

High-sensitivity EM prospecting technique based on measurement of three magnetic components of the natural EM field

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SUMMARY

Typical users of fifth-generation multifunctional equipment, which was put on the market in the late 1990s, showed a preference for a relatively high number of sites measuring two horizontal electric components, and only limited numbers of sites measuring five components of the natural EM field. Five-component measurements were used as local reference sites to calculate apparent resistivity using two horizontal magnetic components for normalization of electric components. Use of the vertical magnetic field was limited mainly to regional surveys. The principal reason for this approach was to lower costs and increase productivity by eliminating the expensive magnetic field sensor, which also requires a relatively longer time for installation in the field compared with the grounded electric-field sensors. As well there are a lot of areas in the world with surface conditions that create significant difficulties for reliable vertical magnetic sensor installation, such as severe winter conditions (frozen ground).

Phoenix Geophysics (Toronto, Ontario, Canada) now sells and uses in surveys precision tripods for magnetic sensors. Highly accurate tripods with a special plastic case for each sensor are manufactured by Toronto-based Advanced Geophysical Operations and Services Inc. (AGCOS). These tripods have several advantages: accurate positioning for one, two, or three magnetic sensors, thermo-stabilization of the sensors, wind resistance, and reduced time for installation, deinstallation, and transportation to the next site.

This approach to natural magnetic-field measurement considerably increases accuracy of measurement and productivity. This method, called the “many-3H technique” has become popular in Canada and Russia due to high sensitivity, high productivity at any time of the year, and suitability for frozen areas and areas covered by rocks with high resistivity. The first industrial kimberlite discoveries in 15 years in the Arkhangelsk region of Russia were made in 2005 using this technique.

Keywords: Magnetotellurics, magnetic sensor, precision tripod, natural EM field, many 3-H

INTRODUCTION

In the last few years, a trend in MT/AMT surveys has been to move from the “many-2E technique” to 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 of this technique is the ease of conducting an effective survey on a regular grid, thereby permitting the use of real induction to see anomalies out of profile. The most successful use of this technique promises to be in mining, but for oil and gas prospecting it also can provide additional important information.

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. Regional studies, including deep crustal studies, were done by research organizations and institutions using this method, and several large conductive anomalies were discovered 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 Weise-Schmucker convention, the real part of the induction vector points away from the conductor, whereas in the Parkinson convention, 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 sensors for magnetic components) 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 early years. But 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).

Since 1996, the many-2E approach has dominated MT survey work (Fox, L., 2001). 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 et al., 2001; Fox, 2003; Ingerov and Fox, 2004). 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 (**Figure 1**). Data collected in this fashion helps ameliorate the problems of data quality in the AMT dead-band (700–3,000 Hz) and permits better interpretation of tipper and real induction vectors.



Figure 1. Precision tripod for three MTC-50 (MT) induction sensors in working position.

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 conductor using anomalies in the Hz field.

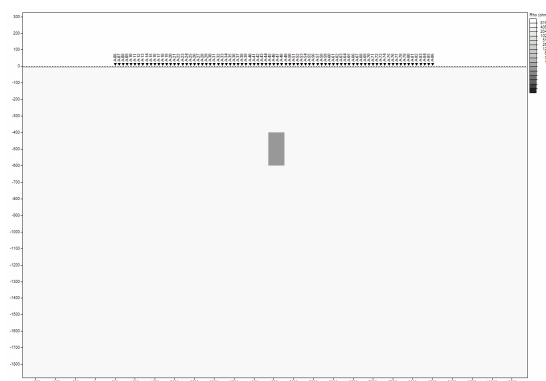


Figure 2. 2D model of conductive body in resistive background.

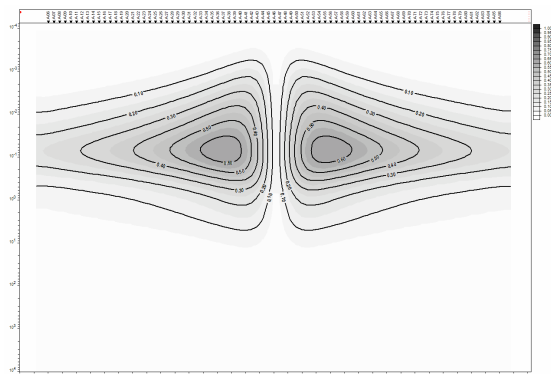


Figure 3. Tipper anomaly above the model of **Figure 2**.

Because in many surveys the more widely used parameter for the magnetic response function is the tipper, the authors analyzed tipper response above different kinds of anomalous bodies, for mining, diamond, and hydrocarbon prospecting.

Figure 2 shows a typical model for mining: a deep conductive body ($\rho_2 = 6 \Omega \cdot m$) placed in a resistive background ($\rho_1 = 6000 \Omega \cdot m$). The top of the ore body is at 400 m depth and the bottom is at 600 m. The width of the body along the profile is 400 m. This 2D model assumes an infinite length orthogonal to the measurement profile (i.e., in and out of the page), which is an acceptable approximation for many situations. The tipper pseudosection, shown in **Figure 3**, displays two extreme anomalies, one on each side of the ore body. The distance between the two maxima is proportional to the depth of the ore body. At the same time, the tipper amplitude at the maximum is proportional to the conductance of the body section and the depth of the conductor. So the main parameters of the ore body can be estimated quickly before 2-D inversion.

PRECISION TRIPODS FOR INDUCTION COIL INSTALLATION

Different tripod constructions have been tested since 2002. In 2005 Phoenix chose models made by AGCOS. The tripod family includes three types:

- an individual tripod for a vertical magnetic sensor
- an individual tripod for a horizontal magnetic sensor

- a collapsible tripod for three orthogonal magnetic sensors

The third version is the most popular because it fully realizes the advantages of precision tripods in field surveys. **Figure 4** shows a tripod for three orthogonal magnetic sensors (AMTC-30) in working position. An essential part of the tripod is the V-block, which keeps the sensors in their plastic tubes precisely aligned in orthogonal position.



Figure 4. Tripod for three AMT sensors at the site of an AMT survey on a frozen lake.



Figure 5. Tripod for three AMT sensors in position for transportation.

Accuracy of installation of the vertical magnetic sensor with this kind of tripod can be significantly better than 1 degree. **Figure 5** shows the same tripod collapsed for transportation.

FIELD TECHNIQUE FOR ONSHORE AND OFFSHORE SURVEYS

The field technique for 3H (or 1H) surveys is very 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 to install the second set of equipment. As soon as the second installation is recording, they return to the first site, retrieve the equipment, and move to install the third site, and so on. This “roll-along” process can be repeated many times, allowing one crew to measure between 20 and 40 sites per day depending on sounding duration and ease of movement on the terrain.



Figure 6. Electroprospecting field crew during winter 3H survey.

Figure 6 shows a field crew during a routine winter AMT survey. A snowmobile is very convenient for moving from one site to another. Nightly data processing and mapping of real induction vector plots allows immediate modification of the survey plan.

The vertical magnetic field (many H_z or many 3H) approach could be successful for oil and gas prospecting, most importantly not just for onshore work but for marine surveys as well (Fox and Ingerov, 2006).

SOME RESULTS OF MT/AMT SURVEYS

In diamond prospecting in western Siberia, an important step is to map deep faults, which determined the position of the diamond pipes. MT with 5-component measurement is the main method to solve this task. As shown in **Figure 7**, resistivity amplitude and impedance phase sense the fault as

well, but real induction vectors correctly show the position of the body and its direction of inclination.

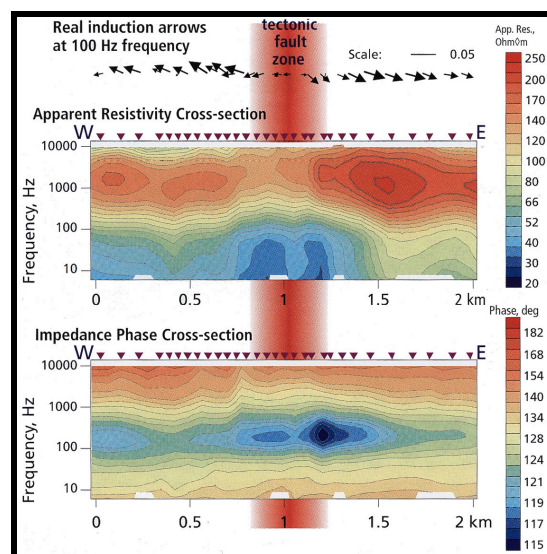


Figure 7. Kimberlite MT survey for deep fault mapping (example provided by Dr. V. Matrosov; Alrosa, 2004).

In Russia, the most effective production using the 3H approach has been by the private company, Northwest, after a successful test at the Siberian Khatat polygon of Alrosa, Russia’s largest diamond company (Nordwest, 2004). Using the same technique, this company discovered a new kimberlite pipe in the Arkhangelsk region of Russia (Nordwest, 2005).

Another example of an AMT survey using the vertical magnetic component is shown in **Figure 8**. The survey was done by the Geological Survey of Canada for deep uranium deposit mapping in northern Canada. As this deposit is enriched with graphite, it is clearly seen as a conductive body. The map of induction vectors in **Figure 8** shows the position of the deep fault, which controls the ore body strike. Tipper data here is useful for obtaining a stable 2-D inversion (**Figure 9**).

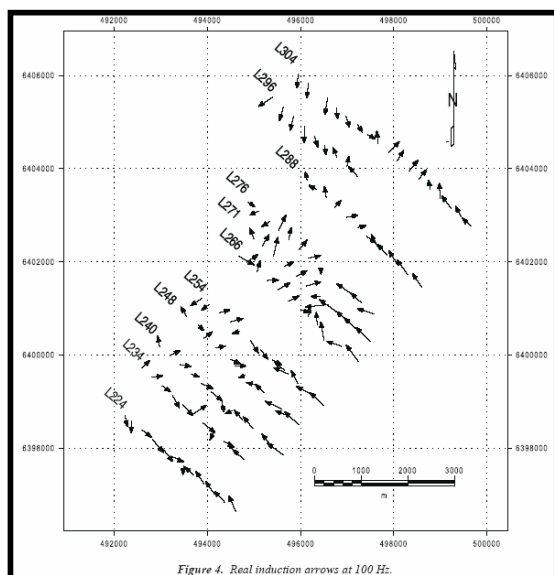


Figure 8. Real induction arrows at 100 Hz, above mineralization zone (Craven, 2003).

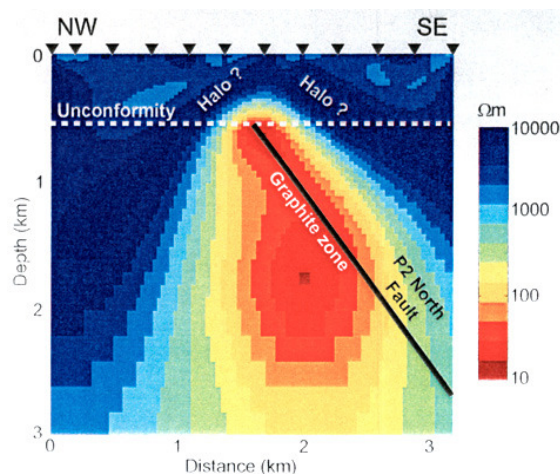


Figure 9. Results of 2D inversion along one profile crossing a deep fault (Craven, 2003).

ADVANTAGES OF THE MANY-1H OR MANY-3H APPROACH

Advantages of the many-3H and few-2E approach include:

- 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 offshore 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.

This many-3H technique brings new advantages to electroprospective work in sensitivity, accuracy, productivity, and reduced survey costs.

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