Mapping of thin conductive dikes and veins overlaid by sediments using methods of Audio Magnetotellurics (AMT) and Magnetovariational Profiling (MVP)

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Summary

The magnetovariational profiling (MVP) method in the high frequency variant (AMT range or higher) has a potential for significant advantages when compared to commonly used electromagnetic techniques (EM) for mining exploration. The MVP method has become cost effective, very sensitive and highly productive in recent years due to the introduction of portable receivers, compact induction magnetic sensors and precision field tripods for quick and very accurate installation of magnetic sensors on any terrain and in any climate conditions.

The method can be successfully applied even for such difficult tasks as mapping of the conductive dikes and veins covered with sediments and having thickness 10 times more than the horizontal thickness of the dike or a vein. Furthermore, the MVP method can reliably identify the position of every individual dike or vein in cases where the distance between them is 2-4 times greater than the thickness of the overlaying sediments.

The quick MVP interpretation technique is based on the use of tipper amplitude frequency characteristic's significant point coordinates and allows one to set drilling targets the next day after acquiring data. MVP can be used simultaneously with AMT or by itself in difficult terrain and ground conditions.

Introduction

Mapping of the steeply dipping geological structures (dikes, veins, faults) has traditionally been done by resistivity methods. These methods work efficiently at low power (1-3m) overburden and normal grounding conditions for the electrodes. But the efficiency of the resistivity methods is significantly reduced under difficult grounding conditions and/or thicker overlaying sediments. In these circumstances, the application of non-grounded electromagnetic (EM) methods is preferred. One of such methods, well-known for more than 50years, is the method of MVP. The method was created in the middle of previous century and was used mainly for regional and deep crust investigations due to the low frequency range of the existing at that time magnetic sensors. Since the introduction at the turn of the 21st century of portable wide band EM data loggers, compact induction magnetic field sensors, and precision field tripods for quick and accurate magnetic sensor installation in a wide variety of terrain and climate conditions, MVP can now be used for mining exploration and geological mapping applications. Other main advantages of the method are high sensitivity, productivity, small field crew size, and significant reduction of field work costs.

In MVP, only 3 orthogonal components of alternative natural magnetic field are measured (one vertical and two horizontal) (Rokityansky, 1975, 1982; Berdichevsky and Dmitriev, 2008). Therefore, electrode grounding for the data acquisition site is no longer required. Induction sensors, installed in the precision field tripods, not only significantly increase the field productivity and accuracy of the data acquisition, but also allow one to carry out very detailed field survey with the site spacing as low as 0.5 m (Ingerov et al., 2008, Ingerov O. et al., 2009).

MVP response functions are the tipper and the induction vector, as well as their components (Rokityansky, 1975, 1982; Berdichevsky and Dmitriev, 2008). It was shown that the coordinates of the significant points at frequency characteristic of these functions allow quick conductive body parameter estimation (Rokityansky, 1975). The technique was proposed in several papers (Ingerov and Ermolin, 2010; Ermolin et al., 2011) for estimation of the main parameters of various 2-D bodies. This technique is based on using coordinates of the significant points at the tipper amplitude pseudosection.

In the current paper, authors try to examine the sensitivity and interpretation accuracy of the AMT and MVP methods for mapping of thin (1m thickness), relatively conductive (resistivity - 6 Ohm·m), vertical and sloping bodies. The vertical thickness of the dikes is 200m. Bodies are located in the relatively high resistive medium (resistivity - 3.000 Ohm·m). Dikes do not extend to the subsurface of the bedrock (the top of the bodies is two meters below the subsurface of bedrock). Besides, bedrock is covered by the mid resistive sediments with 10 meter thickness and 100 Ohm·m resistivity. These 12 meter overlaid rocks shadow the response from the thin veins and dikes for many geological and geophysical methods.

Modeling procedure

All modelling was carried out with industry standard software package. Spacing between AMT-MVP sites was

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1m, frequency range 100,000 - 10 Hz. The frequency density was 14 frequencies per octave.

In **Figure 1**, the upper part shows only a 2D model for which response function calculations were done. First model is the single vertical dike with the parameter described above. Conductance of the dike body section is 33.3 Sm×m. Second model is the combination of three dikes situated 15m apart. In the third model, dikes are situated 40m apart. The second row (**a1-a3**) in **Figure 1** shows the pseudosections of the calculated tipper amplitude at the frequency range of 100, 000 – 100 Hz. The third row (**b1-b3**) shows the tipper phase at the same frequency range. The fourth row (**c1-c3**) shows the amplitude of the TE mode apparent resistivity. The fifth row is the phase of the TE mode impedance.

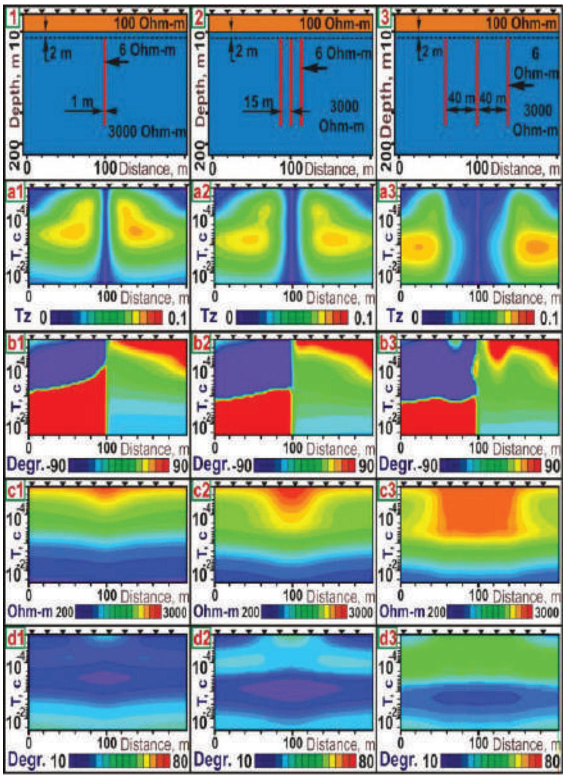

Figure 1. Geoelectrical model (windows 1, 2, 3) and sections Tipper (windows: a1, a2, a3), phase Tipper (windows: b1, b2, b3), the apparent resistivity (windows: c1, c2, c3) and the phase impedance (windows: d1, d2, d3) of the longitudinal component of the Magnetotelluric data.

In **Figure 2**, the first row represents three other models. The first row shows the single sloped dike model. Second row shows the model of the three dikes spaced 40m apart at the top and with common root at certain depth. Third model has the same top part, but in contrast from the previous, it has a common sloping root. In the second (**a1-a3**) and third rows (**b1-b3**), calculated tipper amplitude and tipper phase for corresponding models are represented accordingly.

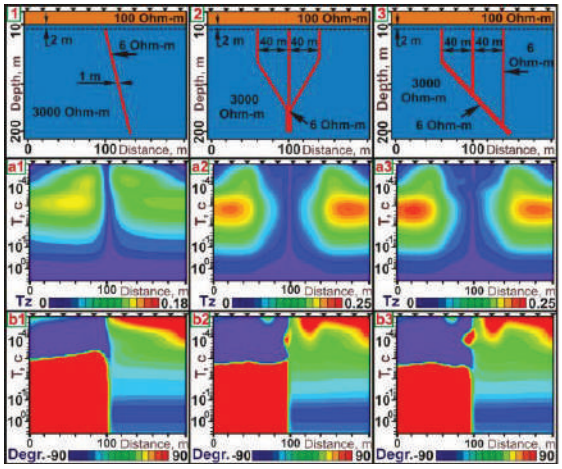

Figure 2. Geoelectrical model (windows 1, 2, 3), sections Tipper (windows: a1, a2, a3) and phase Tipper (windows: b1, b2, b3).

Results and discussion

The tipper amplitude anomaly for single dike is relatively small (less than 0.1), but enough to be detected by MVP, despite conductance of the dike section (33,3 Sm×m) being much bigger than the conductance of overlaid rock (0.1 Sm×m). The large thickness of overlaid rocks plays a more significant role. The position of single vertical dike can be easily detected by the amplitude of the tipper (two separated maxima with minima over the dike) and the phase (dramatic tipper 180 degree change over the dike) at the frequency range of 100,000 – 100 Hz. Total conductance of the anomalous body section can be estimated from the frequency of the tipper amplitude maxima at 3,000 Hz (**Figure 1, a1, b1**). The form of the tipper amplitude anomaly clearly represents the above anomaly of the conductive body, being much larger in the vertical dimension than in the horizontal (Ingerov O. et al., 2009). Another significant advantage of the tipper amplitude is the fact that we can detect presence of the anomalous body at MVP sites which are located at least 100m from the epicentre of the anomalous body. In the resistivity amplitude and phase section, the picture is not so optimistic. In the TE mode, the anomaly is very weak and disbursed In the TM mode - it cannot be seen at all. Therefore, for the thin single dike covered by overlaid rocks, MVP parameters do have significant advantage compared to AMT (**Figure 1**). In the case of three dikes

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located 15m apart, tipper maxima moves to the lower frequency due to the increase of total conductance of anomalous bodies. The area of the small tipper value becomes wider and the epicenter of this area, as well as the zones of the biggest tipper gradient, could show the rough position of every individual dike. There are also several changes at the phase pseudosection of the tipper but they are not as convincing as at amplitude. At the resistivity and phase pseudosections, the anomalies become brighter and wider. They can be detected but we can't definitely confirm the nature of the three anomalous objects in this case (**Figure 1, b**).

At the tipper amplitude pseudosection the signs of each anomalous body position (zone of high gradient at frequency range 100,000 - 1,000 Hz and minima above central dike) appear when the separation of three dikes reaches 40m. Some indications of anomalous body positions at the tipper phase pseudosection are present but using them is more difficult in comparison to the tipper amplitude. The resistivity pseudosection shows detectable anomaly with high gradient zone situated above the two dikes on both sides and the center of anomaly located above the central dike. (**Figure 1, a3, b3, c3, d3**).

In **Figure 2**, there are also three different models in the top row. The first model is a sloping dike. At the tipper amplitude pseudosection the direction of the slope is indicated by the direction of the minima between two maxima.

Another indication of the sloping direction is the relation of the tipper amplitude maxima values. The maxima from the sloping side is significantly less than the maxima from ascending side. Relation of the two maxima amplitudes can be used for the estimation of the sloping angle as was previously described (Ermolin at al., 2011). Position of the top part of the dike is indicated by minimum at the upper part of the tipper amplitude pseudosection. The tipper phase also shows the direction of the sloping dike, but it is not as convincing as the tipper amplitude (**Figure 2**, **1**, **a1**, **b1**).

In cases where three dikes are separated by 40m and have common central root at the position of central dike (**Figure 2, 1**), there are no significant variations at the tipper amplitude and phase pseudosections compared to cases of three separate dikes (**Figure 2, a2, b2**, **Figure 1, a3, b3**). There are only two features that are different: 1) the amplitude of the maxima at least doubles in value, and 2) the frequency of the maxima slightly decreases.

If dikes are 40m apart at the upper part of the cross section and have a common sloping root (**Figure 2, 3**), then the result is the same as mentioned above - the amplitude of the tipper maxima is increasing and maxima is shifting to a lower frequency. Also here we can easily identify the direction of the root sloping, indicated by a different value of the maxima at the tipper amplitude pseudosection, as well as the form of the minima between two maxima.

Therefore, as was described above, the MVP method in combination with AMT (5 channel, 2E+3H) or 3 channel (3H) MVP by itself can effectively detect and map thin veins and dikes covered by sediments. Experts from the National Mineral Resource University (St. Petersburg, Russia) have acquired substantial experience and positive results during the dike exploration in East Siberia, Russia. **Figure 3** shows an example of the detailed field survey with four 5-channel systems deployed.

Figure 3. Example of the detailed MVP survey in the East Siberia, Russia.

Conclusions

1. The high frequency variant of MVP method (AMT frequency range) can be a very effective tool for mining exploration due to high sensitivity, productivity and low cost.

2. MVP can solve thin veins and dike exploration tasks even in areas with sedimentary cover of 10m.

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3. MVP can reliably distinguish individual dikes when the distance between the dikes is 2-4 times greater than the sickness of the overlaying sediments.

4. Quick interpretation techniques based on the use coordinates of the significant points at the tipper amplitude pseudosection could be used to successfully and precisely identify drilling targets.

5. With the capability of MVP to detect remotely located anomalous bodies, it is suggested to conduct a survey of the area in the following steps:

- Quick 3H reconnaissance at rear net of profiles to identify the most prospective area;
- Detailed exploration (5-channel, if possible) at the identified area of interest.

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EDITED REFERENCES

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