Application of magnetovariational profiling method (MVP) for geological mapping and mining exploration

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SUMMARY

In recent years the 5-component audiomagnetotellurics method (AMT) became very popular for mining exploration and geological mapping. This method actually combines two electroprospecting methods based on the use of the Earth's natural electromagnetic (EM) field: audiomagnetotellurics (AMT) and magnetovariational profiling (MVP). The first method is highly sensitive to the behavior of the sub-horizontal layers, and the second - to subvertical boundaries or bodies. The MVP method, besides being a perfect complement to the AMT, can be used independently for mapping tectonic elements, as well as for exploration of conductive bodies with different shapes. The MVP method allows carrying out cost-effective, environmentally friendly, year-around surveys on any terrain since there is no grounding requirement, as well as the application of 3-component precision field tripods for the accurate and quick installation of induction magnetic sensors. Any 3- or 5- component fifth generation AMT/MT equipment be used for the application of the method in the field. However, the most cost effective would be 4 or 8 channel multifunction EM receivers Gepard with the MVP method incorporated in the design. The method of express estimation of conductive body parameters (shape, position, depth, inclination and conductivity) based on the MVP data provides unique opportunity to target drilling of the subsurface objects immediately during the MVP field survey.

Keywords: Magnetotellurics (MT), magnetovariational profiling (MVP), electromagnetic (EM) field, induction vector (C), tipper (R).

INTRODUCTION

The magnetovariational profiling method (MVP) was created in the 50s-60s of the previous century initially as a technique for mapping large geoelectrical anomalies in the Earth's crust and upper mantle (Rokityansky 1982). The low-frequency equipment (10–1000s frequency band), where quartz variometers were utilized as the sensors for the natural magnetic field variations, was intensively used for the field surveys in 50s-80s of the previous century. As a result, several large conductive anomalies were discovered and their parameters were evaluated. The most well-known results are discoveries of Carpathian and Kirovograd conductivity anomalies in Eastern Europe, as well as the EMSLAB project on the Pacific coast of the North America.

Due to the appearance at the turn of this century of the fifth generation of multifunction EM receivers (Ingerov 2011) and the development of express interpretation techniques based on use the significant points of tipper pseudo-section, performance of MVP method for mining exploration and geological mapping was dramatically improved. Other significant development was the implementation into the field survey practice of precision field tripods for quick and accurate induction magnetic sensors installation at the measurement sites. Due to these innovations, the high frequency variant of MVP became the highly accurate, sensitive and productive technique for all-season exploration. To the date, high-frequency variant of the MVP has solid theoretical foundation, precision instruments and equipment for the effective field work, processing software, editing and data analysis procedures, techniques for express interpretation of tipper amplitude curves, as well as software for 2-D and 3-D inversion. The MVP method can be applied independently and serve as excellent complement to the AMT method (in 5 component variant). Some details of practical application of the method are discussed in this paper.

THEORY

The theory for the MVP method was established in the 50s-60s of the previous century thanks to the efforts of Wiese (1965), Parkinson (1959), Schmucker (1970), Rokityansky (1975). Real and imaginary induction vectors have been proposed as the response functions. Close relationships of the real induction vectors orientation to the position of the conductive bodies were established. Two conventions for the real induction vectors orientation were taken:

- Wiese-Schmucker - from the conductor;
- Parkinson's - to the conductor.

Later in 1973, Vozoff (1991) suggested tipper as another response function. This function, in the

form of amplitude and phase, proved to be convenient for solving practical problems and was introduced into the inversion. Tipper is also convenient for developing techniques of express interpretation for single conductive body. Although the original MVP method was developed for investigations of regional conductive anomalies in the crust and upper mantle (frequency range 10s - 1000s), displacement of the frequency range to higher frequencies (10000 - 1 Hz) created a perfect instrument for mining exploration (Ingerov 2008; Ingerov 2009; Ingerov 2011).

FIELD EQUIPMENT

Typical field layout at the observation site is shown in Figure 1 (center). The electric lines (Ex, Ey) are not necessary for the MVP method. In order to record the time series data of 3 orthogonal components of natural magnetic field variation, any wideband 3-5 channel multifunction equipment of the fifth generation can be used (Fox 2008; Ingerov 2011). But the most productive in the field are specifically designed multifunction EM receivers Gepard-4A and Gepard-8A which have 4 and 8 channels respectively, where each channel could be either electrical or magnetic. Implemented in the design flexible channel configuration allows to record 2-4 sites simultaneously (for example, H_{x1}, H_{y1}, H_{z1} + H_{z2} or H_{x1}, H_{y1}, H_{z1} + H_{z2} +H_{x3}, H_{y3}, H_{z3} + H_{z4}). Very instrumental are the sensors of magnetic field. Induction coils with the frequency band of at least 10,000 - 10 Hz can be used, but coils with wider frequency band (50,000 - 1Hz) are preferable. GPS antenna, ground electrode, battery and connecting cables are necessary elements of field equipment set. From the beginning of this century, 3-axis precision field tripods have been successfully used in the field for quick and accurate induction coil installation and transportation on any terrain and climate, as shown in Figure 1.
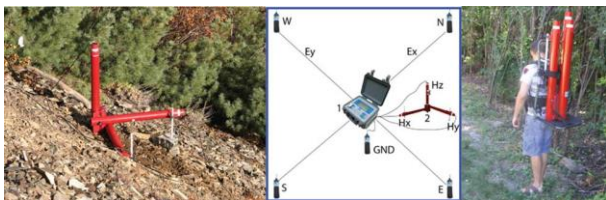

Figure 1. Typical layout of MVP observation site in the field (left – tripod with magnetic sensors in data record mode, center – typical 5-component AMT/MVP site layout, right – tripod with sensors in transportation mode.

Tripods with sensors could be used for year-around field surveys practically at any accessible by foot area and terrain. Upon completion of the data acquisition at the observation site, there is no need to remove magnetic sensors from the tripod, which

can be very quickly (one minute) and easily transformed from working mode to transport mode, and vice-versa. Positioning, orientation and leveling of the tripod takes about 2-3 minutes. For the H_z component measurement, single 1-axis tripods can are used. The application of 1-axis and 3-axis tripods significantly decreases survey costs and improves field productivity of MVP and AMT/MVP methods.

## REGULARITY IN MADNETIC COMPONENTS AND TIPPER ANOMALIES ABOVE CONDUCTIVE 2-D BODIES

In Figure 2 shown are the graphs of H_x, H_z and Tipper above 2-D conductive body with isometric section. Since the alternating electric current is concentrated along Y axis in the conductive body, the circling alternating magnetic field will appear. Projection of this field at the X axis will provide positive local H_x anomaly, which will have very rapidly decreasing amplitude with respect to the distance away from the epicenter of the conductive body.
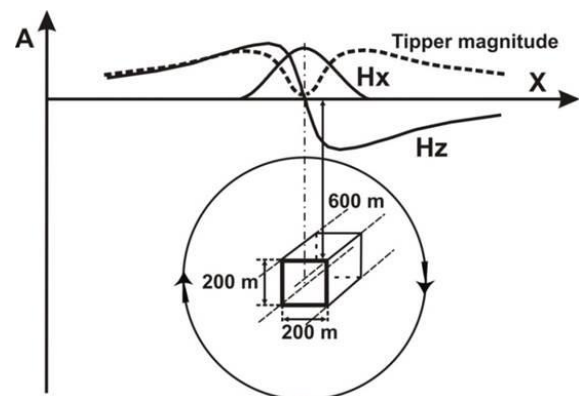

Figure 2. Graph of H_x, H_z and tipper above the isometric 2-D body. H_x and H_z are represented by solid line; Tipper is represented by dashed line.

The H_z produces a very wide bipolar anomaly (that allows H_z to be seen far away from the conductive body) and it sharply changes its sign exactly above the epicenter of conductive body. So, for more accurate estimation of the body's epicenter position, it is logical to reduce the spacing between H_z measurement sites (as was mentioned above). Tipper has the magnitude proportional to the square rout of relation $(H_z/H_x)^{1/2}$. So, a tipper with the positive value has two maxima on both sides of the conductive body and minima exactly above the body's epicenter. Tipper anomaly is decreasing very slowly with the increase of the distance from the body's epicenter. Therefore, it could be seen from far away from the observation profile or site. In Figure 3, tipper pseudo-sections for 2-D conductive bodies with different shapes are shown. As highlighted on the graph, significant values of tipper

anomalies are about two orders in the frequency range. For the isometric body (Figure 3, (a)) the maxima are quite local and the amplitude of the anomaly is relatively quickly descending as the distance from the epicenter decreases. For the horizontal, vertical and inclined bodies, the maxima are quite wider as in frequency, as well as in the distance axis. Each body has its individual form at the tipper pseudo-section which allows to recognize easily the type of body's shape and direction of the dipping. In the Figure 4, tipper pseudo-sections for the isometric 2-D bodies at different depth are shown. It is clearly seen, that with the increase in depth, the distance between two maxima is increasing, but maxima's amplitude is decreasing. These dependences can be estimated both in graphical and analytical form, and could be used for the depth estimation.
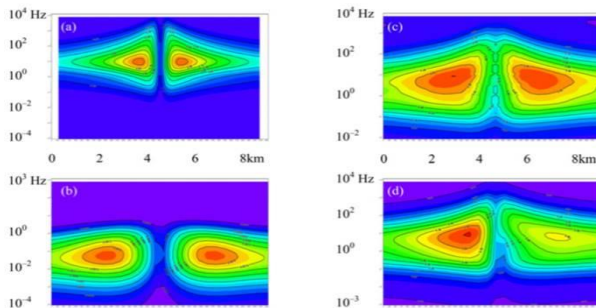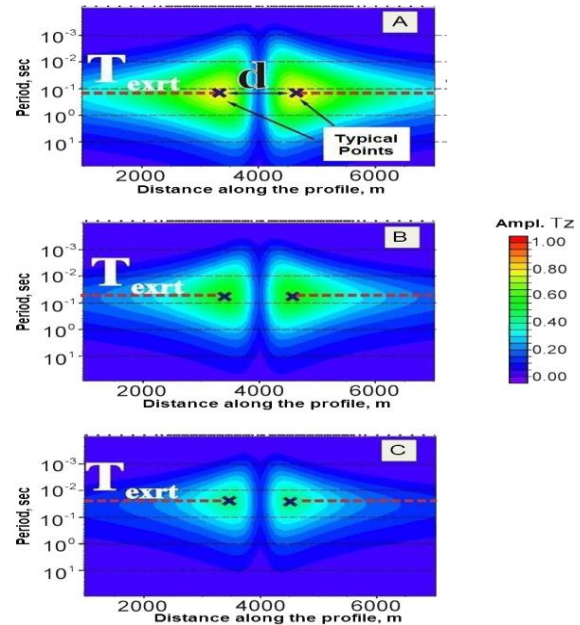

Figure 3. Tipper pseudo-sections for 2-D conductive bodies with different shape: (a) isometric; (b) horizontal; (c) vertical; (d) dipping to the left.
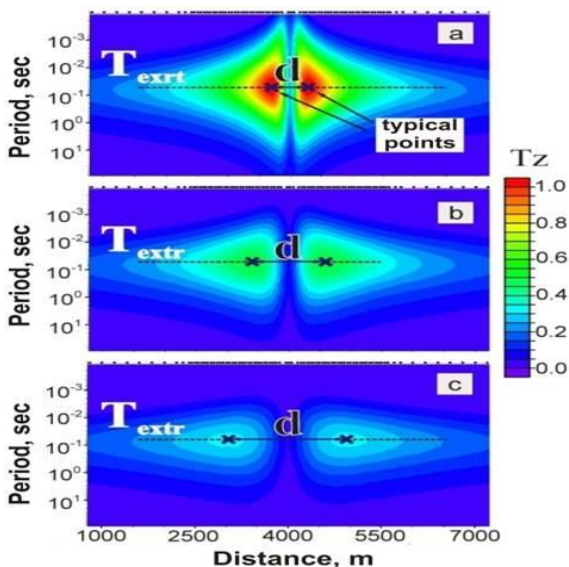
Figure 4. Dependence of tipper maxima position at pseudo-section from the depth of the center of conductive isometric body. (a-300 m, b-600, c-900 m).

In Figure 5, tipper pseudo-sections with different 2-D body conductivity section are shown. The frequency of the tipper maxima estimates the exact conductance of the body's section. So, the real induction vectors help to determine conductive body position in the plane. The tipper pseudo-section along the profiles crossing conductive body helps to estimate the epicenter, shape, direction of the dipping, depth to the center, and conductivity of the section.

Figure 5. Tipper pseudosection for 2-D conductive bodies with different conductivity of the section.

RESULTS OF COMMERCIAL AND SCIENTIFIC SURVEYS

In the last decade, significant amount of 5-component commercial and scientific AMT/MVP field surveys have been carried-out. Some results of MVP method field application are discussed in the works of Ingerov (2010; 2013; 2014) and Ermolin (2011). Figure 6 shows the induction vector pseudo-section (Parkinson convention) across unique natural geological structure - the Patomsky crater (middle of East Siberia, Russia). The real induction vectors at the high frequency clearly show that crater is the high resistive structure in contrast to the host rock (Ermolin 2011).

CONCLUSION

In MVP method for today we have all the necessary attributes of a successful geophysical method:
- Theory;
- The instrumental base;
- Technology of fieldwork;
- Technology of data processing and analysis;
- Technology of interpretation, including 2-D and 3 -D inversion as well as methods

- of express conductive bodies parameters estimation;
- Positive examples of field application.

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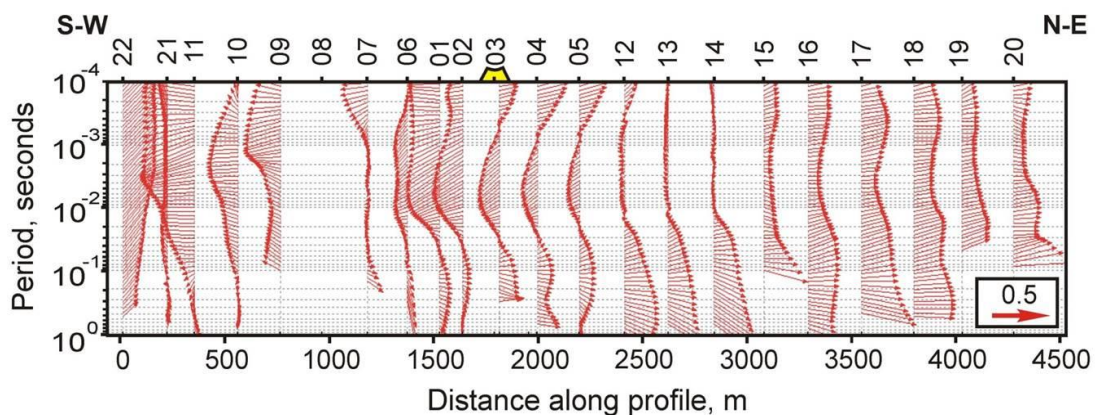
Figure 6. Induction Vectors along the profile through the Patom Crater.