

## Effective All-Season Method for Mining Exploration

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### ABSTRACT

*Magnetovariational profiling method (MVP) was introduced into the field practice in the 1950–60s of the last century, subsequent to the works of Parkinson (1959), Wiese (1965) and Schmucker (1970). During that time period, low frequency variant (10–1000 sec frequency range) was widely used for the detection and parameter estimation of large electrical conductivity anomalies in the Earth's crust and upper mantle. The appearance of the 5th generation of electroprospecting equipment in the 1970–80s allowed MVP method to become a regular add-on to magnetotelluric soundings (MT) in the 5-component variant. At the turn of the century, active implementation into field survey practice of the 5th generation digital multifunction EM instruments resulted in significant increase in the number of audio-magnetotellurics (AMT) measurements, which were widely used for mining exploration. In turn, the demand for the induction vector and tipper interpretation techniques was emphasized. Besides the development of effective 2-D inversions, express interpretation methods which allowed estimation of the parameters (depth, conductivity, angle of inclination, etc.) of the conductive body during the course of the field survey were proposed. Consequently, as well as due to the application of precision field tripods for quick and accurate installation of the magnetic sensors, the 3-component MVP method became an effective independent ground electroprospecting technique for addressing a wide range of mining exploration tasks.*

### INTRODUCTION

Magnetovariational profiling method (MVP) was established in in the 1950-60s and widely used for the detection and parameter estimation of large anomalies in the electrical conductivity of the earth's crust and upper mantle (Wiese, 1965, Vozoff, 1991, Parkinson, 1959, Schmucker, 1970, Rokityansky, 1975, 1982). Quartz variometers served as sensors of magnetic components of the EM field, effectively operating in the 10–1000sec frequency range. This frequency range did not allow for the implementation of the method for mining exploration tasks. The situation changed fundamentally at the turn of the century when 5th generation multifunction equipment appeared on the market, including portable audio-magnetotellurics (AMT) band induction sensors (Fox, 2008; Ingerov, O., 2011). Subsequently, 5-channel AMT became widely used in mining exploration. This experience demonstrated that magnetovariational response functions (induction vector and tipper) significantly increase the possibility of conductive objects localization and can be used independently at the exploration stage. This is particularly appealing, since conducting 3-component measurements of the magnetic field does not require instrument grounding, which is desirable when conducting exploration on crystalline shields or during the winter months. However, there is also a considerable difficulty, created by the need to install an induction sensor of the vertical magnetic field component on hard terrain. A fundamental solution to this problem was found in Canada in the first decade of this century. It consists of installing the induction magnetic sensors in custom precision tripods. This allowed the MVP method to become all-season and increased the productivity of works performed using this method by multiple times. In addition, methods of rapid interpretation of the vertical cross-sections of the tipper with the purpose of establishing the

main parameters of ore bodies were proposed at the same time in the works of Ingerov and Ermolin (2010) and Ermolin et al. (2011). Thus by the end of the first decade of the current century the MVP method became self-sufficient, highly sensitive, and highly productive for mining geophysics (Ingerov et al., 2013, 2014a). This method can be used independently or in conjunction with the AMT method (if local conditions allow for grounding). The MVP method has a well-developed theoretical base (Rokityansky, 1975, 1982), productive high-precision equipment (Ingerov, I., 2011), data processing and interpretation software, and methods of express interpretation (Ingerov and Ermolin, 2010).

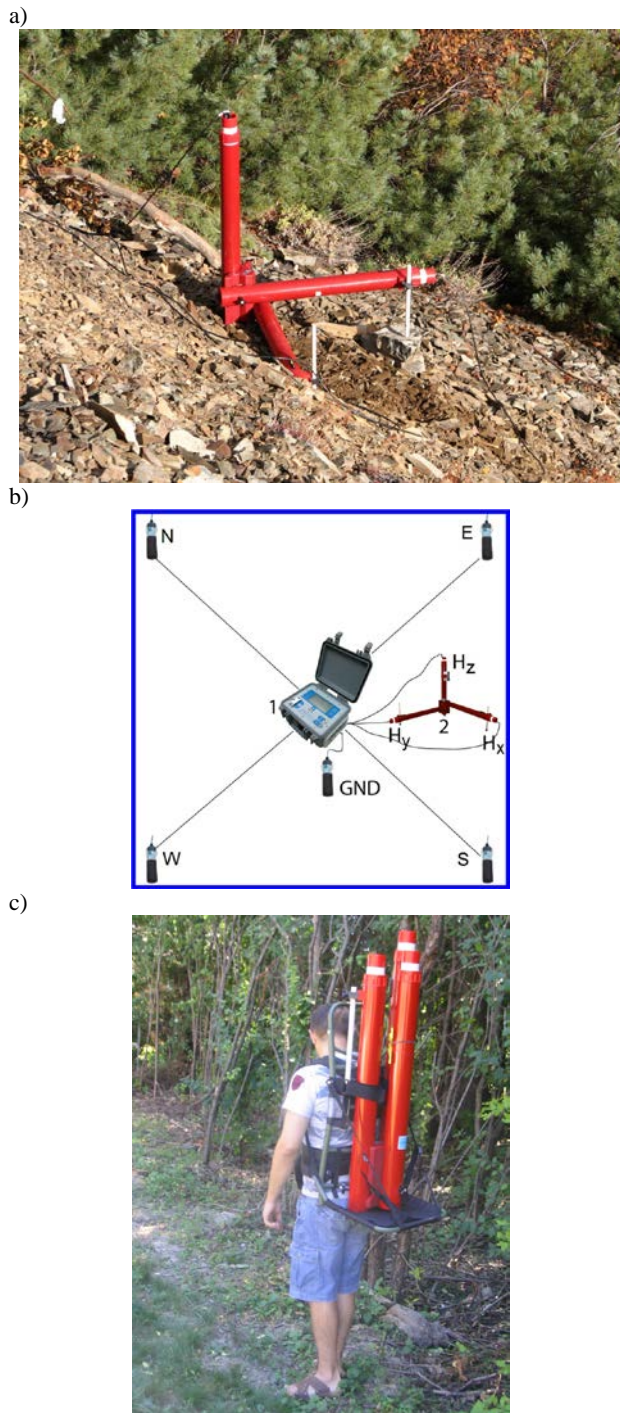
### Theory

The method's theory was developed in the middle of the last century through the work of Wiese (1965), Vozoff (1991), Parkinson (1959), Schmucker (1970), Rokityansky (1975, 1982). Real and imaginary induction vectors, as well as tipper magnitude and phase, were proposed as response functions. Links were established between these functions and the parameters of conductive objects. To date, effective 2-D and 3-D inversion programs of magnetovariational response functions have been developed and methods of express interpretation of vertical tipper cross-sections have been proposed, with the purpose of establishing the parameters of conductive objects (Ingerov and Ermolin, 2010).

### Field Equipment, Instruments and Methodology of Field Work

To register three orthogonal magnetic components of the earth's natural alternating magnetic field, a wide-range of 5th generation multi-function equipment with three, five or more recording channels can be used (Ingerov, I., 2011). Figure 1b

shows a layout of a field installation in a 5-channel version. If receiving electric (E) lines are removed, we are left with a standard installation of the MVP method.

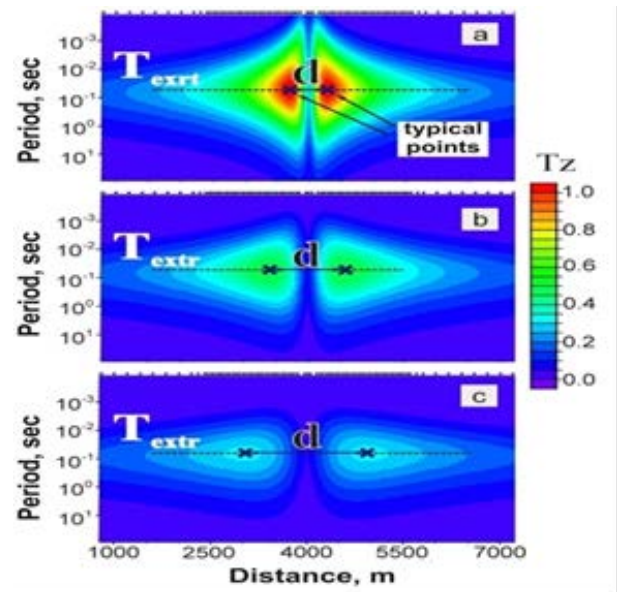


**Figure 1:** Typical layout of MVP (with AMT) observation site in the field; a) Tripod with magnetic sensors in data record mode; b) Typical 5-component AMT/MVP site layout; c) Tripod in transportation mode.

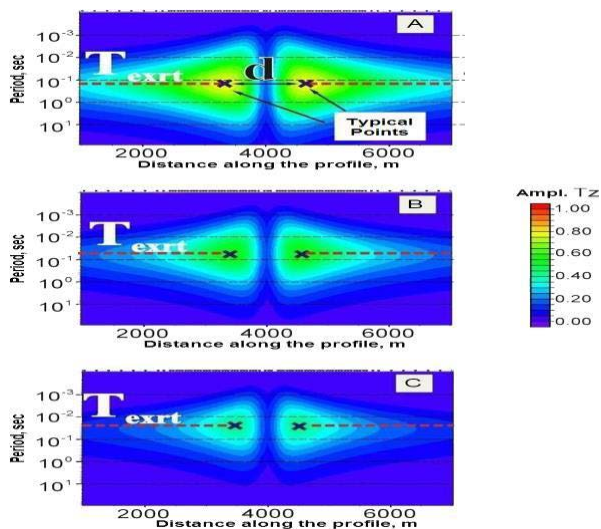
A distinguishing feature of this modern field work technology is the fact that all three magnetic field sensors are installed in a three-axis tripod. The tripod has two configurations: the operating position, where the sensors are located orthogonally, oriented to the azimuth, and leveled (Figure 1a), and the transportation mode, where sensors are parallel. In the latter case, they are easy to transport using a custom frame (Figure 1c). Converting the tripod from its transport mode to the operating mode (and vice versa) takes 1–3 minutes. The use of tripods significantly improves productivity and accuracy of field work, as well as increases the thermal stability of magnetic sensors. In detailed surveys using 4- and 8-channel multi-function devices, tripod application can also improve productivity due to the fact that they allow the field team to record the field on 2–4 sites simultaneously. Data processing is performed with standard programs and does not require any specialized software. However, it is desirable to use programs that allow the use of a remote reference station and the calculation of the magnetic tensor.

### Methods of Express Interpretation

On vertical tipper pseudo-sections over conductive objects, one can observe two maxima anomalies, amplitude and location of which on the vertical pseudo-section is closely tied to the parameters of the body, such as: depth of the center of the deposit, total longitudinal conductivity of the object, and the form (angle of inclination) of the object. Some of the mentioned factors are shown in Figure 2 and Figure 3. Using analytical or graphic dependency, it is possible over the course of field work to estimate the location of desirable objects and adjust the course of the field work (Ingerov and Ermolin, 2010; Ermolin, et al., 2011).



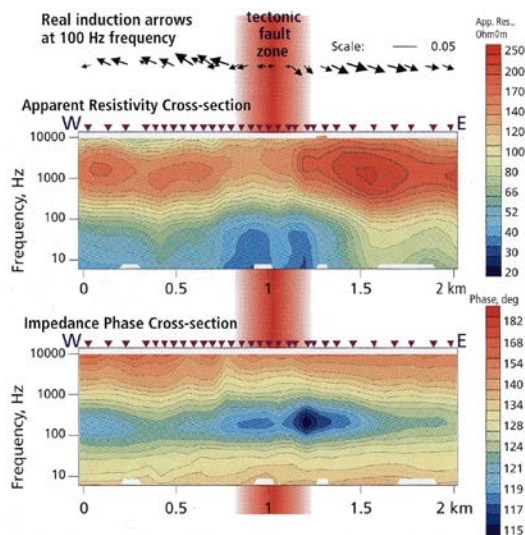
**Figure 2:** Dependence of tipper maxima position on the pseudo-section from the depth of the centre of the conductive isometric body; a - 300 m, b - 600m, c - 900 m; d is increasing with the depth.



**Figure 3:** Tipper pseudosection for 2-D conductive bodies with different conductivity of the section. T is increasing with the increase of d.

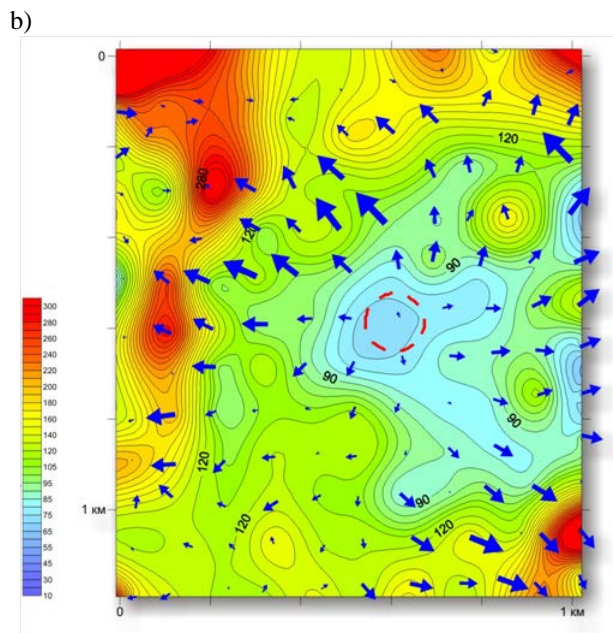
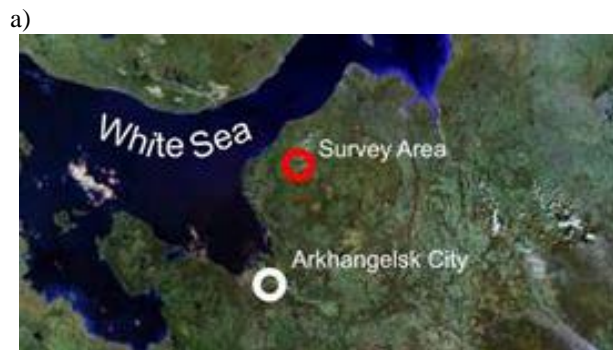
**Field Results of Commercial and Scientific Works**

Figure 4 shows the result of field work on a regional profile in Siberia. The work was performed by Alrosa Co. Ltd. (Russia). The goal of the survey was to establish exact location of the fault controlling the position of kimberlitic dikes. The top part of the Figure 4 shows real induction vectors according to the Wiese-Schmucker convention (directed away from the conductor). The position of the fault clearly coincides with the location of the change in vector direction.



**Figure 4:** Practical results of MVP method response functions application during mining exploration surveys. Kimberlitic AMT survey for deep fault mapping (Alrosa Co. Ltd., 2004); Induction vectors (Wiese-Schmucker plotting convention) and vertical amplitude and phase resistivity cross-sections above the fault in Yakutiya region (Russia); Results of MVP survey.

Figures 5a, b show the location and results of the MVP survey conducted in the Arkhangelsk region with the goal of locating kimberlitic pipes. The survey was conducted by Nord-West Ltd. (Moscow, Russia). Figure 5b shows real induction vectors constructed according to the Wiese-Schmucker convention. The direction and size of the vectors clearly indicate the location of a kimberlitic pipe, which is a more conductive object (Alrosa Co. Ltd., 2004).



**Figure 5:** a) Location of the survey area; b) Apparent resistivity and induction vectors at 500 Hz. Induction vectors (Wiese-Schmucker convention) point away from kimberlitic pipe in Arkhangelsk survey (Nord West Ltd., 2005).

**CONCLUSIONS**

To date, the MVP method has all the attributes of a successful geophysical method:

- Theory;
- Instrument base;
- Advanced technology of field work using precision tripods;



- Software for data processing, editing and analysis of field data;
- Interpretation technology, including 2-D and 3-D inversion methods for rapid determination of parameters of anomalous objects.

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