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FIELD EVALUATION OF A FOUR-COMPONENT DOWNHOLE VLF-EM LOGGING SYSTEM

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INTRODUCTION

Ground and airborne very low frequency electromagnetic (VLF-EM) surveys have been used successfully to delineate electrical conductors and map geological contacts (Wright, 1988). Downhole VLF logging, however, has not been used routinely. This is partly because the application of the technique has not been adequately demonstrated. For this reason the Geological Survey of Canada (GSC) and Scintrex Inc. entered into an informal collaborative research agreement to demonstrate the broad range of potential uses of downhole VLF-EM (DHVLF-EM) surveys in mineral exploration and structural mapping.

The potential of the DHVLF-EM technique is demonstrated with field results from six selected sites, each representing a different geological condition. These sites include Chalk River Nuclear Laboratories, East Bull Lake, Bells Corners, the Victoria graphite deposit, the McConnell nickel deposit, and the Stratmat Cu-Pb-Zn massive sulphide deposit.

THE VLF-EM METHOD—A BRIEF REVIEW

As in the surface and airborne VLF surveys, downhole VLF measurements are made utilising the same VLF communication stations as transmitters,. These stations radiate electromagnetic waves in the 3 to 30 kHz frequency band. Two commonly used stations in the eastern US and Canada are NAA (Cutler, Maine), transmitting at 24 kHz, and NSS (Annapolis, Maryland), transmitting at 21.4 kHz. The transmitting towers are considered to be vertical electric dipoles. The horizontal magnetic field is generated parallel to the ground, while an E-field is generated vertically, at right angles to the magnetic field. At large distances compared to the antenna height, the E- and H-fields can be considered to be plane waves. Currents are generated when VLF-EM waves propagate through the earth. Two types of current flow are observed; vortex or inductive currents that are associated with confined, highly conductive bodies, and galvanic currents that circulate on a regional scale and interact with a variety of targets. Knowledge of the difference between these currents is essential for a correct interpretation of the VLF data since they generate different VLF responses (Wright, 1988).

FIELD MEASUREMENTS

Figure 1 shows the Scintrex DHVLF-EM logging system. The system consists of two main components: the Scintrex IGS-2 receiver on the surface and the Scintrex VLF probe. A reference coil that measures the horizontal vector of the magnetic field on the surface is attached to the receiver. The VLF probe has two electrodes, spaced 10 m apart, that measure the E-field along the borehole, and three orthogonal coils that measure the three magnetic field components of the VLF signal. The in-phase and quadrature components of the four measured fields are recorded as a percentage of the reference magnetic field. The reference coil is oriented to obtain the maximum coupling for the station used. A console added to the surface receiver sends signals to the relay in the probe that switches between the E-field and H-fields so that each of the four fields is measured separately.

The original Scintrex DHVLF-EM logging system was designed for step-wise measurements of the axial E-field and the three orthogonal H-fields for several VLF transmitting stations. The initial field tests of DHVLF-EM by the GSC were carried out in this mode (Cinq-Mars and Mwenifumbo, 1991). The DHVLF-EM system was shown to have great potential as a relatively inexpensive EM logging system for applications in mineral exploration and structural mapping. The GSC then recommended that the system be modified to make continuous measurements of the E-field and the three H-field components. The final field tests were carried out in a continuous logging mode and several logging parameters were evaluated including logging speed, sample time and sample depth interval. These tests indicated that holes may be logged at speeds of 1 to 3 m/minute without any loss in data quality. Continuous logging measurements proved to be more efficient, especially when logging deep holes.

Thirteen parameters are recorded including depth and the in-phase, quadrature and reference for each of the E-field and the three H-field components. The orientation of the two H-field components (X' and Y', Figure 1) that are perpendicular to the borehole axis are not fixed nor measured. Probe rotation often causes a significant response in these two components. Because of the uncertainty in their orientation, the two H-field components are numerically combined to form one component that is orthogonal to the borehole axis.

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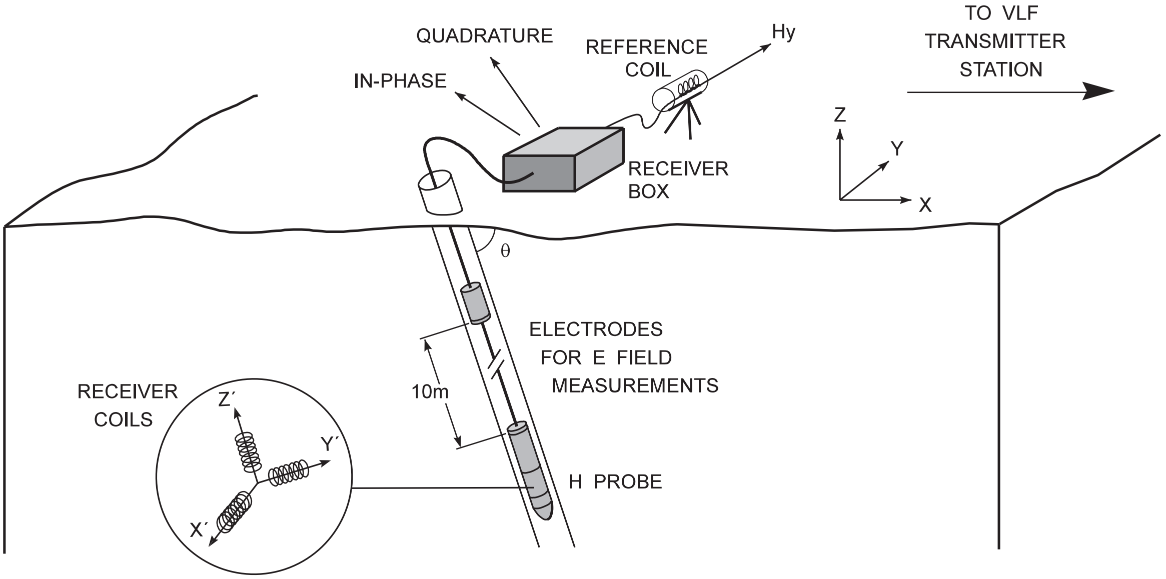

Figure 1: *Schematic block diagram of the borehole VLF logging equipment. The E-field and Z'-magnetic field components are parallel to the borehole axis.*

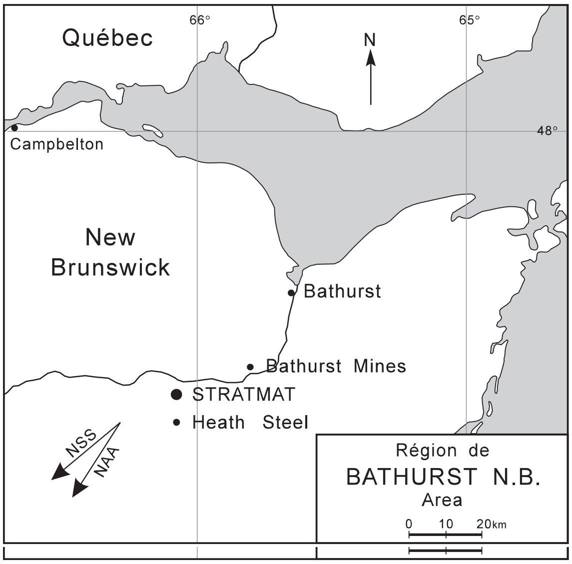

Figure 2: *Location of the Stratmat deposit, just north of the Heath Steele deposit. The two VLF stations, NAA and NSS are orientated almost parallel to each other at this deposit.*

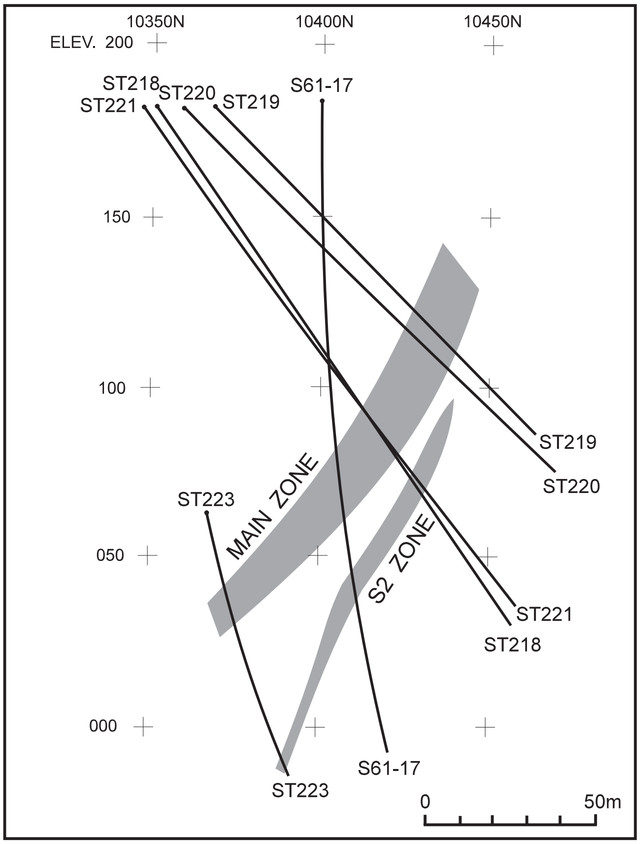

Figure 3: *Geological cross-section of the Stratmat deposit as interpreted from a hole-to-hole mise-à-la-masse survey (after Mwenifumbo et al., 1990).*

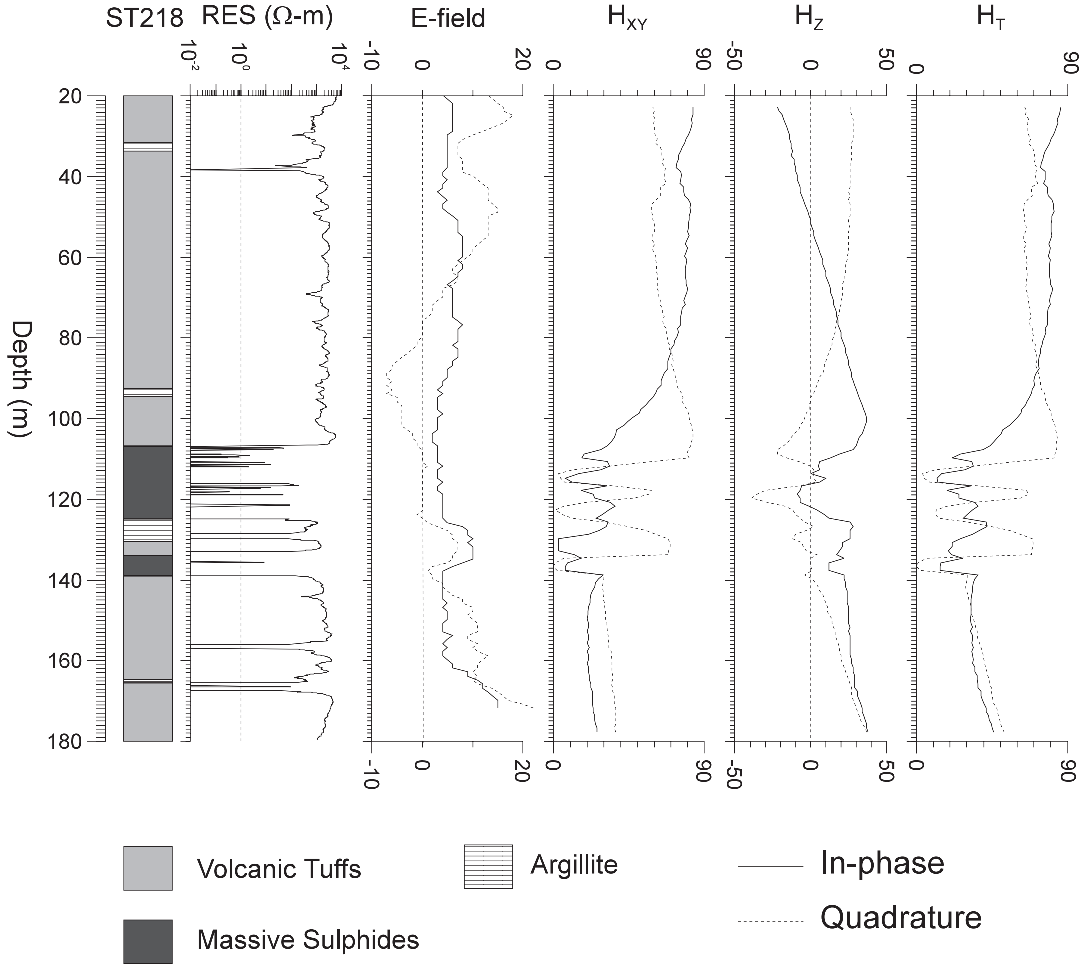

Figure 4: *DHVLF in-phase and quadrature components of the E- and H-fields acquired in hole ST218, Stratmat deposit, New Brunswick, using station NSS. The normal array resisitivity log is also presented to compare the responses within the massive sulphides.*

FIELD EXAMPLES

Downhole VLF data acquired at Chalk River, East Bull Lake, and Bells Corners illustrate the utility of the method in fracture mapping. The DHVLF-EM data from the Victoria graphite deposit, Stratmat massive sulphide deposit and McConnell nickel deposit demonstrate the use of the method in mapping highly conductive orebodies. All these examples are presented in the poster paper. The following example is from the Stratmat massive sulphide deposit.

The Stratmat massive sulphide deposit is located in Northern New-Brunswick, 45 kilometres southwest of Bathurst (Figure 2). The Stratmat property is underlain by felsic to mafic volcanic and metasedimentary rocks. The Zn, Pb and Cu massive sulphides occur as stratabound deposits within structurally repeated metasedimentary horizons (Robertson and Ascough, 1991). The deposit has been extensively studied with surface and borehole geophysics. Figure 3 is an orebody interpretation based on a hole-to-hole mise-à-la-masse survey (Mwenifumbo *et al.*, 1990). The DHVLF-EM data discussed below were acquired in hole ST218.

Figure 4 shows the in-phase and quadrature components of the axial E-field (E), the axial H-field (H_z), the H-field perpendicular to the borehole axis (H_{xy}) and the total H-field (H_t). The galvanic resistivity log is also shown for comparison. Hole ST218 intersects both the Main zone and the S2 zone (Figure 3) at roughly 70° with a bearing of 315° and a dip of 45°. The two massive sulphide zones are clearly delineated on the electrical resistivity log. DHVLF-EM responses show dramatic changes in the magnetic fields (H_{xy}, H_z, H_t) across both massive sulphide zones. The E-field component is more difficult to interpret — the 10 m electrode spacing may be too large to accurately resolve the massive sulphide zones.

CONCLUSIONS

Downhole VLF-EM measurements of the axial E-field and three orthogonal H-field components of the VLF signal were recorded at several sites in Ontario and New Brunswick. Both step-wise and continuous measurements were made for the two main transmitting stations, NAA and

NSS. These measurements demonstrate the broad range of potential uses of the technique to mineral exploration and structural mapping.

Little has been done on the quantitative interpretation of downhole VLF measurements (Couture, 1983). The data from the present study provide an excellent suite for quantitative interpretation that is currently under investigation. Model studies are also suggested to improve the quality of interpretation, and to enhance the usefulness of the DHVLF technique.

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