MTS and MVP data integration to estimate the 2D anomaly bodies parameters situated away from measuring profile

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SUMMARY

When using MT and AMT in regional investigations or reconnaissance surveys in exploration areas, it is common practice to measure the vertical magnetic component (Hz) of the natural electromagnetic (EM) field.

The magnetovariational profiling (MVP) method combines the MT and AMT horizontal magnetic (Hx, Hy) data with Hz data to produce information about prospective anomalous bodies located below as well as outside the measuring profile. Induction vectors calculated from this data can help to locate the position of prospective apparent resistivity anomalies. However, questions remain as to the size, depth (to centre or top), and total conductivity of the anomalous body. MVP can estimate these parameters.

The total conductance (G) of the body can be estimated from the frequency (f_{max}) of tipper maximum magnitude. Greater depth and/or distance from the observation profile reduces the anomaly's amplitude without affecting the frequency of the maximum. Additionally, some graphical and analytical procedures can be used to estimate G as well as the distance L of the body's epicentre from the profile and the depth H to the top of the body.

Keywords: Natural EM-fied, tipper, 2D bodies situated away profile.

INTRODUCTION

MVP is practical because of the latest developments in 5thgeneration MT-AMT equipment. Precision tripods for magnetic induction sensors make it possible to install the sensors orthogonally in rocky or frozen ground or on steep slopes. The MVP functions obtained (tipper, induction vectors, and their components) provide rich information about horizontal inhomogeneities in the subsurface conductivity distribution with high accuracy in very different climate and surface conditions (Ingerov et al., 2009). In the magnetotelluric method, four horizontal components of the earth's naturally varying electromagnetic field are measured: two magnetic components (Hx, Hy) and two electrical components (Ex, Ey). The MT and MVP methods are realized simultaneously by measuring in addition the vertical magnetic component (Hz) (Berdichevsky, 2008; Jones, 1981; Rokityansky, 1975 and others). Figure 1a shows the 5-component scheme of MT/MVP station installation. Figure 1b shows a typically installed tripod containing magnetic sensors.

The MVP method was well developed by Parkinson (1959), Wiese (1965), Schmucker (1970), Rokityansky (1975), Berdichevsky and Dmitriev (2008), Vozoff (1991), Jones (1981) and others. The response functions in the MVP method are real and imaginary induction arrows, tipper amplitude and phase. Tipper is

$$T = \sqrt{\left(\frac{Hz}{Hx}\right)^2 + \left(\frac{Hz}{Hy}\right)^2}$$

The relationship of significant features of induction vector components with parameters of the body, and the method to estimate the total conductance G of the body (from the horizontal magnetic component orthogonal to the body), were established by Rokityansky (1975).

Ingerov and Ermolin (2010) conducted research into the case of a profile orthogonal to a 2D anomalous body. They investigated the relationships between the parameters of 2D anomalous bodies with different types of cross-sections and the co-ordinates of significant points of the tipper magnitude pseudosections: f (the frequency of positive extrema), d (the horizontal distance between positive extrema), and T (the relative magnitude of the anomaly).

In the present paper, the authors use the same functions to estimate the parameters of a 2D anomalous body situated outside and parallel to a single MT-MVP profile. The study used WinGLink™ software to model different distances L and depths (H) to the top of the anomalous body.

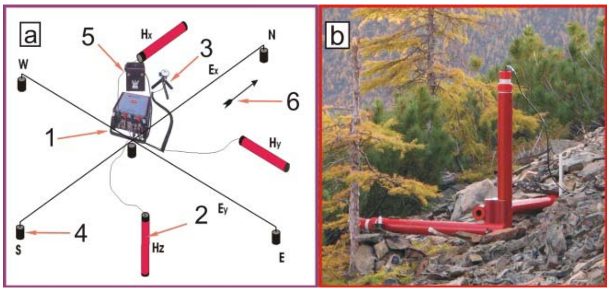

Figure 1. The scheme of MTS/MVP station installation. (a) Site layout for measurements: (1) 5-component (2E + 3H) receiver, (2) magnetic sensor, (3) GPS receiver, (4) nonpolarizing electrode, (5) battery, (6) azimuth of E channels. (b) Magnetic sensors installed in precision tripod.

METHOD AND MODELING

In this study, the authors estimate the parameters of a long, 2D conductive body with isometric section, located parallel to the MT-MVP profile at distance L and depth H (Figure 2). Distance L is greater than the depth H to the top of the body and the size of the side of the isometric section (Figure 2b). The presence of this conductor produces a corresponding negative extreme on the MT amplitude curves (the induction effect, Berdichevsky M.N. and Dmitriev V.I., (2008)). The depth H to the top of the body can be estimated from the TE-mode MT curves by the simple H asymptote method (Rokityansky, 1975). However, it remains unknown whether the conductor is situated below the profile or on either side. If it is to the side, the MT curves can give an estimate of only the total distance to the top of the conductor, R:

$$R = \sqrt{H^2 + L^2} \qquad (2)$$

Consider the case of the large conductive body with squarecross-section located outside the profile, as shown in Figure 2 (not drawn to scale).

The long-period MT parameters at many measurement stations will characterize a 2D geoelectric situation. The MT polar diagrams will be of essentially a single shape: the primary impedances will be ovals and the secondary impedances will have four symmetrical lobes. Although the possibility of a 2D interpretation is demonstrated, an inversion based on this data would not be correct. If we add MVP data to the analysis, as a first step we can easily establish the position of the body relative to the profile, because induction arrows in the Parkinson convention point toward the conductor (Parkinson, 1959; Figure 2 (a, 3)). As a second step, an analysis of the tipper magnitude spectra (Figure 2c) and pseudosection can be performed. Rokityansky (1975) presented a frequency graph showing that the maximum horizontal magnetic component transverse to the conductive body or the vertical component (Hz) depend upon the conductance G of the anomalous body cross-section. In Ingerov and Ermolin's work (2010) it was shown that the conductance G of a body section can be calculated from tmax in the tipper magnitude pseudosection using the formula:

$$G = 2 \cdot 10^5 / f_{\max} \qquad (3)$$

where f_{max} (or $1/T_{max}$) is the frequency of the maximum of the tipper section.

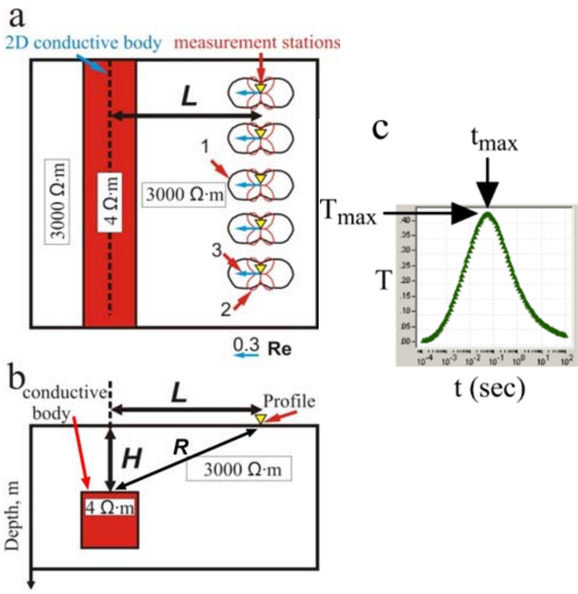

Figure 2. (a, b) Geoelectrical model (not to scale) of 2D conductive body (section 200 x 200 m). (a) Plan view (1) amplitude of primary impedance in magnetotelluric polar diagrams for period 0.06 seconds; (2) amplitude of additional impedances; (3) induction arrows for period 0.06 seconds in Parkinson convention (pointing toward conductor). L is the distance from the measurement station to the centre of the conductive body (1000 m). (b) Section along line L. H is the depth to the top of the body (400 m). (c) Tipper magnitude (T) spectrum; note that at any station on the profile, Tmax = 0.41 in this spectrum.

Figure 3 shows vertical pseudosections of tipper magnitude along a profile orthogonal to a 2D anomalous body. Three different depths to the top of the body are shown: 125 m, 325 m, and 725 m (a–c, respectively). The conductance G of the section of the body is the same in each case. Figure 3 shows that the frequency (or period) of the tipper maximum is the same for any station on the profile, but that magnitude decreases significantly with increasing H and increasing distance L of the MVP site from the epicentre of the body. The maximum is seen in each tipper pseudosection, and the value of fmax is the same for every station. This fact allows estimation of G for an anomalous body with isometric section from any station at any distance away from the body as long as the tipper anomaly is still of reasonable magnitude.

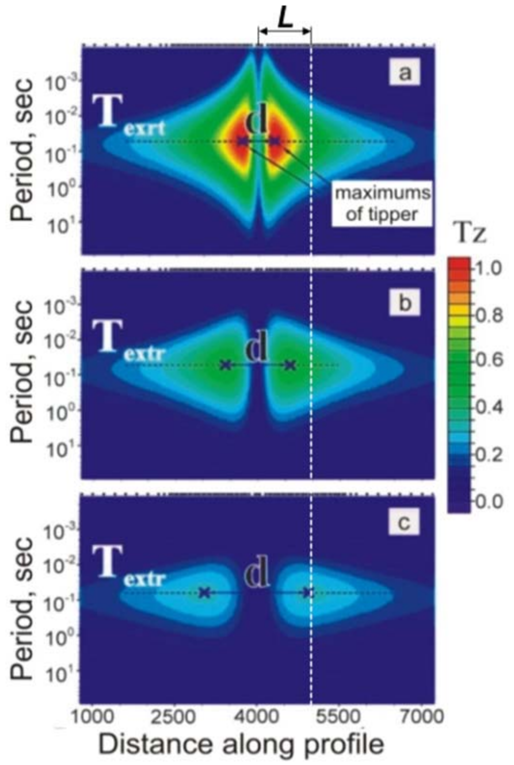

Figure 3. Vertical pseudosections of tipper magnitude constructed for three 2D models with the same value of the total conductance (G) and different values for the depth of the upper edge of the anomalous conductor. (a) 125 m, (b) 325 m, (c) 725 m (Ingerov and Ermolin, 2010).

Now, on a profile that is parallel to the strike of a conductive body, we don't have a full picture as in Figure 3, but at every site we have a tipper magnitude spectrum similar to Figure 3c. The magnitude of the tipper maximum depends on parameters G, H, and L, but the abscissa of the maximum (fmax or tmax) is dependent on parameter G only. So we can use the ordinate of the tipper maximum to obtain H and L, if we know R. If we know R, equation 1 has two unknown parameters, so we have to use additional information to determine the two unknowns.

These additional data we can get from MT. From MT TEmode curves (Berdichevsky, 1968; Rokityansky, 1975), we can determine the distance R to the top of the conductive body, which contains parameters L and H (depth to the top of body) according to equation (1).

To obtain H and L separately, the authors undertook 3D modeling using WinGLink™ software. We used the base model shown in Figure 1 with varying H and L and constant G as for Figure 1a. This procedure was repeated for several different values of G as well. As a result of the modelling, we have several different tables (one for each G value). Each table has three columns: T (tipper), L, and H. Every table therefore shows tipper T as a function of L and H. This function can be shown graphically as a map of contour lines, a map of curves, or a surface map.
The authors used Surfer™ 8 software to create the surface map shown in Figure 4.

In Figure 4 we have a surface with coordinates T, L and H; G is fixed at the value for the model of Figure 2 (10 000 Sm•m). This surface has a positive structure in T which decreases with increasing L and H values. Although not shown, it is obvious that with increasing G, the T magnitude also increases, so every G value will produce a different surface.

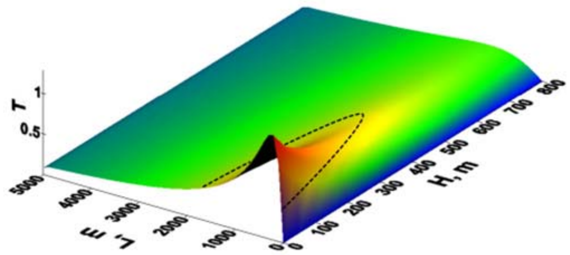

Figure 4. Dependence of tipper magnitude maxima T on parameters H and L (parameter G is fixed at 10 000 Sm•m, as in the model of Figure 2). The dashed line represents the intersection of the horizontal slice at T = 0.41 with the surface.

For the parameters of the conductive body and profile position that are shown in Figure 2, where L = 1000 m and H = 400 m, the tipper maximum (Figure 2c) is Tmax = 0.41. In the Surfer software, we can make a horizontal slice at the level T = 0.41 to obtain the function L = F(H) where T = 0.41. The graphic of the function L = F(H) where G = 10 000 Sm•m and T = 0.41 is shown in Figure 5(1).

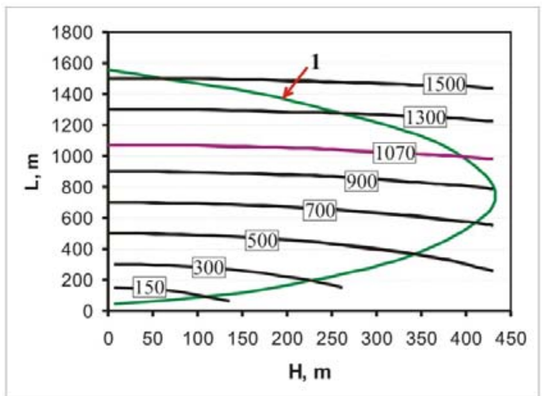

Figure 5. Two types of function overlapped in the same coordinates: (1) L = F(H) for constant G and Tmax (G = 10 000 Sm•m and T_{max} = 0.41), derived from the horizontal slice of Figure 4. The curves of the second type are nomograms of the function $L = \sqrt{R^2 - H^2}$, with the values of R shown in the rectangles.

It is reasonable to overlap the graph obtained from the slice with nomograms of the parameter L as a function of R and H expressed by:

$$L = \sqrt{R^2 - H^2} \qquad (4)$$

The nomograms are the subhorizontal curves that intersect the graph of function F in Figure 5. If we obtain R from MT curve interpretation, we can find the value of L and H from the co-ordinates of the intersection of the corresponding nomogram and the graph of function F (Figure 5(1)). As seen in Figure 5, we can achieve a reasonable estimate of the parameters of the conductive body, which can be used in practice.

RESULTS

On the basis of 2D modelling, two ways of estimating the parameters of a conductive 2D body situated outside of and parallel to the measurement profile are possible: graphical and analytical. The graphical method herein described of finding the depth (H) and distance (L) to the top of an anomalous conductive 2D body with isometric section situated away from the measurement station and parallel to it can be summarized as follows:

1. The map of induction arrows is analyzed to estimate the direction to the conductive body.

2. The Tmax and fmax are defined from the tipper magnitude spectrum at one of the MT-MVP sites. The conductance (G) of the section of the anomalous body is defined by equation 2 using the frequency (f_{max}) of the tipper maxima (T_{max}). The R parameter is defined from the magnetotelluric TE curve.

3. On the basis of 2D modelling, a graph of the function L = F(H) for the evaluated G and Tmax is constructed in the same co-ordinates as nomograms of $L = \sqrt{R^2 - H^2}$ labelled by R value.

4. The depth (H) and distance (L) of the conductive body are determined from the intersection of the function F and the nomogram of the evaluated value of R. Thus, by using only the MT TE amplitude spectrum and the tipper magnitude spectrum from a measurement profile situated parallel to and at a distance from an anomalous 2D body with isometric cross-section, all the parameters of interest (G, H, L, and R) can be estimated.

CONCLUSIONS

1. Five-component MT measurements have significant advantages for interpretation.The MVP method can detect a 2D conductor situated outside the MT-MVP profile and can determine from real induction vectors on which side of the profile the conductor is situated.

2. From the frequency of the tipper magnitude pseudosection maxima, the total conductance of the conductive body section can be estimated using graphical or analytical relationships between G and tipper magnitude maxima.

3. The distance to L the conductor epicenter, the depth H to the top of the conductor, and conductance G can be estimated by interpreting MT/MVP spectra and by using graphs and nomograms as shown herein.

4. Enough information may be available to decide if the conductor could be considered as a target for additional detailed exploration.

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