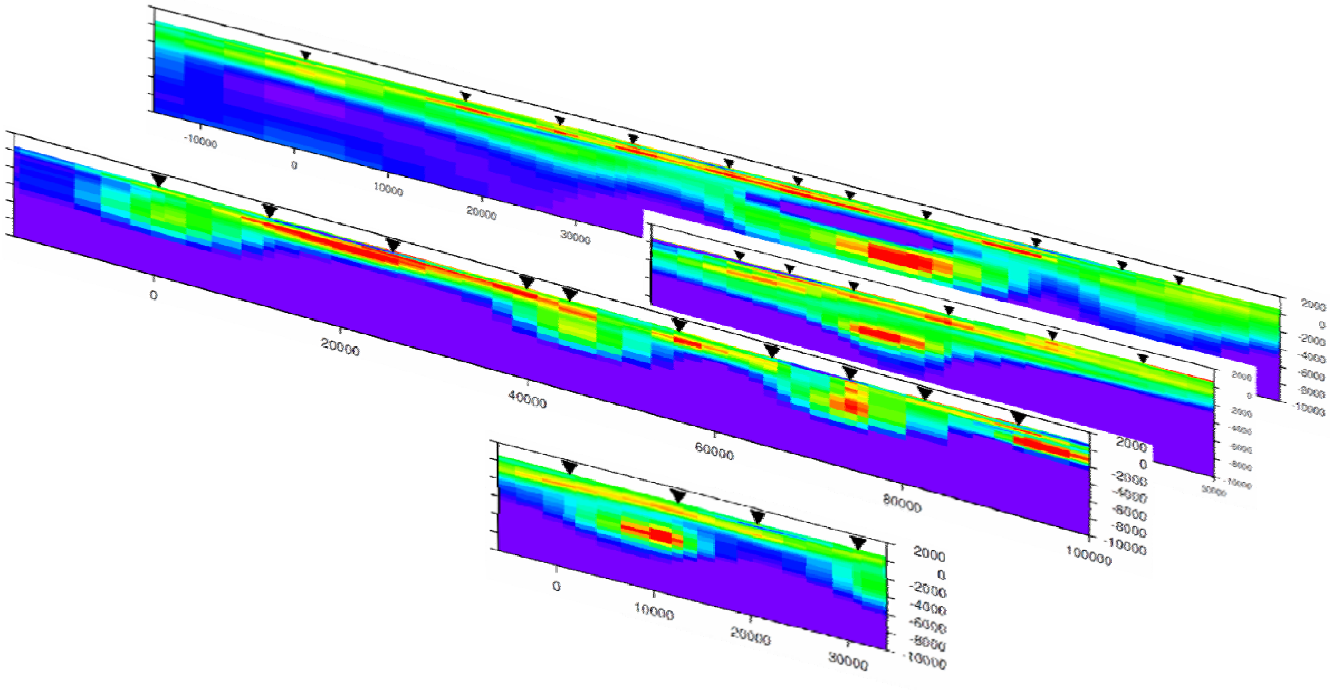

Figure 4: 2-D inversion results for MT profiles 1, 2, 3 and 6 (back to front) from the Remanso do Fogo region, positioned geographically.

References

Braun, O. P. G.; Mello, U.; Della Piazza, H. Bacias Proterozóicas Brasileiras Com Perspectivas Exploratórias Para Hidrocarbonetos. In: Raja Gabaglia, G.P; E. (Coord.). *Origem E Evolução De Bacias Sedimentares*. Rio De Janeiro, Gávea;. Petrobras/Serec, P. 115-132:1990.

Egbert, G.D.; Eisel,M., Programs For Robust Single Station And Remote Reference Analysis Of Magnetotelluric Data: Unix (And Pc) Disponível Em: Www.Cg.Nrcan.Gc.Ca /Mtnet. 2000

Gamble, T.D.; Goubau, W.M.; Clarke, J. Magnetotellurics With A Remote Magnetic Reference. Geophysics, 44, P. 53-68, 1979.

Groom, R.W.; R.C. Bailey, Decomposition Of Magnetotelluric Impedance Tensors In The Presence Of Local Three-Dimensional Galvanic Distortion. J. Geophys. Res., 94b, P. 1913-1925. 1989.

Porsani, J.L., Estudo Magnetotelúrico Na Bacia Do São Francisco. Relatório Final I. Cenpes/Susep/Segef, 57p. 1993.

Porsani, J.L.; Fontes, S.L. O Método Magnetotelúrico Aplicado A Bacia Do São Francisco, Minas Gerais. Brasilian Jornal Of Geophysics, Vol. 19 (2), P. 145-154, 2001

Rodi, W., and Mackie, R.L., 2001. Nonlinear conjugate gradients algorithm for 2-D magnetotelluric inversion. Geophysics, vol 66, 1, 174-187