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Results of helicopter electromagnetic surveys along the Kapuskasing transect, District of Cochrane, Ontario

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MINERAL RESOURCES DIVISION

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RESULTS OF HELICOPTER ELECTROMAGNETIC SURVEYS ALONG THE KAPUSKASING TRANSECT, DISTRICT OF COCHRANE, ONTARIO

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CONTENTS

ABSTRACT

An helicopter electromagnetic and magnetic survey was carried out in 1987 by a contractor, Aerodat Limited of Mississauga, Ontario, along a transect north and south of Kapuskasing, Ontario. The survey was a contribution to the Canada-Ontario 1985 Mineral Development Subsidiary Agreement under the Economic and Regional Development Agreement and it was funded by the Geological Survey of Canada. The purpose of the survey was to provide geophysical data in support of a Quaternary mapping program. Subsequent to the survey, experiments with various data processing techniques were carried out to determine whether overburden conductivity and thickness can be reliably determined from the electromagnetic data. This Open File report contains copies of 7 photomosaics with the layout of the survey and 16 sets of stacked profiles which contain the measured data and calculated overburden conductivity and thickness. Two routines were used in the calculations: least squares inversion based on singular value decomposition (SVD) and centroid depth algorithm (z*).

1. INTRODUCTION

From 1985 to 1991, the staff of the Electrical Methods Section, Mineral Resources Division, conducted geophysical surveys applied to mapping of Quaternary sediments in northeastern Ontario. The ultimate aim of the project was to develop a geophysical methodology in support of the drift prospecting technique, notably for the detection of buried till sequences. Funding for the project was provided by the Canada-Ontario Mineral Development Agreement. A detailed overview of the project was given in a previously released GSC Open File report (Palacky and Stephens, 1991).

The Val Gagné test site in northeastern Ontario was surveyed in 1985 with the time-domain GEOTEM system and a multifrequency, multicoil helicopter electromagnetic (HEM) survey followed in 1987. The results of the latter survey were released as a GSC Open File (Palacky, 1992). Airborne and ground geophysical surveys at the Val Gagné site were described in Palacky et al. (1992b).

In February 1987, 830 line km of HEM surveys were flown along three transects in northeastern Ontario (District of Cochrane). The Fraserdale transect followed Highway 634 from Smooth Rock Falls to Smoky Falls. The Timmins transect survey was carried out along logging roads west of Mattagami River between Smooth Rock Falls and Kamiskotia Lake west of Timmins. The Kapuskasing transect followed forest roads from Guerney Lake, northeast of Kapuskasing, to Lisgar Lake, south of Kapuskasing. Along each transect, two lines were flown in opposite directions 50 m from the centre of the road that was followed.

After interpretation of airborne geophysical data, selected anomalies were followed up on the ground using the horizontal-loop electromagnetic (EM) method. The complete set of all ground EM measurements was released as a GSC Open File (Palacky and Stephens, 1991). The surveys were treated in detail in several papers (Palacky and Stephens, 1990, Palacky, 1991, Palacky et al., 1992c, 1992d). Results of Rotasonic drilling at 70 sites (Smith, 1990, 1992) were used to improve interpretation of EM surveys.

Transect HEM data were reprocessed using two data processing algorithms: inversion based on singular value decomposition (SVD) and centroid depth algorithm (Palacky et al., 1992a). This Open File includes a complete set of HEM data (stacked profiles) from the Kapuskasing transect. In addition to the measured parameters, estimated overburden conductivity and thickness are presented. The location of the survey lines is depicted in Figure 1.

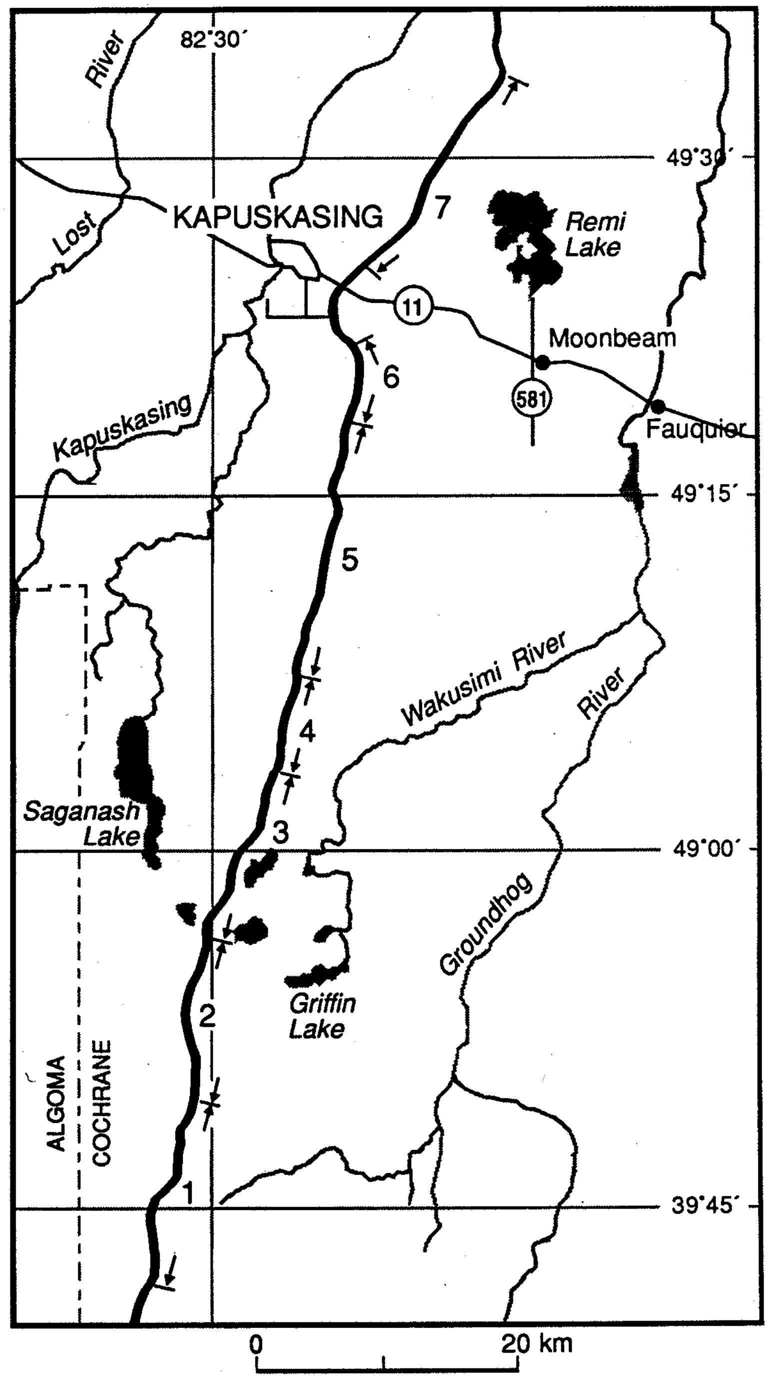

Figure 1:

Map of the Kapuskasing area with the location of seven HEM segments.

2. HELICOPTER ELECTROMAGNETIC MEASUREMENTS

The sensors used in the helicopter surveys by the contractor, Aerodat Limited of Mississauga, Ontario, included a total-field proton precession magnetometer (Geometrics G-803), a Herz Totem-2A VLF system measuring total field and quadrature component data at two frequencies (21.4 and 24 kHz), and a closely coupled, multi-frequency, multicoil HEM system whose principles have been described by Palacky and West (1991). The nominal flight height of the helicopter was 60 m. The magnetometer and the VLF system were towed separately in two small birds (respective nominal terrain clearances were 40 and 50 m).

The HEM transmitters and receivers (spacing 6.5 m) were rigidly mounted in a bird whose mean terrain clearance was kept at 30 m. Two pairs of vertical coaxial coils were operated at frequencies of 935 and 4531 Hz; there were also two pairs of horizontal coplanar coils at 4175 Hz and 32 kHz. Details of airborne operations were given in the contractor's report (Lechow, 1987).

The measured HEM data were first calibrated and levelled. While the vertical coaxial coil data are more suitable for identification of small bedrock conductors, the horizontal coplanar response is better coupled to horizontal layers. In moderately conductive areas, such as the Kapuskasing transect, the in-phase response at the lowest frequency is close to zero and the amplitude increases with frequency. The thicker and/or more conductive the underlying ground, the higher the HEM response. The parameter best reflecting this change is the ground conductance (product of conductivity and thickness).

In the original 1987 survey contract, the specifications called for the calculation of three parameters for all four frequencies:

1) Apparent conductivity using a 200 m thick horizontal layer (in principle identical to homogenous half-space for all frequencies used).
2) Apparent depth to bedrock. Assumption was made that overburden is lacustrine clay having a conductivity of 30 mS/m (milliSiemens/metre).
3) Apparent overburden conductance.

In calculating the first two parameters (apparent conductivity and overburden depth), one of two assumptions had to be made. The overburden is either very thick (in excess of 50 m) and its composition changes, or the overburden is homogenous and its thickness varies. The first assumption was found unrealistic everywhere in northeastern Ontario. The second one was satisfied at the Val Gagné test site and therefore no attempt has been made to reprocess HEM data from that locality. Along the Kapuskasing transect, the overburden is not homogeneous and its thickness is highly variable. A different approach was needed to extract meaningful information from HEM data. The results are presented in this Open File.

In 1992, conductivity patterns along the transect were studied in detail. Ground conductivity measurements with the Geonics EM-31 instrument and the results of inversion of horizontal-loop APEX MaxMin data were correlated to apparent conductivities estimated from HEM survey data (Palacky, 1993).

3. INVERSION OF HELICOPTER ELECTROMAGNETIC DATA

Since 1989, experiments with several inversion techniques have been carried out in cooperation with Aerodat Limited in an attempt to obtain more reliable estimates of overburden thickness and conductivity. HEM data from the Kapuskasing transect, where results of ground EM surveys and drilling provided sufficient ground truth, were repeatedly reprocessed to obtain optimum results. In this report, results obtained by means of two inversion techniques are presented.

Singular Value Decomposition Algorithm

Singular value decomposition (SVD) inversion technique is based on finding the best least squares fit between the calibrated and levelled HEM data and the calculated response of a layered conductive medium. The use of the ridge regression algorithm was proposed by Inman (1975). The principles of SVD inversion and its use in interpretation of geophysical data have been explained by Mencke (1989). Examples of processing of frequency-domain HEM measurements have been published by Paterson and Reford (1986). The computer programs used by Aerodat Limited are based on software developed by Holladay (1980) for inversion of EM soundings.

For SVD inversion of HEM data, the following constraints were introduced:

1) Conductivity of the bedrock was fixed at 0.5 mS/m.
2) Conductivity of the overburden could vary only between 3 and 30 mS/m. Using statistical analysis of resistivities of clay, till and sand, Palacky and Stephens (1990) found this conductivity range to be typical of Quaternary sediments in northeastern Ontario.
3) Existence of an air layer with zero conductivity was assumed in areas where the tree cover caused inaccurate radar altimeter readings.

At each point along the survey profile, six measured and subsequently levelled values of in-phase and quadrature components at three frequencies (4175, 4531 and 32,000 Hz) and radar altimeter reading were used as input. The lowest frequency (935 Hz) could not be used in the inversion because of small amplitudes measured at most locations. The input values were compared with modelled HEM data for the same frequency and component. The normalized RMS error, defined as a difference between the measured and modelled values, was squared and normalized by the datum magnitude for the given frequency. The RMS error was calculated after each iteration. The calculations were discontinued when a preset error level was achieved or when the number of iterations reached 10.

The outputs of the routine are as follows:

1) Overburden conductivity (in S/m - Siemens/metre).
2) Overburden thickness (in metres).
3) Overburden conductance (in Siemens).
4) Air-layer thickness (in metres).
5) RMS error (in percent).

Centroid Depth Algorithm

The centroid depth (z*) algorithm was developed by Sengpiel (1988) for interpretation of groundwater HEM surveys. The centroid depth concept was originally proposed by Schmucker (1970) for inversion of magnetotelluric measurements. Data recorded at a given frequency are treated separately which adds to interpretation stability: a levelling error at one frequency affects only one set of results.

The algorithm inputs are the in-phase and quadrature readings, the outputs are centroid depth z* (in metres) and ambient conductivity of the half-space below z* (in S/m). The centroid depth decreases with increasing frequency. To map the vertical change of conductivity with depth, it is possible to combine the responses obtained with different coil configurations using the fact that over a layered medium, the coplanar response is four times the coaxial response. As in SVD inversion, coaxial data recorded at 935 Hz had to be omitted because of low signal. For each point along the survey profile, three values of z* and conductivity are available. For a given point along the transect, an apparent conductivity section was obtained by interpolating conductivities between z^*_1, z^*_2 and z^*_3 and extrapolating them to the surface and the arbitrarily established cut-off depth.

4. DESCRIPTION OF HEM PROFILES

The Kapuskasing transect was flown in two directions and the survey results were compiled in seven segments (Figure 1). For each segment, the flight line location is depicted on a photomosaic (scale 1:20,000). All measured and calculated parameters are depicted as stacked profiles at a scale 1:20,000. The complete listing of profiles is given in Table 1. There are two flight lines for each segment (east and west of the road). Line name S-KAP-E4 indicates segment 4, which is located south of Kapuskasing, and the flight line located to the east of the road. Also listed in the table are line numbers (uniquely assigned to each profile), flight numbers, and the day of survey execution. Segments S-KAP-E3 and S-KAP-W3 consist of two parts because they were flown during two flights (7 and 9).

The location of any point in the stacked profiles can be recovered on the photomosaic by measuring the distance from the nearest fiducial. The horizontal scale of the stacked profiles is the same as that of the mosaic (1:20,000).

On each stacked profile, the following parameters are depicted (measured parameters - Box 1 to 6, calculated parameters - Box 7 to 10):

Box 1: Thick line: Hoffman HRA-100 radar altimeter trace (height of the helicopter above the ground in metres). Scale: 25 m per division.

Thin line: Total magnetic field. Relative scale: 25 nT (nanoTesla) per division.

Box 2: Time scale, with tick marks every second (bottom of the trace). Hand-picked fiducials - small numbers and tick marks at the top of the trace.

Box 3: Coaxial HEM data at 935 Hz: thick line - in-phase component, thin line - quadrature component. Scale: 20 ppm per division.

Box 4: Coaxial HEM data at 4531 Hz: thick line - in-phase component, thin line - quadrature component. Scale: 20 ppm per division.

Box 5: Coplanar HEM data at 4175 Hz: thick line - in-phase component, thin line - quadrature component. Scale: 40 ppm per division.

Box 6: Coplanar HEM data at 32 kHz: thick line - in-phase component, thin line - quadrature component. Scale: 80 ppm per division.

Box 7: Results of SVD inversion:

Thin line: air layer, as defined in Section 3. Scale 2 m per division.

Thick line: rms error; scale 2 percent per division.

Box 8: Calculated parameters:

Thick line: conductance of overburden calculated using the horizontal layer model; logarithmic scale in Siemens, one decade per 2 divisions.

Thin line: conductivity determined by SVD inversion of HEM data; logarithmic scale, one decade per 2 divisions.

Box 9: Output of the centroid depth algorithm:

Shaded conductivity pseudosection obtained by interpolation and extrapolation of conductivities calculated at centroid depth locations. Vertical scale: 15 m per division. The key to grey shading is included on each set of stacked profiles.

Three traces depict centroid depth z* calculated for frequencies 4175 Hz (thin line), 4531 Hz (thick line) and 32 kHz (thin line). The scale is the same as for the pseudosection.

Box 10: Results of SVD inversion:

Overburden thickness. Scale 15 m per division.

TABLE 1

Line Name	Line #	Flight #	Date
S-KAP-E1	3051	9	7/2/87
S-KAP-W1	3043	9	7/2/87
S-KAP-E2	3052	9	7/2/87
S-KAP-W2	3042	9	7/2/87
S-KAP-E3	3053	9	7/2/87
S-KAP-W3	3041	9	7/2/87
S-KAP-E3	3011	7	6/2/87
S-KAP-W3	3004	7	6/2/87
S-KAP-E4	3003	7	6/2/87
S-KAP-W4	3012	7	6/2/87
S-KAP-E5	3013	7	6/2/87
S-KAP-W5	3002	7	6/2/87
S-KAP-E6	3001	7	6/2/87
S-KAP-W6	3014	7	6/2/87
N-KAP-E7	3020	8	6/2/87
N-KAP-W7	3030	8	6/2/87

5. CONCLUSIONS

Helicopter electromagnetic (HEM) surveys are a rapid and relatively inexpensive means of Quaternary reconnaissance mapping. Multifrequency, multicoil HEM data from the Kapuskasing transect in northeastern Ontario have been processed using two data processing routines: inversion with singular value decomposition (SVD) and centroid depth (z*) algorithm. The SVD inversion requires more computer time and is often unstable because of highly correlated input parameters. To obtain satisfactory results, accurately levelled and calibrated data are required for consistency between frequencies. The centroid depth algorithm, which treats data measured at each frequency separately, is inherently more robust.

Evaluation of the results along the Kapuskasing transect has shown that the centroid depth algorithm produces more reliable results. The 32 kHz centroid depth was remarkably close to the actual depth to bedrock at sites where drilling data were available (Palacky et al., 1992a). Conductivities determined by either method can be used to interpret the predominant composition of Quaternary sediments. If surveys were repeated with improved instrumentation that would allow more accurate levelling, the relative merits of the two techniques would have to be reassessed.

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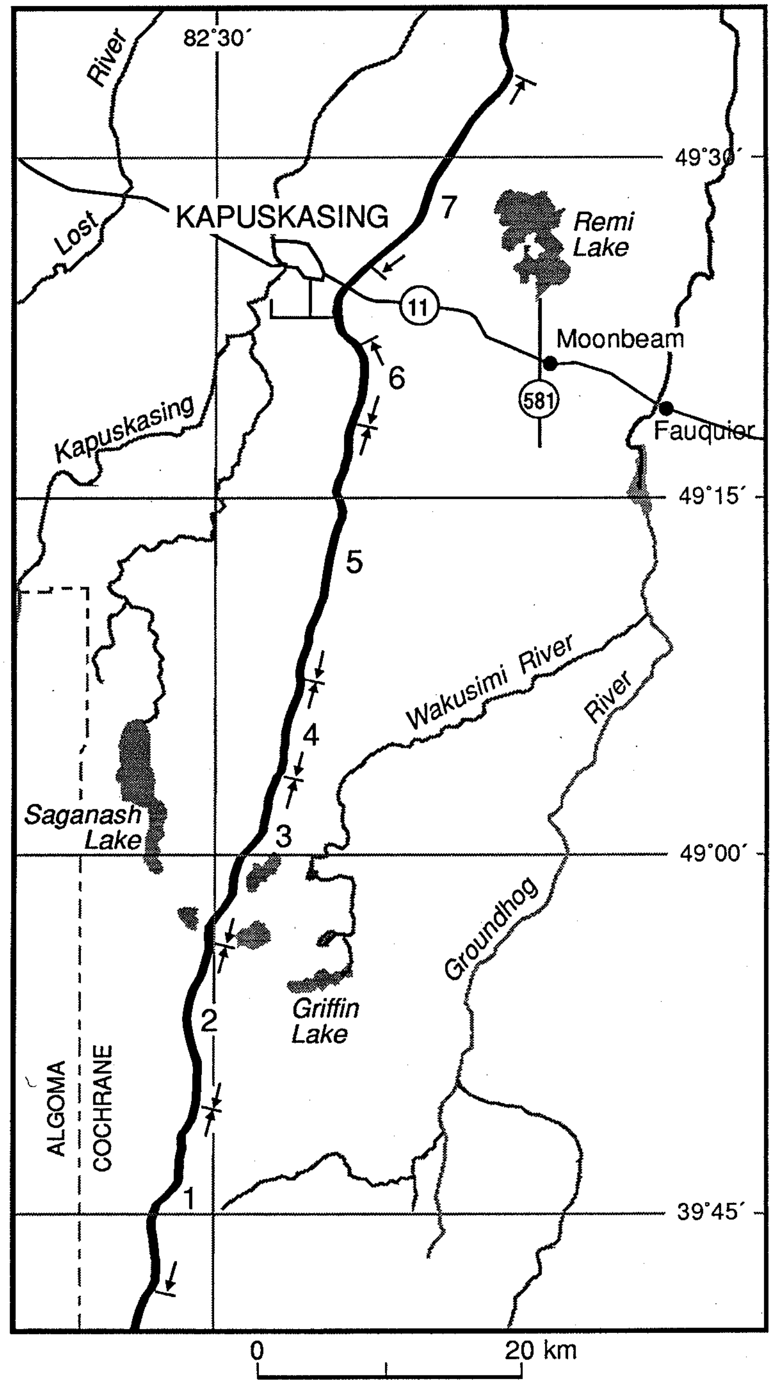

Figure 1:

Map of the Kapuskasing area with the location of seven HEM segments.