6149. Non-grounded Surface Electroprospecting Technique

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Summary

The oldest MT technique (MVP) has been given new life with the fifth-generation of multifunctional equipment and precision tripods for magnetic sensor installation. The relatively recent many-3H technique brings new advantages to electroprospecting work in sensitivity, accuracy, productivity, reduced survey costs, and effectiveness in terrain with difficult grounding conditions. New interpretation techniques permit the estimation of parameters of anomalous bodies using tipper amplitude pseudo-sections. Tipper and induction vector data have been successfully used to locate productive kimberlite pipes in Russia.

Introduction

In the last few years, MT/AMT mining surveys have trended away from the "many-2E" toward a "many-3H" technique. The trend was caused by advantages in resolution of the geological targets, high productivity of surveys using precision tripods for induction-coil magnetic sensor installation, and the ability to conduct surveys in winter and over highly resistive ground. Another important advantage is the ease of conducting an effective survey on a regular grid. Also, real induction vectors see anomalies off line. The most successful use of this technique promises to be in mining, but it can also provide additional important information for oil and gas prospecting.

Some History of the Development of the New Technique

The Magneto Variation Profiling method (MVP) could be called the oldest electroprospecting method, because the first experiments with measurement of the magnetic components of the natural EM field were made in the 19th century (Rokityansky, 1982). The method made significant strides in the 1950s and 1960s when the theoretical basis was further developed and (low frequency range) field equipment was created. Research organizations and institutions conducted regional studies, including deep crustal studies, using this method, and discovered several large conductive anomalies in different parts of the world. Among the discoveries whose parameters have been estimated are the well-known Carpathian and Kirovogradskaya anomalies in Central and Eastern Europe (Rokityansky, 1982).

The response functions calculated from results of 3H measurement, such as tipper and induction vectors (real and imaginary), have been defined, as well as simple techniques for parameter estimation of 2D conductive anomalies (Berdichevsky, 1968; Rokityansky, 1982). Two conventions for induction vector representation were established. In the Wiese-Shmucker convention, the real part of the induction vector points away from the conductor, whereas in the Parkinson convention favoured in Western countries, the real part of the vector points toward the conductor (Rokityansky, 1982).

From the 1960s to the 1980s, 5-component measurement became the reality for MT surveys in exploration for hydrocarbon deposits and for regional surveys. Reliable second-generation multifunctional equipment (CES-1 and CES-2 with quartz variometers as magnetic sensors) permitted high quality data acquisition in the former Soviet Union. These data brought many productive industrial results in anticline structure prospecting as well as in salt dome investigations in the 1970s and 1980s. However, the use of this type of equipment did not become standard and declined as induction coils replaced quartz variometers as magnetic component field sensors (Ingerov, 2005).

During many surveys conducted by the authors in the Canadian Shield, it was established that induction vector and/or tipper data are very useful for ore body localization as well as for fault mapping (Fox, 2003). However, accurate and reliable magnetic sensor installation is difficult on rocky or swampy ground as well as on frozen ground. A solution has been found in the development of precision tripods for magnetic sensor installation. In parallel, the authors have worked to mitigate the problems of data quality in the AMT dead-band (700–3000 Hz) and have developed techniques expressly for interpretation of tipper and real induction vectors. This interpretation technique has its basis in the coordinates of the tipper's extremes, which are caused by the presence of the anomalous body.

Tipper Anomalies Above Different Geological Bodies

It has been shown by Lam et al. (1982) that the magnetic response function can easily distinguish shallow and deep anomalous bodies, and that the real induction vector is the most stable, sensitive, and reliable function for estimation of anomalous parameters. Rokityansky (1982) developed a simple and productive technique to estimate the main parameters of a deep 2D conductor (with elliptical cylinder section) using anomalies in the Hz field.

Because in many surveys the most widely used parameter for the magnetic response function is the tipper, the authors analyzed tipper response above different kinds of anomalous bodies common in mining and hydrocarbon prospecting. Figure 1 shows tipper pseudo-sections above four basic electroprospecting anomalies. **Figure 1 (a)** shows the tipper anomaly over a 200 m x 200 m 2-D conductive anomaly ($\rho = 4\Omega \bullet$ m) 500 m deep in a resistive background ($\rho = 1000\Omega \bullet$ m). This is a bright, symmetrical anomaly with two identical extremes approximately 2000 m apart at about 10 Hz.

The amplitude of the extremes (in this case, 0.90) is commonly dependent on the size, depth, and conductivity of the body, while the co-ordinates of the extremes depend mainly on the size and depth. Therefore, tipper pseudo-sections provide enough data to estimate the main parameters of the anomalous body.

Figure 1 (b) is a pseudo-section above a resistive horizontal 2-D layer ($\rho = 100\Omega \bullet$ m) in a relatively conductive background ($\rho = 4\Omega \bullet$ m), typical of common oil or gas deposits. The layer is 200 m thick and it runs 2000 m along the profile. Depth to its top is 2000 m.

The tipper anomaly is symmetrical but its form is very different from the preceding model. The extremes are at a lower frequency (0.01 Hz) and at an increased distance (4000 m). The amplitude of the extremes is very small (< 0.01), so detection of the anomaly requires either precision measurement or a more favourable geological situation such as greater layer thickness or resistivity differences, shallower depth to the hydrocarbon deposit (Fox and Ingerov, 2006), or epigenetic resistivity changes above the deposit.

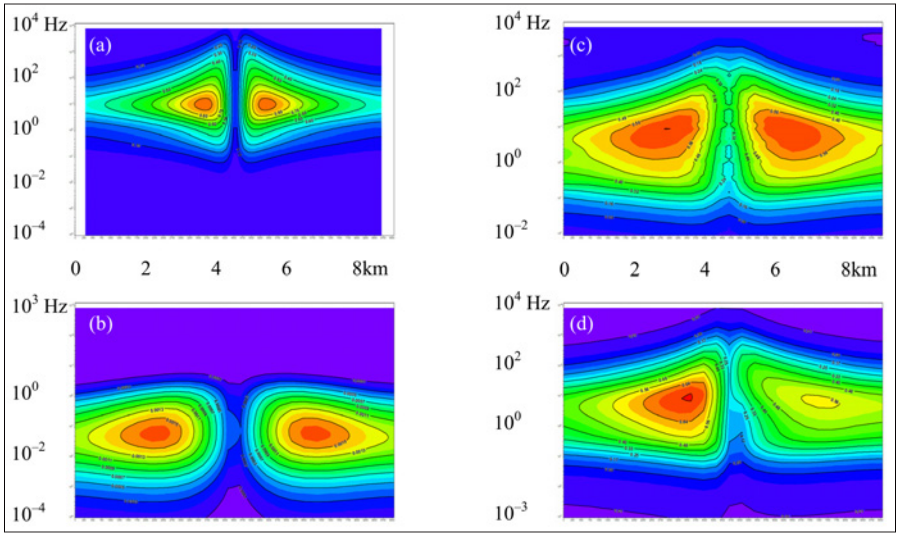

Figure 1: Models showing typical signatures of geologic structures: (a) conductive body; (b) resistive layer; (c) vertical fault; (d) dipping fault.

Figure 1 (c) is the pseudo-section of a vertical conductive fault that does not reach the surface. Again, the tipper anomaly above it is very different from the preceding models: it covers a wide frequency band, and the distance between extremes tends to increase at lower frequencies.

Figure 1 (d) shows a fault that dips about 30° to the right. Here, the anomaly is asymmetrical: the amplitude is less on the side to which the fault dips. It is very easy to see from the pseudo-section the direction of the dip.

The examples of Figure 1 show that from tipper amplitude pseudo-sections, the type of anomalous body can be recognized and the main parameters can be estimated by using the co-ordinates and values of the extremes before 2-D inversion.

Variation with Depth and Conductivity

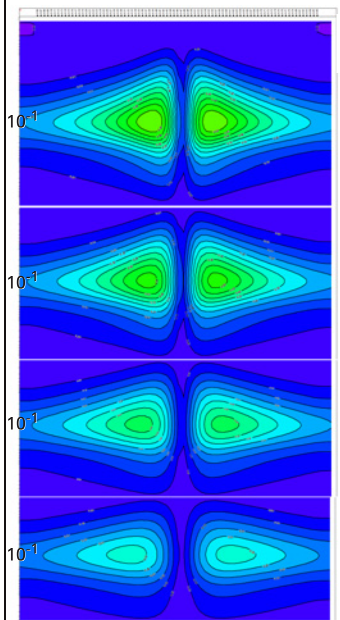

Figure 2 at left shows four tipper pseudosections of a 2-D, 200 m x 200 m conductive ore body at different depths. Resistivity of the ore body is $4\Omega \bullet m$, background resistivity is $4000\Omega \bullet m$, with a relatively lower resistivity overburden (25 m thick with resistivity of $100\Omega \bullet m$). Although the relatively conductive overburden (sediments and weathered crystalline rocks) weakens the deep anomaly, the pattern is still easily visible. The depth of the centre of the anomalous body increases from 500 m at the top of the figure to 1100 m at the bottom. As the depth increases, the horizontal distance (D) between the two positive extremes increases, while the magnitude (M) decreases. It is significant that the frequency of the extremes does not change with depth. Therefore, a low-resistivity body as in our example can be reliably detected in the AMT frequency band (10,000 Hz–1 Hz) at a depth of more than 1 km. The total longitudinal conductivity (G, defined by Rokityansky 1982) of the anomalous body is:

$$0.25(\sigma\Omega \bullet m^{-1}) \times 200m \times 200m = 10000m^2\Omega \bullet m^{-1}.$$

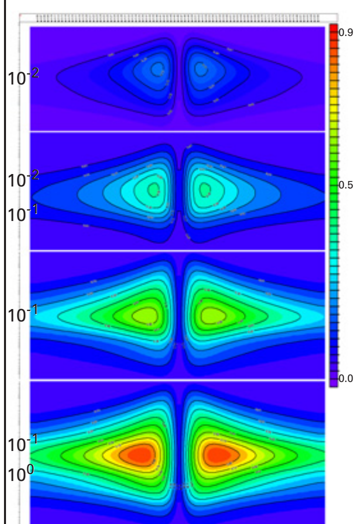

Figure 3 at left shows four tipper pseudosections for different resistivities (varying G) of the anomalous body. From top to bottom of the figure, resistivity decreases from 32 to $2\Omega \bullet m$. With decreasing resistivity (increasing G), the magnitude of the extremes changes significantly, and so does the ordinate (frequency in Hz). The horizontal distance between extremes changes much less. So, obtaining from the tipper pseudosection three parameters—magnitude of extreme (M), frequency of extreme (F), and distance between the two extremes (D)—we can estimate the parameters of the anomalous body such as low resistivity (ore, faults), or high resistivity (some ores, dikes, oil and gas deposits). It is also known that a negative extreme between two positive extremes shows on the x-axis the position of the epicentre of the anomaly (Rokityansky, 1982).

Precision Tripods for Easy Transportation and Rapid Installation of Induction Coils

Different tripod constructions have been tested since 2002. In 2005 Phoenix chose models made by the Toronto-based geophysical company, AGCOS. The tripod family includes three types: (1) an individual tripod for a vertical magnetic sensor; (2) an individual tripod for a horizontal magnetic sensor; and (3) a collapsible tripod for three orthogonal magnetic sensors. The third version is most popular because it fully realizes the advantages of precision tripods in field surveys: rapid installation and easy transportation.

Figure 4: Centre: crew ready to transport tripods to site. Clockwise from top left: tripods with three sensors folded for transport by backpack; installation for an AMT survey site on a frozen lake; installed at close spacing on level ground; installed on a steep slope.

Figure 4 above shows tripods with three orthogonal AMTC-30 magnetic sensors in transport and working positions. The V-block is an essential part of the tripod, keeping the sensors in their plastic tubes precisely aligned orthogonally for data acquisition and in parallel for backpack transport. The accuracy of vertical magnetic sensor alignment with this kind of tripod can be as good as 0.01 degree.

Field Technique for Surface Surveys

The field technique for 3H (or 1H) surveys is simple. Using the AMT method, the field crew prepares two sets of equipment with induction magnetic sensors installed in tripods. They install one set of equipment and set it recording, then go immediately to the next site and install the second set. As soon as the second site is recording, they return to the first site, retrieve the equipment, and proceed to install the third site. This "roll-along" process can be repeated many times; one crew can measure between 20 and 40 sites per day depending on sounding duration and ease of movement on the terrain.

Some Results of MT/AMT Surveys

This 3H technique has produced positive results for geological mapping and mineral exploration in several countries. Success was expected for deposits of sulfide polymetallic and graphite-controlled ores but recent success in diamond exploration was a surprise. The resistivity differences between kimberlite bodies and the surrounding rock are very small; in Russia, exploration is further complicated by a young sedimentary cover 20–80 m thick. Nonetheless, Alrosa (Russia's largest diamond producer), among others, had some good results using tipper and induction vector data (**Figure 5**, left). In Yakutia, Russia, the kimberlite pipes' position is controlled by some regional faults whose direction is well-known. MT is the key method used to localize these faults, and induction vectors are the most accurate parameter for mapping the faults (Alrosa, 2004). **Figure 5** (right) shows the results of a 2005 winter AMT survey by Nordwest (Moscow), Russia's largest electroprospecting contractor, in the Arkhangelsk region of Russia. The induction arrows show the epicentre of a kimberlite pipe, the first productive discovery in Arkhangelsk in 15 years.

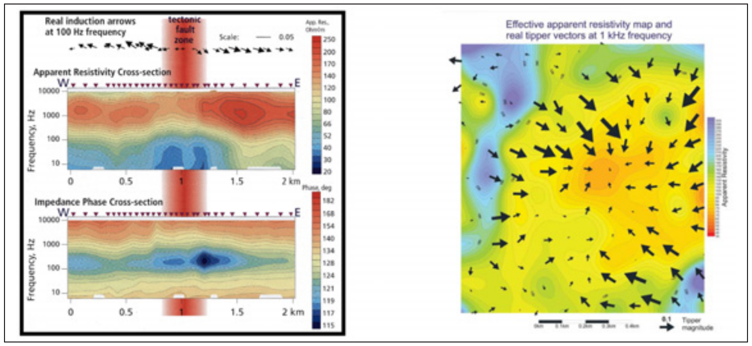

Figure 5: (left) Kimberlite AMT survey for deep fault mapping (Alrosa Co. Ltd., 2004; Wiese-Shmucker plotting convention). (right) induction vectors (Parkinson convention) point to kimberlite pipe in Arkhangelsk survey (Nordwest Ltd., 2005).

The main advantages of the "many-3H, few-2E" approach are:

- off-line sensitivity using real induction vectors
- no requirement for continuous line and/or grid coverage
- effectiveness for both reconnaissance and detailed surveys
- minimal requirements for crew and equipment
- no grounding problems on resistive or frozen surface
- quick estimation of parameters of anomalous bodies
- 2E detailed survey requirement only when crossing an anomaly
- significant cost reduction
- possibility to improve onshore hydrocarbon exploration results

Conclusions

The oldest MT technique (MVP) has been given new life with the fifth-generation of multifunctional equipment and precision tripods for magnetic sensor installation. The many-3H technique brings new advantages to electroprospecting work in sensitivity, accuracy, productivity, reduced survey costs, and effectiveness in terrain with difficult grounding conditions.

References

Berdichevsky, M.N., 1968. Electroprospecting by method of magnetotelluric profiling. Nedra, Moscow, 360pp.

Fox, L., 2003. Past, Present and Future of Magnetotellurics. Presentation to KEGS 50th Anniversary Conference, Toronto, Canada.

Fox, L. and Ingerov, O., 2006. Detection of resistivity of offshore seismic structures mainly using vertical magnetic component of earth's naturally varying electromagnetic field. International Patent Application PCT/CA2006/ 000042.

Ingerov, O., 2005. Application of electroprospecting methods for hydrocarbon exploration. Reports of the St. Petersburg Mining Institute (in Russian), 162, 15–25.

Lam, H. et al., 1982. The response of perturbation and induction arrows to a three-dimensional buried anomaly. GEOPHYSICS 47, 1, 51–59.

Rokityansky, I.I., 1982. Geoelectromagnetic Investigation of the Earth's Crust and mantle. Springer-Verlag, Berlin, Heidelberg, New York, 378 pp.

Alrosa Co. Ltd., 2004. AMT AND DIAMONDS: Kimberlites in Yakutia. The Phoenix (newsletter of Phoenix Geophysics Ltd.) 31, 5; www.phoenix-geophysics.com.

Nordwest Ltd., 2005. Arkhangelsk kimberlite discovery. Presentation to seminar, St. Petersburg Mining Institute, Russia.