Introduction

The 5-component measurements of the Earth's natural alternating electromagnetic field (E_x, E_y, H_x, H_y, H_z) are currently used extensively for mining exploration by implementing two methods simultaneously: the Audiomagnetotellurics Method (AMT), measuring 4 horizontal components (E_x, E_y, H_x, H_y) [Berdichevsky M. N., Dmitriev VI, 2009], and the Magnetovariational Profiling Method (MVP), measuring 3 orthogonal magnetic components (H_x, H_y, H_z) [Rokityansky, 1982]. The AMT-MVP method's scope of application makes the development of methods of robust parameter assessment of conductive anomalous bodies important for rapid correction to the direction of field survey and the assignment of the borehole coordinates [Ingerov I., 2011., Ingerov O. et all., 2008, 2009]. For two-dimensional bodies, effective express interpretation techniques have been proposed in the following publications: Rokityansky, II, l982., Ermolin E., et all., 2011., Ingerov O., Ermolin E., 2010., Ingerov O., et all., 2013. These allow to quickly identify the main parameters of the 2-D body (cross-sectional shape of the body, the total longitudinal conductivity of the body's cross-section (G), depth (H), etc.), based on the frequency response and the tipper's pseudo-section.

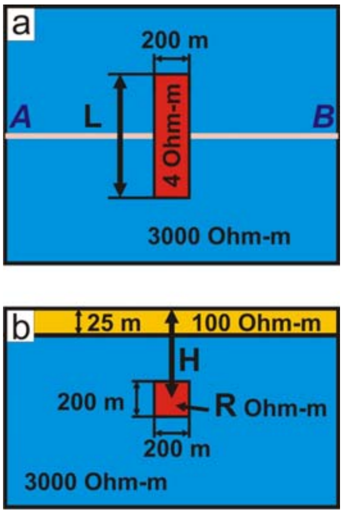

***Figure 1**. The base 3-D geoelectrical model. a– map, b – AB cross-section.*

It makes sense to develop similar methods for finite bodies (which are closer to reality), and to define sound boundaries of application for certain formulas and graphical correlation. Taking advantage of MVP parameters becomes even more important since responses of 3-D bodies appear very weak in the AMT data. For example, the 3-D 200×200m×200m body, which differs from the host medium 1000 times in resistance and is located at a 300m depth, is almost not visible in the AMT parameters (within the accuracy limits), both in the resistivity data and its phase. In order to find a solution for outlined problems, authors performed a significant amount of 3-D modeling using WingGlink software.

Modelling

The basic model is provided in Fig.1. It is a body with a square cross-section with a side being a = 200 m, situated at the depth (H), which takes on the value of 100m - 1000m. The body's resistance (R_o) is 4 Ω, and the body itself is placed in high resistivity medium of 3000 Ω. The upper layer is 25m, with resistance of 100 Ω, which simulates a weathered rock layer, thus creating some shielding effect. The main variable is the length of the body (L), which varies in the latitudinal range from 200m (isometric 3-D body) to 200,000m (two-dimensional body with isometric cross-section). The calculations of the response functions for AMT (resistance and phase) and the MVP (real induction vector, the amplitude (magnitude) and phase of the tipper), have been performed in a wide frequency range from 0.01 to 10,000 Hz for a sets of profiles (Figure 2, 3), situated orthogonally to the anomalous body, both crossing the body and extending beyond. Sufficiently thin steps (40 m) along the profiles have been used.

Modelling results

Figure 2a shows a map of the tipper phase calculated for a cube with the side of 200m (L/a = 1) and with the center located at a 300m depth. Such a body is not noticeable in the AMT parameters, but abrupt changes in polarity along a line could be seen in the tipper phase, which is passing through the center of the body. Figure 2b shows the map of the amplitude of the tipper for an elongated body (quasi-2-D, L/a is equal to 25). The figure shows that the maximum anomaly is observed near the center of the elongated body and the amplitude of the anomaly decays rapidly toward the edges.

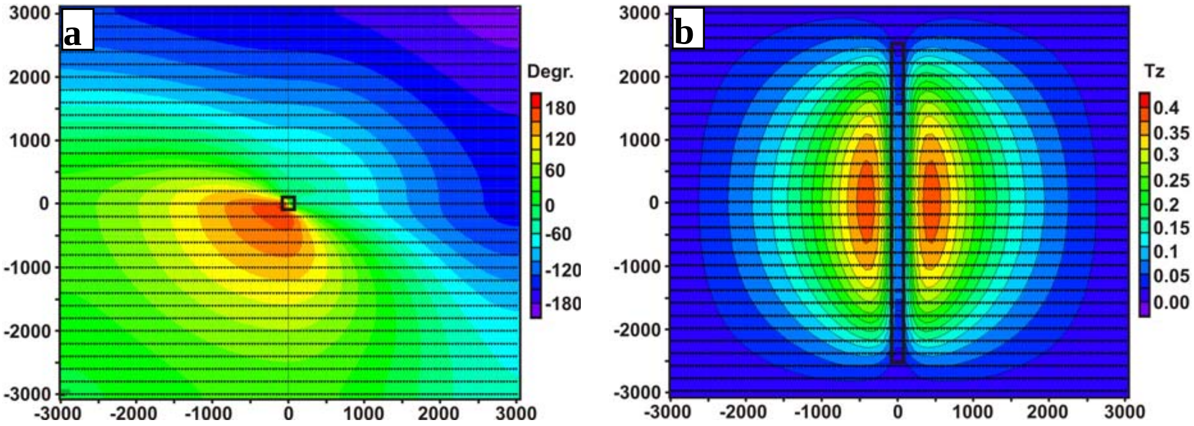

Figure 2. *Map of values: a - tipper phase for 0.0012 sec (L = a = 200 m, H = 300 m, R = 4 Ohm-m); b - tipper amplitude for 0.011 sec. (L = 5000 m, a = 200 m, H = 300 m, R = 4). Projection of the anomalous body is shown in black outline.*

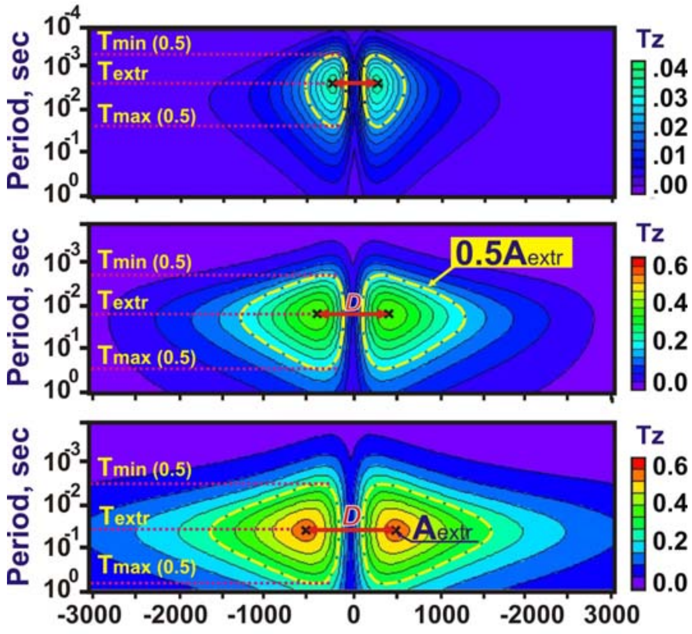

Figure 3*. Tipper cross-section for three 3-D models. R = 4 Ohm-m, H = 300 m are constant, but L is variable (a – 740 m, b – 5000 m, c – 20 000 m).*

The effect of the body's relative length on the tipper anomalies

Isometric bodies create symmetrical tipper anomalies. Thus, the value of the tipper above the body is equal to zero. In order to estimate the parameters of anomalous 2-D objects in previous works, authors have used easily recognizable character data points on tipper cross-sections: the distance between the two maxima (D); maxima's period (Textr); amplitude of the maxima (Aextr) and the characteristic data points on the isometric lines with the value of 0.5 from Aextr.

As was expected, for bodies close to 3-D, the amplitude of the response in both the AMT and the MVP functions is drastically decreasing. As shown in Figure 3, when the relative body length (L/a) is changing, the amplitude varies significantly (the shorter the length is, the smaller the amplitude of the anomaly and its frequency band is shifted to higher frequencies). Also, the shape of the anomaly changes (anomaly becomes narrower with decreasing L/a).

Patterns described above allow us to offer a methodology for assessing the value of the relative body length (L/a), which is based on the shape of the tipper amplitude anomaly. For this purpose, the coordinates of the data point intersects of the tipper amplitude isometric lines with the value of 0.5 Textr are used, where vertical lines are passing through the anomalies maxima (Figure 3,4). Further, parameter P = (Textr / Tmin) (Tmax / Textr) is calculated. Parameter P graph is shown in Figure 4. On the left side of the graph (values L/a = 1-5), a horizontal asymptote at P = 0.33 (3-D section) is observed. On the plot of L/a = 5-100, an ascending curve is observed, where the values of P are naturally increasing to 0.68 (quasi 2-D). It is followed by a horizontal asymptote at 0.7, which corresponds to the 2-D case.

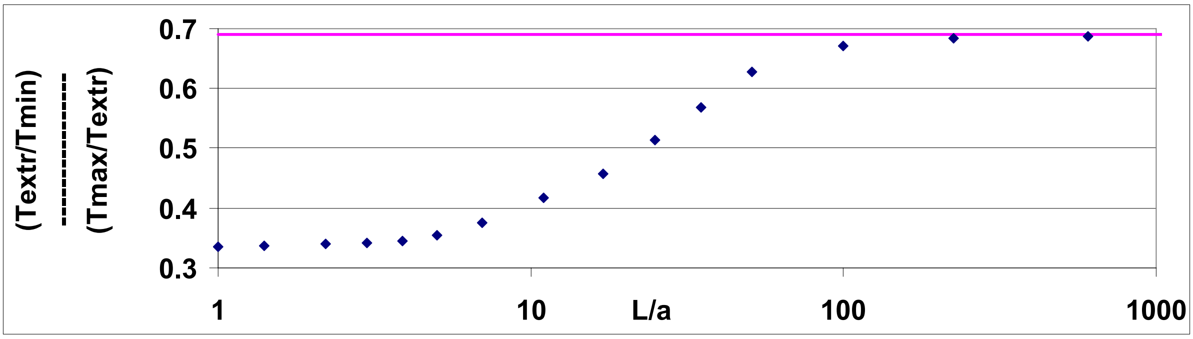

Figure 4. *Proportional correlation of the characteristic periods (P-parameter) on the isometric line 0.5 from Aextr to the relative length (L / a). P volume for 2-D case is shown by line.*

The effect of the relative length of the body on the value of the anomalies

Graphs of proportional correlation of the characteristic values on the tipper cross-sections (Textr, Aextr, D, H) are shown in Figures 5a, 5b, 5c, 5d. In general, a reduction of the L value (i.e., an increase of three-dimensionality) leads to a significant weakening of the anomalous effect on the tipper frequency characteristics and changes the anomaly's shape.

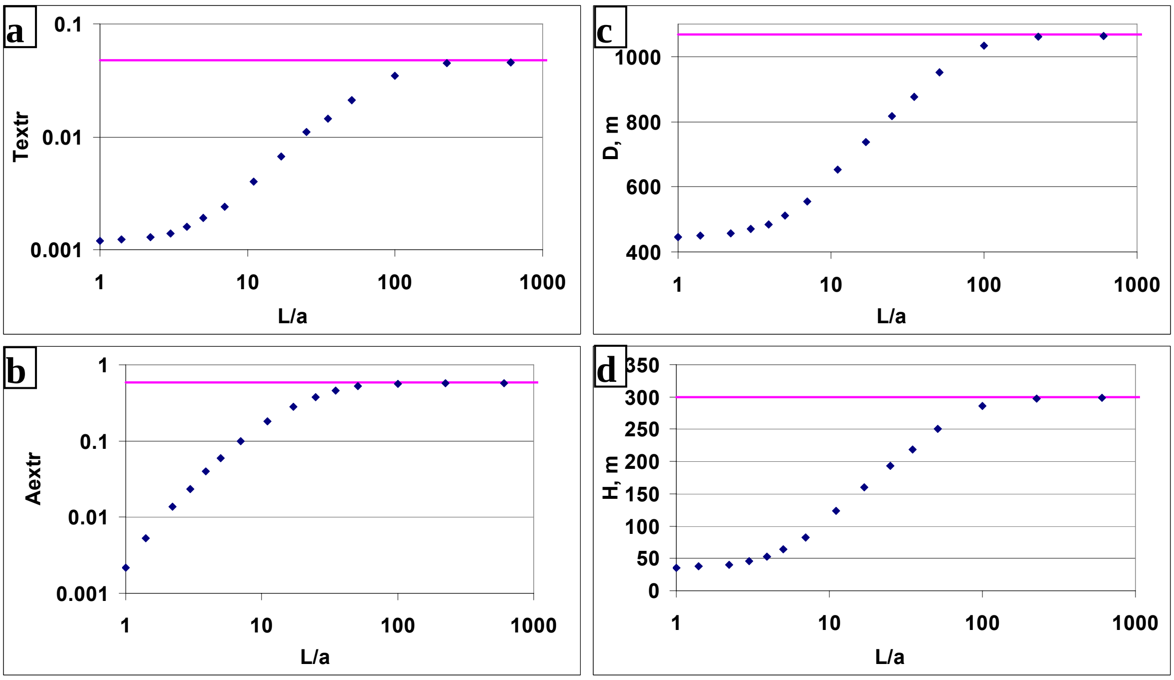

Figure 5. *Proportional correlation of the characteristic values on the tipper cross-sections: Textr (a), Aextr (b), D (c) and calculated depth of the body (d) to the values of L/a. Assessment of the body's center depth using the formula for the 2-D case (d). Line shows the values for the 2-D case.*

In the shape shown in Figure 5a, 5c, plots are mostly similar to the correlation shown in Figure 4. With the values of L/a < 10 (pure 3-D situation) it has a close to sub-horizontal curve. Another sub-horizontal curve is observed at L/a> 100 (2-D case). These two sub-horizontal curves are connected by a steep ascending curve. The Textr and Aextr values on the tipper cross-sections, depending on the L/a parameter, vary by the order of two in the magnitude (100 times). The Aextr parameter (Fig. 5b), in contrast to other graphs, is continuously descending with a decreasing value of L. Authors have carried out the calculations to determine the depth of the 3-D anomalous object's center for the results of 3-D modeling from the bodies with different values of L/a. Figure 5d shows the results of H calculation using the derived formula for 2-D bodies [Ingerov O., Ermolin E., 2010.]:

$$H = 0.42 \cdot D + 150 \quad (1)$$

For values of L/a that are less than 100, the calculated depth will be significantly understated.

The methodology for determining parameters of anomalous bodies (3-D and quasi 2-D) using tipper frequency response

The same procedures as described for 2-D bodies [2,6,8] can be applied. However, two operations must be added:
- The calculation of the P parameter and then a determination of the relative length L/a of the body using the graph (Fig. 4);
- The determination and implementation of corrections based on the L/a value (the correction factors can be entered in both observed functions and calculated parameters using the graphs shown in Figure 5).

Conclusions

For 3-D and quasi 2-D bodies, tipper anomalies are observed and could be used to determine the parameters of bodies. In this case, anomalies will be substantially smaller in amplitude when compared to the 2-D case.

The amplitude of the anomalies greatly depends on the relative length of the body.
It is expedient to determine the parameters in the following sequence:
- Determine the value of L/a;
- Define the parameters of the body using 2-D dependencies;
- Implement corrections for L/a value, using the dependencies proposed by the authors.

Since the anomalies of MVP parameters for 3-D and quasi 2-D conductive bodies are much weaker in amplitude, during the course of the field survey, the accuracy of the magnetic sensors alignment to respective axis's and the maintainance of their temperature stability is crucial.

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