Shallow structures and electrical stratigraphy of the Pantanal basin, SW Brazil, using Audiomagnetotellurics

Shimeles Fisseha*, Naomi Ussami, IAG-USP, Brazil

Antonio L. Padiliha, Ícaro Vitorello, INPE, Brazil

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Abstract

We present results of audiomagnetotelluric (AMT) soundings carried out along a NE-SW profile traversing the Pantanal Wetland, SW Brazil. The Pantanal is a Quaternary sedimentary basin underlain by metasediments of the Neoproterozoic Paraguay fold-and-thrust belt. Twenty AMT stations, each containing 22 harmonic frequencies in the frequency range 1000 – 1 Hz, were acquired and inverted using a 2D-MT inversion algorithm to study shallow geoelectric structures within and beneath the wetland basin. The resulting 2D model shows good agreement with available information from seismic, gravity and borehole data. Important lateral variations in electrical conductivity within the sedimentary package are observed and are discussed in terms of lithostratigraphy and depositional history of the basin. The MT study in the audio frequency range has enabled to define a half -graben geometry for the basin which has not so far been outlined. Moreover, the positions of likely fault planes have been traced and correlated with independent geophysical and geological data.

Introduction

The Pantanal wetland is a 137,000 km^2 large alluvial plain in southwest Brazil, close to the borders of Bolivia and Paraguay (Fig. 1). Due to lack of chronostratigraphic details of the sediments in Pantanal depression; only limited lithologic description can be given. Unlithified sands are the dominant sediment type filling the basin. In the central portion, the following sequence is observed. At the bottom, fine to coarse sands with fragments of limestone eroded from the carbonate platform of the fold belt are dominant. These are overlain by medium to coarse sand with large content of fragments of ferruginous sandstone. The upper few meters of the sedimentary fill, as described byWeyler, (1962), are characterized by fine grained sediments (silt and mud). As seen from the surface, these sands are arranged in large fan shaped bodies, resembling alluvial fans, such as the Taquari fan. Normal faults are mostly observed on the western border of the basin. Sediments were deposited in a discordant manner over the metasediments and metamorphic rocks of the Paraguay belt and the Amazon craton. On the basis of geomorphologic evidence and fossil analysis, Almeida (1964) suggested the age as Plio-Pleistocene (~2.5 Ma) for the inception of the Pantanal depression. The eastern and northeastern boarders of the Pantanal basin are formed by metasediments of the Cuiabá group and outcrops of granitic rocks along narrow belts, which are covered by Paleozoic sediments of the Paraná basin. The northern and southern boundaries are marked by rocks from the Upper Proterozoic Paraguay belt (Alvarenga et al., 2000). The Amolar and Aguapei ridges, which are parts of the Amazon/Rio Apa craton, delineate the western and northwestern borders of the basin, respectively.

Ussami, et al. (1999) discussed the role of fore bulges in producing uplift and flexural extension in the brittle upper crust which mechanically reactivated the basement which is composed mostly of the Neoproterozoic Paraguay fold/thrust belt. Their work integrated results of two-dimensional flexural modeling of deformation and associated bending stresses with geological, drill-hole and geophysical gravity and seismic data available to that date.

The natural-source audiomagnetotelluric (AMT) method is an attractive option to study the Pantanal basin due to its ability to image conductive structures within the sedimentary cover and the resistive basement from about tens of meters to a few kilometers. This study describes the results of an AMT survey across the whole Pantanal depression, giving new information on shallow structures and electrical stratigraphy of the sedimentary package.

AMT data, Pantanal

Twenty AMT stations (Figure 1), each containing 22 frequencies in the range 1000 – 1 Hz were collected using a commercial GMS06 broad-band MT system (Matzander, 2001). The responses in this frequency range were generally of good quality in terms of error bars and scattering. At the majority of the stations, the data above 1000 Hz were of inferior quality and can not be used due to the a well-known problem in AMT soundings (the “AMT dead band”; Garcia and Jones, 2002).

Estimation of the transfer functions (TF) for the Pantanal data set was done using programs for robust single station and remote reference analysis (Egbert and Eisel, 1998). Removal of surficial distortion effects from the estimated impedances and determination of the regional strike (N6°W) were undertaken using the methods of McNeice and Jones (2000). Finally, regional impedances in the TE- and TM – mode estimates were inverted jointly using the REBOCC inversion code (Siriprunvarapron and Egbert, 2000). This inversion approach seeks the minimum structure subjected to a desired misfit level, which is the root mean square misfit between the data and the model.

Results and Discussions

Figure 2 shows typical observed data from Pantanal region, together with the smooth model response curves fitting the observations reasonably. The modeled responses are generated by the 2D model shown in Figure 3, which was generated by the joint (TE- and TM-mode) inversion of the AMT data set.

The resistivity stratification is correlated with the prevailing geology as follows:

(1) the topmost, low resistivity (5 – 150 Ω-m), corresponds to the unconsolidated Cenozoic sediments of the Pantanal formation with a gradational increase in resistivity both from west to east and from bottom to top;

(2) on either flanks of the profile, the high resistivity blocks (> 1000 Ω-m), is attributed to basement rocks;

(3) in the middle, the vast region of intermediate, wide range resistivity (100 – 1000Ω-m) represents the Neoproterozoic sedimentary and metasedimentary rocks of the Paraguay fold/trust belt.

From this geoelectrical model, the Pantanal exhibits an asymmetric geometry half graben with west ward polarity. The maximum basin depth reaches as deep as 800 m at some localized depression, such as beneath station 03 positioned close to the Paraguay River. Wide separations between sounding stations limited detailed mapping of the sediment/basement contact. Nevertheless, a depth variation between 200 m and 500 m was observed from the edges to the middle of the depression. In general terms, the joint 2D inversion model shows good agreement with available information from seismic, gravity and borehole data. Important lateral variations in electrical conductivity within the sedimentary package are observed and are discussed here in terms of lithostratigraphy and possible structures in the shallow parts of the basin.

The indications of possible fault planes were basically interpreted from the inversion model, where the low resistivity responses extend down to the basement rocks. The low resistive responses within the basement could be due to either the conductive sediments filling the down throw side of the proposed faults or the effects of week zones along the basement surface, giving rise to anomalous conductive signature comparable to the overlying basin fill sediments. Such interpretation must be regarded with caution if based only on the available AMT data because of the large distance between the stations. However, additional information from the seismic section (Figure 4; Catto, 1975) and gravity modeling (Konzen, 2003) provided supporting evidence for the presence of possible structural weakness around those points. It can be noted that the seismic line runs parallel to the north of the AMT profile.

Figure 5 shows a composite, interpreted section of the basin fill sediments and shallow basement rocks. It was sketched based mainly on the 2D model resulting from the inversion of AMT data and 1D inversion of individual soundings. The faults in this model were proposed by Ussami et al. (1999) and thought to provide a possible mechanism for the inset of the young sedimentary basin through reactivation due to flexural extension caused by the sub-Andean foreland peripheral bulges.

Concerning the lithologic variations, the most visible information is the lateral variation in resistivity on the upper part of the basin (Figure 3) which could likely be attributed to the variation in the origin and transport mechanism of sediments during the course of deposition. According to Ussami et al. (1999), this phenomenon is closely related to the mechanism in which the movement of the bulge from west to east changed the erosional and depositional pattern in Pantanal. At the initial stage of deposition, sands with limestone fragments resulting from the erosion of the western carbonate platform, started to fill the depression. This pattern was gradually changed to sands with ferruginous sandstone, either from erosion of the Tertiary arid climate deposits or the Paleozoic/Mesozoic sediments of the Paraná basin in the east.

The same reasoning can be used to explain the variation with depth. In this case, the bottom sequence contains fragments of calcareous rocks from the west where the top sequence is dominated by erosion from the east (Figure 4). Hence, the observed low resistivity response of the inversion model, which is dominant at the western flank and the bottom portion of the basin, is attributed to the clay rich sediments of carbonate origin. The relatively resistive eastern flank and top sediments are thought to be caused by coarse grained ferruginous sand.

Conclusions

Although there were a seismic profile and scattered bore-hole log sections in the Pantanal region, the geometry of the basin has not been so far clearly outlined. This study has provided information on the depth variation of geoelectrical structures and has enabled us to image the asymmetric half graben sedimentary fill depression. In spite of being poorly constrained by the available data, the positions of likely fault planes within the sedimentary basin are considered to be one of the main findings of this AMT study. This result is also supported by additional seismic and gravity data.

Apart from confirming the basic hypothesis on the driving mechanism of the young basin, reactivation of pre-existing faults within the Neoproterozoic Paraguay fold/thrust belt during recent (Quaternary) uplifting, the detection of these faults may shade light on the recent speculation of neotectonic activity in the central flood plain of the alluvial fan (Konzen, 2003). The lithostratigraphic variations within Pantanal is reflected as geoelectric response variation and interpreted in terms of differences in material origin and erosion pattern related to the eastward migration of the peripheral bulge during inception of the basin and sediment deposition.

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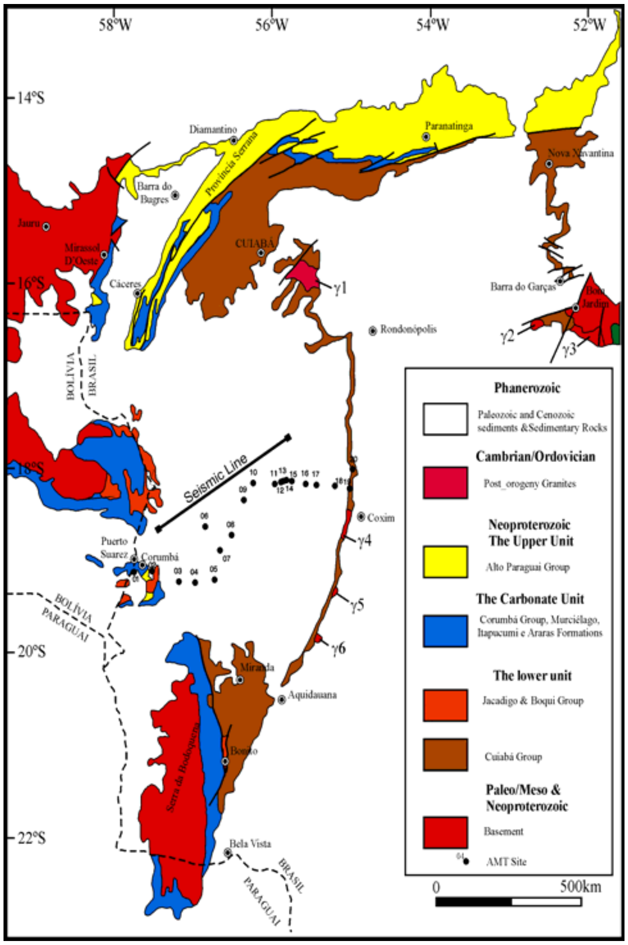

Figure 1. Geologic map of the Pantanal basin and the surrounding Precambrian terranes with location of the AMT sites (map partially modified from Alvarenga et al., 2000).

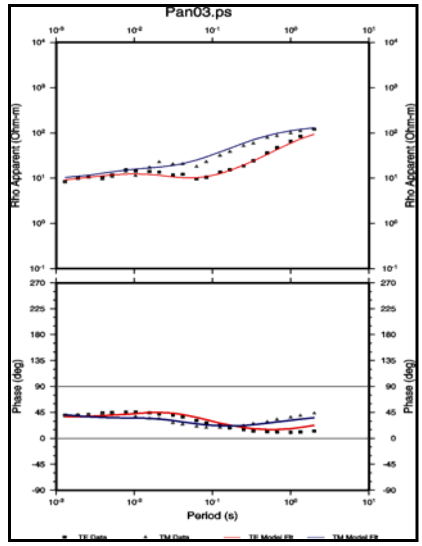

Figure 2. AMT typical basin response curves showing apparent resistivity (top) and phase (bottom) data. Colored solid lines show a theoretical response of the 2D model.

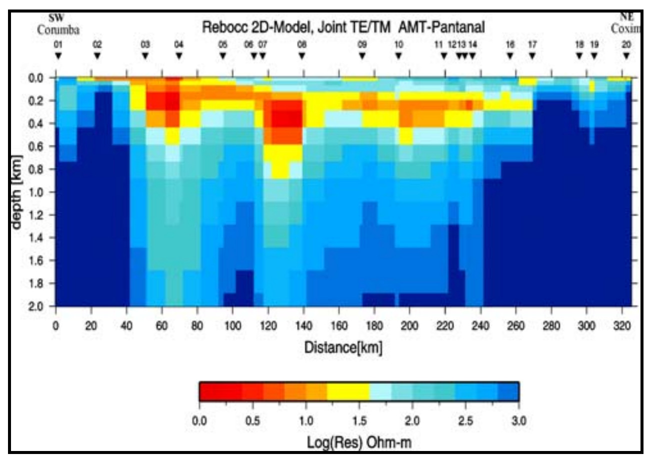

Figure 3. 2D model resulted from joint TE and TM inversion.

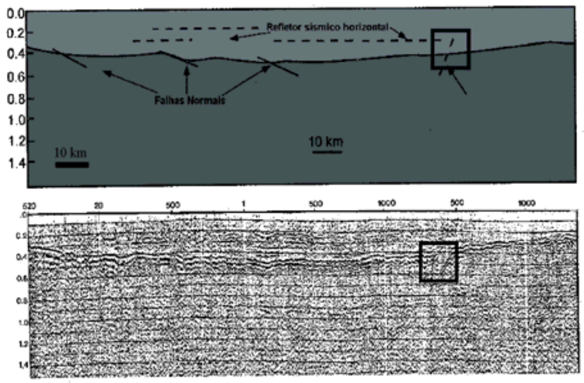

Figure 4 Interpreted seismic section from central Pantanal (modified from Catto, 1975).

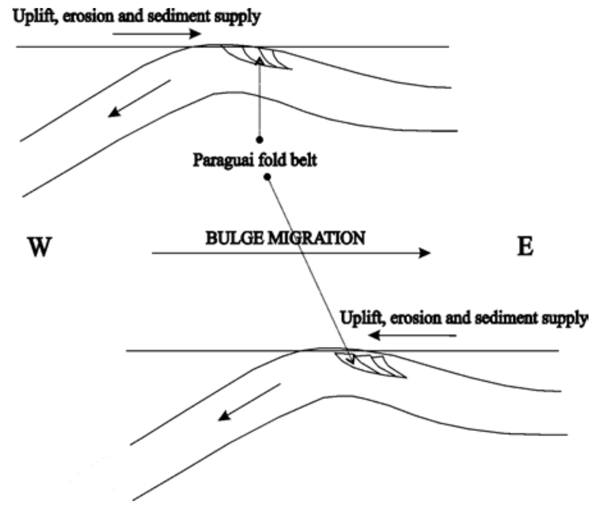

Figure 6. Schematic representations of the bulge migration and sediment transport during basin fill (modified from Ussami et al., 1999).

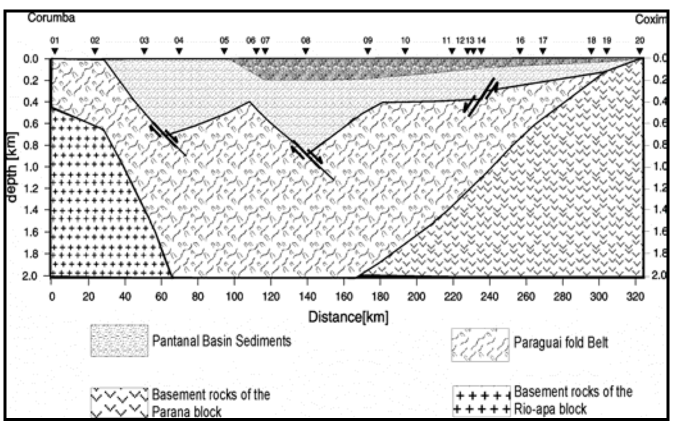

Figure 5. Interpreted section of the Pantanal basin and its basement rocks.