Geoelectric Dimensionality of a magnetotelluric (MT) survey in Parecis Basin, Brazil.

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Abstract

A survey of eighty-eight broadband (0001-1000s) magnetotelluric (MT) sounding stations was deployed in a transect from Parecis Basin, Brazil, in a direction almost perpendicular to the dominant structural lineament. An image of the subsurface conductivity distribution was obtained from the 2-D inversion of MT data, linked to well logging resistivity data. In a first time, we assumed previously a 2-D dimensionality for the inversion procedure, using as geoelectric "strike" an angle of 140^0 ($\pm$ 15 ^{0}) clockwise with respect to the geographic north. This is the direction of the dominant regional structural lineaments shown by the elongated geometry of the basin and by the lineaments revealed in the aeromagnetic data. In a second time, we went to check the consistency between the direction previously adopted for the 2D inversion and the intrinsic directionality deduced from rotational properties of the tensor impedance through a procedure of decomposition (McNeice and Jones, 2001), where we retrieve the geoelectric regional direction for a set of 36 MT soundings in the profile. The results show that the distribution of angles is not uniform as it would be expected but that the direction previously assumed is perfectly compatible with the trend of the mean directions calculated for the "strike. " This result shows that in the presence of indications of the directions of structural lineaments, it is not necessary to proceed the decomposition of tensor impedance.

Introduction

Parecis' Basin, one of the Brazilian intracratonic basins, is located in the center-west Region, covering an area of about 400.000 km^2 in States of Mato Grosso and Rondônia, Brazil (Fig. 1). Presently, Parecis' Basin is almost entirely covered by airborne (magnetics and gravity) and terrestrial (gravity) geophysical surveys. Recently, we perform a very long magnetotelluric (MT) sounding profile crossing the Basin in the direction almost N-S. It was assumed a 2-D dimensionality condition with a geoelectric strike suggested by the magnetic trend exhibited by the aeromagnetic surveys (Fig.2). The 2-D inversion of the MT profile was performed using a routine developed by Rodi and Mackie (2001) which finds regularized solutions (Tikhonov regularization) to the two-dimensional inverse problem for MT data using the method of nonlinear conjugate gradients. The forward model simulations were computed using finite difference equations generated by network analogs to Maxwell's equations. The algorithm inverts for a user-defined 2D mesh of resistivity blocks, extending laterally and downwards beyond the central detailed zone, and incorporating topography (Fig.3). This inversion procedure was constrained by using well-logging resistivity data (exploratory well 2-SM-1-MT).

Method

The magnetotelluric (MT) method uses natural EM fields measured at Earth's surface to estimates the subsurface electrical resistivity. Amplitude, phase and directional relations between the electric field E and the magnetic induction **H** are connected by the 2x2 response impedance tensor $\underline{\mathbf{Z}}$, $\mathbf{E} = \underline{\mathbf{Z}} \cdot \mathbf{H}$ Actual measurements of **E** and **H** are noisy so $\mathbf{E} = \underline{\mathbf{Z}} \cdot \mathbf{H} + \varepsilon$. $\underline{\mathbf{Z}}$ is estimated by robust methods from the recorded time series of **E** and **H** in the Fourier domain:

$$\left\langle \underline{\mathbf{Z}}(\omega) \right\rangle = \left\langle \mathbf{E}(\omega)\mathbf{H}(\omega)^{\mathsf{T}} \right\rangle \left\langle \left(\mathbf{H}(\omega)\mathbf{H}(\omega)^{\mathsf{T}}\right)^{-1} \right\rangle \quad (1)$$

where **T** is the Hermitian transpose and the quantities in brackets are cross- and auto-powers of **E** and **H**, respectively. The 2-D dimensionality condition (i.e. the presence of geoelectric strike) is described by the rotational properties of the impedance tensor

$$\underline{\mathbf{Z}}_{\mathbf{obs}}(\theta_0) = \mathbf{R}(\theta_0)\,\underline{\mathbf{Z}}_{\mathbf{2D}}\mathbf{R}^{\mathsf{T}}(\theta_0) = \begin{pmatrix} \cos\theta_0 & -\sin\theta_0 \\ \sin\theta_0 & \cos\theta_0 \end{pmatrix} \begin{pmatrix} 0 & Z_{xy} \\ Z_{yx} & 0 \end{pmatrix} \begin{pmatrix} \cos\theta_0 & \sin\theta_0 \\ -\sin\theta_0 & \cos\theta_0 \end{pmatrix} \quad (2)$$

where $\underline{\mathbf{Z}}_{obs}$ is the observed impedance at the sounding station, **R** is a rotation tensor and $\mathbf{Z}_{2D}$ is the impedance rotated to the strike direction θ_0 measured from the geographic north. The corresponding field rotations are given by

$$\begin{cases} B_x(\theta) = Z_{xy}H_y(\theta), & \text{TE mode} \\ B_y(\theta) = Z_{yx}H_x(\theta), & \text{TM mode} \end{cases} \quad (3)$$

The strike direction θ_0 can be found by differentiating **Z** with respect to θ in order to give an angle θ_0 which maximizes or minimizes $\left|\mathbf{Z}'_{xy}(\theta_0)\right|^2 + \left|\mathbf{Z}'_{yx}(\theta_0)\right|^2$ for all frequencies:

$$4\theta_0 = \tan^{-1}\frac{\left[(\mathbf{Z_{xx}}-\mathbf{Z_{yy}})(\mathbf{Z_{xy}}+Z_{yx})^* + (\mathbf{Z_{xx}}-\mathbf{Z_{yy}})^*(\mathbf{Z_{xy}}+\mathbf{Z_{yx}})\right]}{\left|\mathbf{Z_{xx}}-\mathbf{Z_{yy}}\right|^2 - \left|\mathbf{Z_{xy}}+\mathbf{Z_{yx}}\right|^2} \qquad (4)$$

This leaves four possible solutions or two strike directions with a $\pi/2$ ambiguity which can be solved from independent information (vertical magnetic data - tipper strike) or from geologic insights. The tipper is a MT quantity which depends on the vertical component of magnetic induction $\mathbf{H}_z$. This component is ≈ 0 except near lateral conductivity changes (2-D situations). The tipper **T** gives a relationship between $\mathbf{H}_z$ and the horizontal magnetic induction components: $\mathbf{H}_z=\mathbf{T}_x\mathbf{H}_x+\mathbf{T}_y\mathbf{H}_y$. For a 2-D structure with strike in the *x'* direction, in those coordinates, the tipper **T** reduces to $\mathbf{H}z=\mathbf{T}_{x'}\mathbf{H}_{x'}$(4a). This *x'* direction corresponds to the tipper strike angle (Vozoff, 1991).

Decomposition of MT impedance tensor.

A true 2-D conductive structure has an impedance tensor described by eq. (2). However, small local inhomogeneities will produce a galvanic, frequency independent, distortion of the regional telluric currents. In this case, the observed impedance tensor is written as

$$\mathbf{Z_{obs}} = \mathbf{RCZ_{2D}R^T} \qquad (5)$$

where **C** is a real telluric distortion tensor which can be factorized as a product of modified Pauli spin matrices:

$$\mathbf{C} = g\mathbf{TSA} \qquad (6)$$

g is a scaling factor ("site gain"), **T, S** and **A** are tensors, called *twist*, *shear* and *anisotropy*, respectively. The factor *g* and anisotropy **A** form together the indeterminable part of **C** which is absorbed into the regional impedance, $\mathbf{Z}_{regional}=g\mathbf{AZ}_{2D}$. The *twist* tensor, **T**, and the *shear* tensor, **S**, are the determinable parts of **C**. **T** rotates clockwise the electric field produced by $\mathbf{SAZ}_{2D}$ through the *twist* angle *atan*(*t*) and **S** develops anisotropy on an axis which bisects the regional induction principal axes, rotating a vector by the *shear* angle, *atan*(*e*). The observed impedance expressed with the Groom-Bailey (1989) factorization becomes

$$\mathbf{Z_{obs}}(\theta_0) = \mathbf{RTSZ}_{regional}\mathbf{R^T} = \begin{pmatrix}\cos\theta & -\sin\theta\\ \sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}1-te & e-t\\ e+t & 1+te\end{pmatrix} \times \begin{pmatrix}0 & A\\ -B & 0\end{pmatrix}\begin{pmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{pmatrix} \qquad (7)$$

Determination of the strike angle.

Following the above procedures, we have obtained frequency independent estimates of the *twist*, *shear* and regional *strike* for a set of 36 soundings stations from the MT profile using the *strike4.1* program of McNeice and Jones (2001, op.cit.). This can be done if these estimates can be found over a sufficiently wide band of frequencies. This is done by constraining iteratively the *twist*, *shear* and *strike* in order to find a frequency band where the misfit error is acceptable. We apply a four steps procedure: i) an unconstrained decomposition, were the distortion parameters were allowed to vary freely ($-45^o <$ *shear* $< 45^o$), ($-60^o <$ *twist* $<60^o$) and ($-360^o <$*strike*$< 360^o$); ii) we constrain the *twist* angle to its median value for a representative frequency range and we repeat the decomposition procedure; iii) the *twist* constrained data shows generally an improved stability in *shear*, then we constrain the *shear* angle at its median value over a representative frequency range and we repeat the decomposition procedure; iv) if the *twist* and *shear* constrained data results in a stability in *strike* angle over a representative period range, now we constrain the *strike* angle at its median value and we repeat the decomposition procedure, obtaining, finally, individual *strike* angles for each MT station. An example plot of (a) unconstrained, (b) shear constrained, (c) twist constrained and (d) fully constrained distortion parameters of the impedance tensor for the sounding station MT-22. is shown in Fig.4. The strike angles obtained for each of the MT stations and the corresponding rose diagram with the angle distribution are shown schematically in Fig. 5 and Fig.6.

Discussion and conclusions.

The determination of regional strike in the presence of noise and galvanic distortion can leads to instability in decomposition procedures. This occurs for the sounding stations 02mt46, 02mt61, 03mt12 and 02mt15 when the decomposition analysis failed because the shear angles were very near to $\pm 45^o$. In these cases the decomposition models becomes underdetermined. In order to recover the regional impedances, we use the strike found in adjacent stations or other independent information (like geological strike). The inherent $\pi/2$ ambiguity of the strike determination (Eq.4) was solved by using the tipper strike (Eq.4a). For most soundings, the average period range adopted as representative of stability in strike angle was 0.05 – 10 sec. The behavior of strike angle along the profile is not uniform as expected. In a first time, we assumed a previous geometric dimensionality for the 2-D inversion procedure, using for the direction of the geoelectric "strike" an angle of 140^0 ($\pm$ 15 ^{0}) clockwise with respect to the geographic north. This is the direction of the dominant regional structural lineaments indicated by the elongated geometry of the basin and the lineaments revealed by the aeromagnetic data. The decomposition of tensor impedance show that the distribution of angles is not uniform as it would be expected but that the direction previously assumed is perfectly compatible with the trend of the mean directions calculated for the "strike. " This result shows that in the presence of clear indications of the directions of structural lineaments, it is not necessary to proceed the decomposition of tensor impedance.

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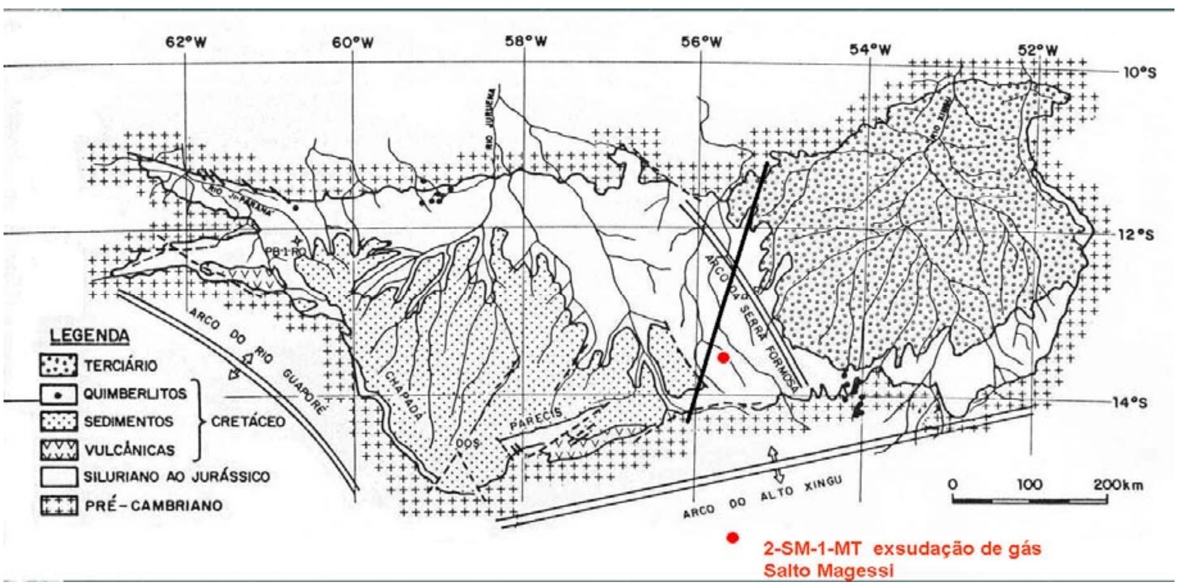

Fig. 1. Geological map of Parecis Basin (simplified from Siqueira, 1989)

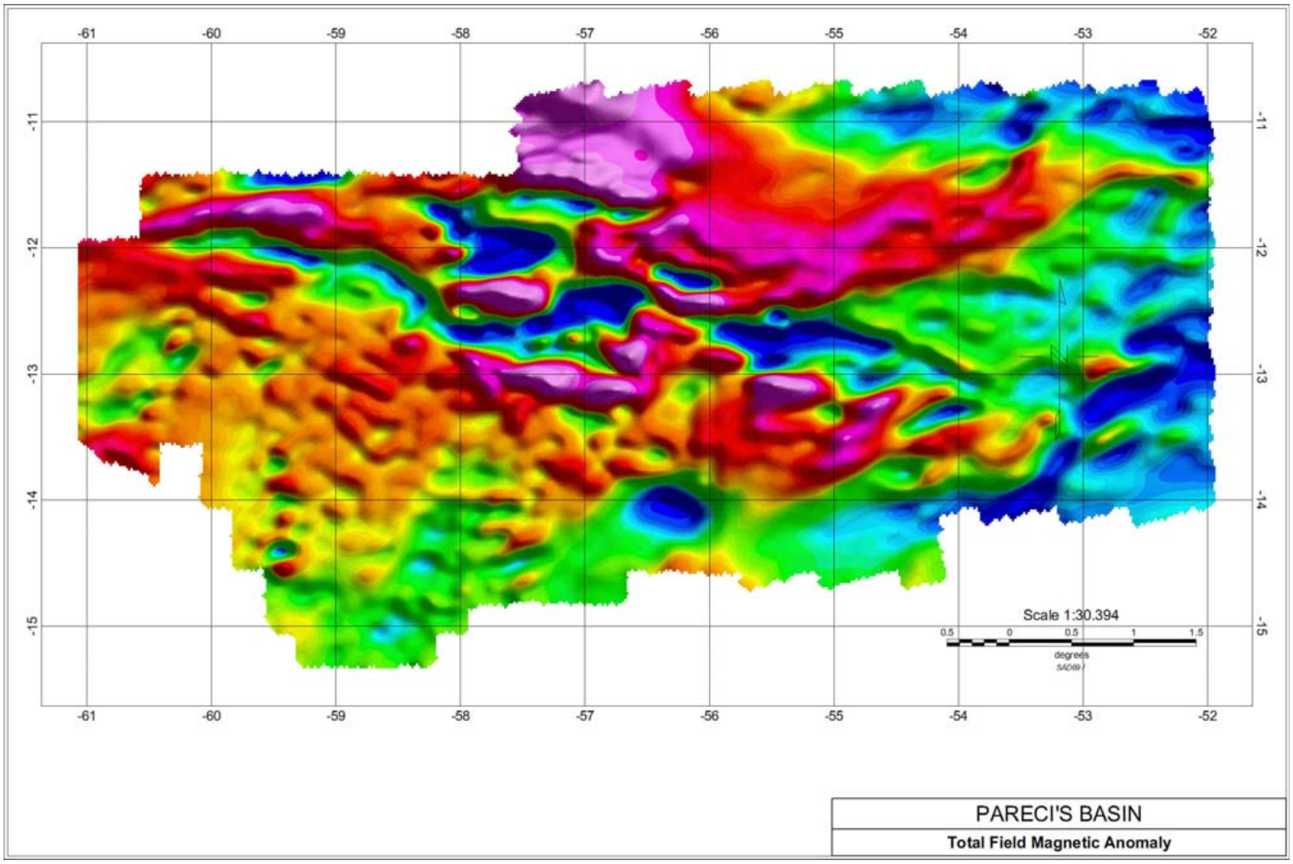

Fig. 2. The trend of the total field magnetic anomaly map suggest a geological strike in a direction (~E40^{o} – 50^{o}S). This direction was used to rotates the MT impedance tensors for the 2-D inversion (fig.3).

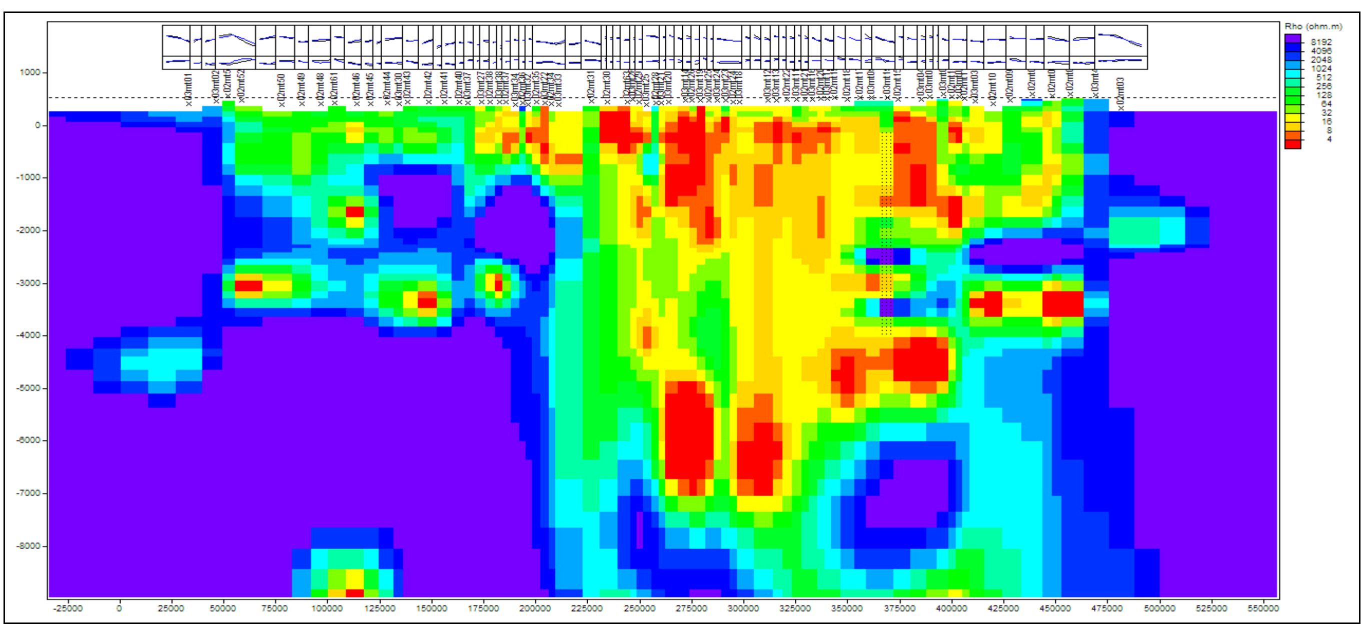

Fig 3. 2-D inversion of MT data of the Pareci's Basin profile (Flexor and Fontes, 2004)

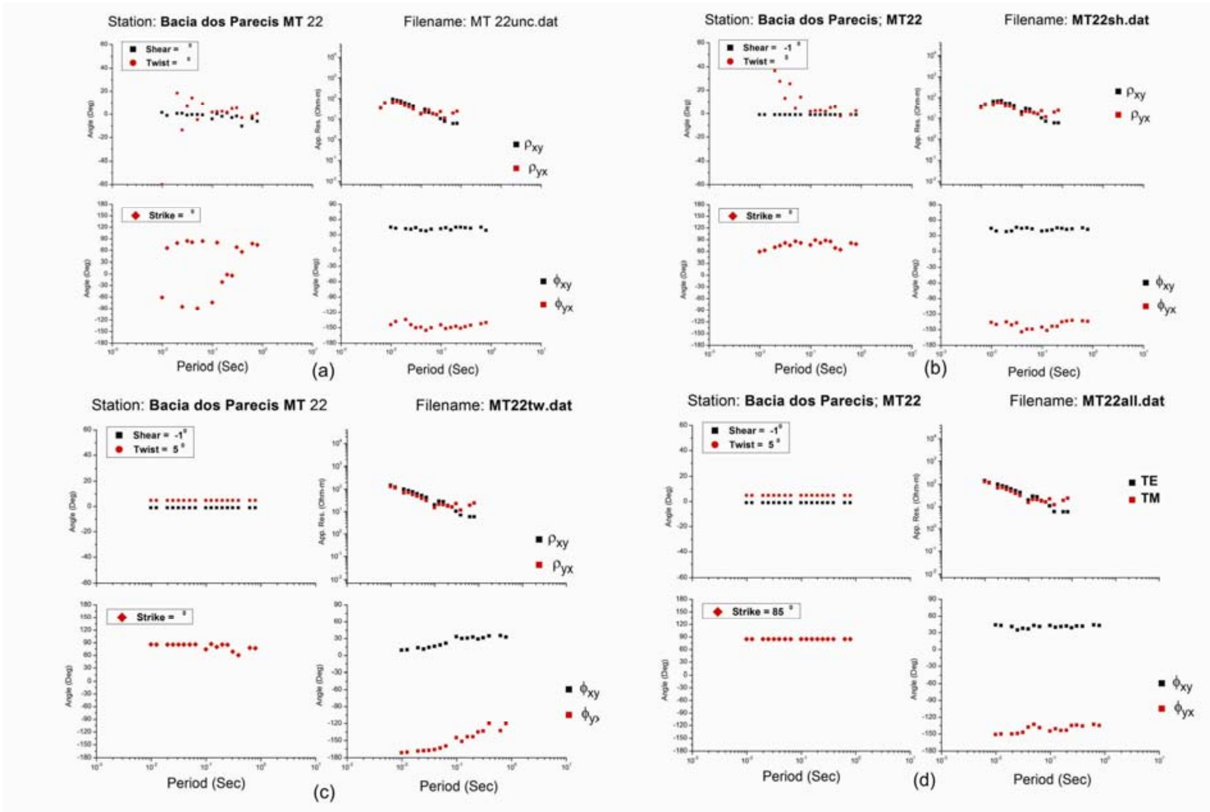

Fig. 4 An example plot of (a) unconstrained, (b) shear constrained, (c) twist constrained and (d) fully constrained distortion parameters of the impedance tensor for the sounding station MT-22.

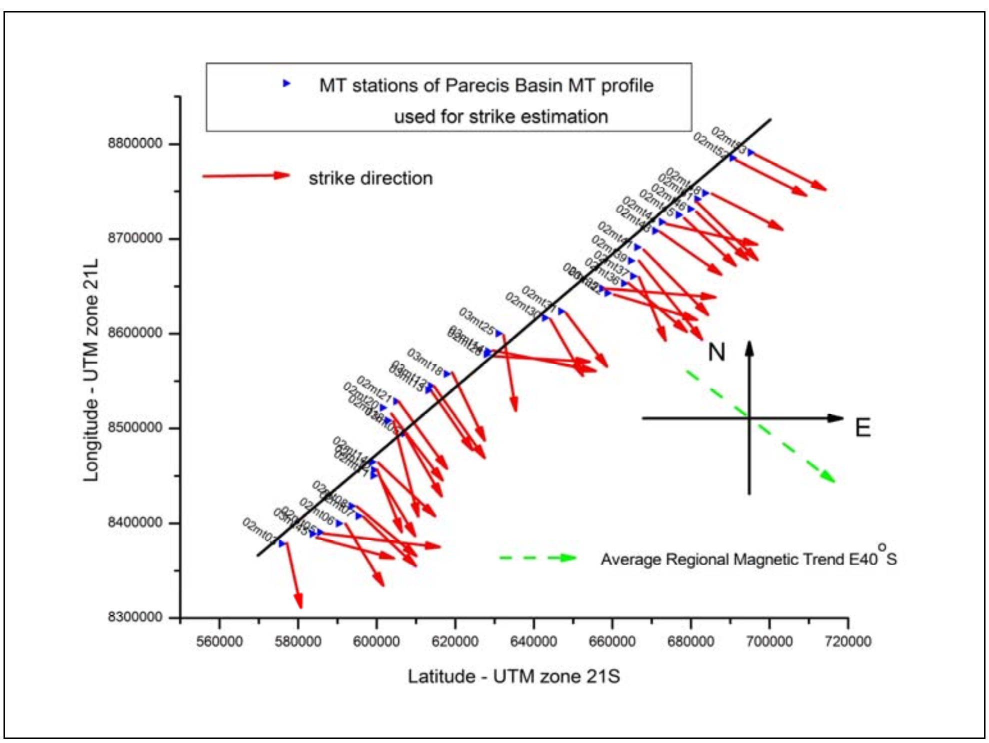

Fig.5. Geoelectric strike directions (red arrows) estimated at selected sounding stations of Parecis Basin MT profile

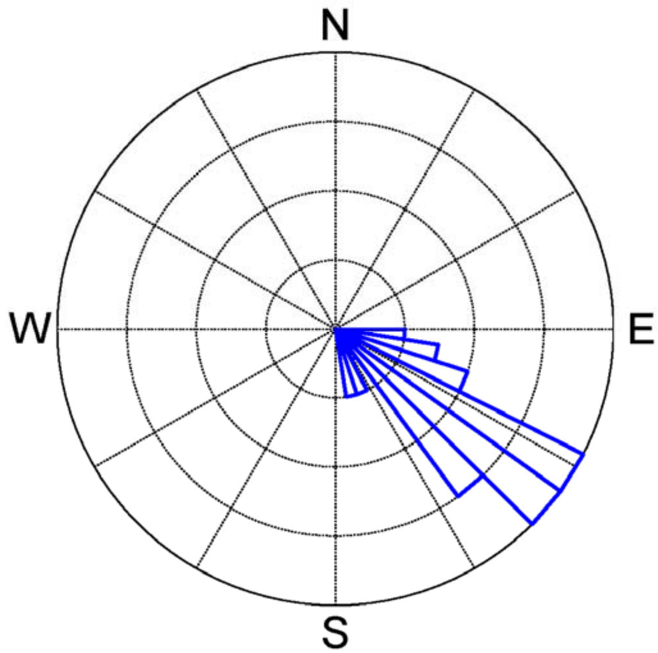

Fig.6 Rose diagram of the estimated geoelectric strike angles, showing the coherence with the *a priori* geological strike used for the 2-D inversion of MT data.