Electrical and magnetic properties of the Duport gold deposit, western Ontario, Canada

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SUMMARY

Ground geophysical measurements have been made using magnetometer, magnetic susceptibility, EM31 and TEM instruments at the shear-hosted Duport gold deposit in Shoal Lake, western Ontario, Canada in order to help relate airborne EM and magnetic survey data to geological features. Ground magnetic survey results show a broad anomaly correlating with an anomaly in the airborne magnetic data as well as several narrow discontinuous anomalies that are not as clear in the airborne data. The magnetic data have been modelled using steeply dipping plates possessing both induced and remanent magnetization. The broad anomaly is due to dominantly induced magnetization in the magnetite-rich diorite rocks. The narrow discontinuous anomalies are associated with strong induced magnetization in a schistose basalt unit and remanent magnetism in a pyrrhotite-rich altered basaltic rocks. In-phase EM31 and HEM results are able to delineate induced magnetization in the diorite and quadrature EM31 results indicate that the pyrrhotite-rich rocks have enhanced electrical conductivity. The combined electrical and magnetic results are consistent with pyrrhotite contents of 10% in narrow zones within the basaltic rocks and magnetite contents of around 3% in the magnetite-rich rocks. Examination of the relation between gold assay values and magnetic susceptibility measurements made on drill-core suggests that highest gold content occurs near the margin of the magnetite-rich schistose basalt.

Key words: Gold deposit, electromagnetic survey, magnetic survey

INTRODUCTION

The Duport gold deposit is a shear-hosted gold deposit located in Shoal Lake, western Ontario, Canada (Figure 1.) The deposit outcrops on Cameron Island, a small (330 m long by 150 m wide island) and extends down dip beneath the lake. It was discovered in 1896 and has been mined during several different time intervals (Smith 1987). During the 1930’s a total of 1080 tonnes of ore was shipped from the site with an average grade of 115 g/t Au (Clow & Valliant 2004).

The Duport deposit has been examined in a number of geophysical surveys, extensive drilling programs, and underground development. Most recently, a HEM survey was done over the deposit and surrounding areas in 2005, providing a total coverage of 2700 km, and an additional diamond drilling has been completed.

Figure 1. Duport Deposit is located in Shoal Lake, in western Ontario, Canada.

The objective of the present work is to use ground geophysical surveys to relate the HEM and airborne magnetic data to the important geological features of the site. Although the geometry of the Duport deposit is now fairly well known, understanding the relation the airborne geophysical signatures and the geology is important for additional exploration in the area.

Preliminary Modelling

Previous results have shown that the Duport deposit is associated with a significant magnetic anomaly. In order to properly interpret the results of EM31 and HEM surveys considered in this study it is useful to review responses from magnetic and conductive bodies. We use a simple model to examine the basic effects rather than attempting to model a realistic ore body.

Figure 2 shows the responses for the GEONICS EM31 and Fugro DIGHEM system, as configured for the Duport survey, over magnetic and conductive half-spaces. The coil configurations involved are horizontal coplanar (HCP) coils (DIGHEM coplanar and EM31 vertical dipole responses), vertical coplanar (VCP) coils (EM31 horizontal dipole response), and coaxial (CX) coils (DIGHEM coaxial responses).

At low to intermediate values of conductivity the effect of increasing conductivity is strongest in the quadrature EM31 and HEM responses. At high values of conductivity the in-phase response becomes comparable in size. For all systems, at the conductivity values shown, the in-phase response due to conductivity has the same sign as the quadrature response.
The effect of increasing susceptibility is seen most strongly in the in-phase responses. For the EM31 instrument, the effect of induced magnetization may be differentiated from that of conductivity by the difference in sign of the response between the VCP and HCP modes. The effect of induced magnetization is present at all frequencies in the HEM data. At lower frequencies the effect of strong induced magnetization is larger than the effect of moderately enhanced conductivity.

The sign of the sensitivity of the HCP in-phase response to induced magnetization depends on the elevation of the coils above the surface. When the coil elevation above the surface is less than about 40% of one coil separation the induced magnetization effect has the same sign as the conductivity effect whereas at higher coil elevations the induced magnetization has the opposite sign. In their normal mode of operation the EM31 and HEM HCP data will be affected by magnetization with different signs.

![Figure 2. Responses of magnetic and conductive half-spaces. Upper two panels correspond to EM31 responses and lower three to DIGHEM coplanar responses. In-phase responses are shown in red and quadrature responses in black. Negative responses are denoted by a dashed line. Calculations were done using EMIGMA.](image)

**GEOLOGY**

The Duport deposit lies in the Lake of the Woods Greenstone Belt, in the Wabigoon Subprovince of the Archean Superior Province. Gold occurrences are scattered throughout the greenstone belt and mineralization is confined to D₂ deformation zones and spatially associated with syn- to late-tectonic intrusions and iron-rich rocks (Ayer et al., 1991).

Gold mineralization at the Duport deposit is hosted by Lower Keewatin assemblage which consists mainly of tholeiitic mafic flows with some komatiitic and felsic volcanic rocks (Smith 1987). Cameron Island lies within the Duport deformation zone on the contact of the Stevens Island diorite and extrusive mafic rocks.

![Figure 3. Geology of the area surrounding the Duport deposit (modified from Smith 1987). Cameron Island lies within the Duport deformation zone on the contact of the Stevens Island diorite and extrusive mafic rocks.](image)

**Cameron Island Geology**

Limited outcrop on Cameron Island allows the surface geology to be subdivided into two main units (Smith 1987, Melquist, 2005). The southeast part of the island consists of coarse-grained rocks of the Stevens Island diorite. This unit is also referred to as a gabbro (Figure 4). The northwest part of the island consists of finer-grained basaltic rocks. These rocks show evidence of localized shearing and in places gossans are associated with weathered rocks providing an indication of relatively high sulphide content.

![Figure 4. Cameron Island Geology.](image)

Higher-resolution geological information on the Duport deposit is available from diamond drilling. Most of the drilling has involved holes collared to the northwest of the island and plunging to the southeast to intersect the shear zone. Figure 5 shows an interpreted cross-section of the Duport deformation zone, which strikes at Az030°-035° and dips 65°-75° northwest. The deformation zone is subdivided into variably deformed basalt units and narrow lenses of intrusive rocks. The gold mineralization occurs in two narrow shear zones, the Main and East Zones, which are associated with schistose and brecciated basaltic units.

The rocks provides that evidence multiple alteration events occurred in association with the deformation. In the Main Zone, gold is found with sulphides within a network of quartz veins formed during breccia-type mineralization (Smith 1987). The gold mineralization in the East Zone occurs in silicified and sulphidized rocks formed during replacement-type mineralization of schistose basaltic rocks.
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Figure 4. Map of Cameron Island showing the location of mapped outcrops and interpreted geological boundary (from Melquist 2005). The map shows the locations of ground geophysical measurements from the present study and cultural features, mainly old buildings and trenches, from mining operations. In-phase EM31 data were collected on lines 100S and 150 S.

Figure 5. Cross-section of the Duport Deformation Zone at Cameron Island (modified from Smith 1987). Section is approximately perpendicular to Cameron Island.

GEOPHYSICAL SURVEYS

Airborne Surveys

The HEM completed over the Duport Deposit was flown for Halo Resources using the Fugro DIGHEM system and frequencies ranging from 900 Hz to 56,000 Hz. The mean terrain clearance was 30 m, the line azimuth was Az123°, the line spacing was 50 m, and the sampling frequency was 10 Hz corresponding to about 3.3 m spacing at 125 km/hr. Total magnetic field (TMF) measurements were recorded using a sensor in the EM bird.

Figure 6 shows the contoured responses for the TMF and HCP coils for the portion of the survey around Cameron Island. The magnetic response is dominated by a broad positive 2000 nT anomaly on the southeast part of the island. There is also an indication of a narrow parallel positive anomaly to the northwest of the geological contact. This feature becomes more evident if the data are high-pass filtered.

The EM in-phase responses all show a negative response in the southeast of the island and the similarity of the shape of this response to the TMF anomaly provides an indication it is due to induced magnetization. As shown in Figure 2 the induced magnetization response is expected to be negative, and the 900 Hz response is expected to provide the response that is least influenced by conductivity effects.

The lower frequency quadrature responses and the higher frequency in-phase responses are spatially correlated with the bathymetry of the lake. These observations are interpreted to be due to the conductive lake sediments. The EM results do resolve a region in the northwest of Cameron Island, with higher in-phase and quadrature responses occurring in this region at all frequencies. Based on the results in Figure 2 this region can be interpreted as a zone of enhanced conductivity.
Ground Magnetic and EM surveys

The ground geophysical surveys were completed as undergraduate thesis projects (Cook 2006, Krakowka 2007). The ground magnetic survey involved the collection of 270 data points on 9 lines on Cameron Island (Figure 4) using a Scintrex MP-2 proton precession magnetometer with sensor at 1.5 m height. The EM31 survey included a full quadrature-mode survey of the island consisting of 160 data points on 6 lines using both horizontal and vertical dipole configurations. The survey was completed without a data logger so it was necessary to repeat the survey to collect in-phase data. The in-phase survey involved collection of 45 data points on 2 lines using horizontal and vertical dipole configurations. Preliminary TEM soundings were done in background and conductive areas identified in the EM31 survey using a GEONICS PROTEM47 with a 10 x 10 m transmitter loop and a receiver coil at 15 m offset (Figure 4).

The ground geophysics responses are shown in Figure 7. The ground magnetic response is quite different from the airborne response (Figure 6) and is dominated by a very large, narrow, positive anomaly, exceeding 15,000 nT in magnitude, in the northwest of the island. The large anomaly is observed on several lines but its magnitude and along-strike position vary. The data appear to define a sinuous feature with a strike length of about 100 m. Less visible in Figure 7 are a negative 5000 nT anomaly immediately to the northwest of the large high and a positive anomaly in the far northwest of the island. The ground data also show moderately enhanced values in the southeast of the island in the location of the largest airborne TMF responses.

The EM31 quadrature responses are similar for the vertical (HCP) and horizontal (VCP) dipole modes. The responses are dominated by large positive anomalies in the northwest of the island that correlate with negative magnetic anomalies. Measured values in the southeast of the island are very low.

An example of the EM31 in-phase response is shown in Figure 8. In the northwest of the island there is a correlation of positive anomalies in the HCP and VCP modes indicating the influence of conductivity on the response. However, in the southeast of island the in-phase response is characterized by a large positive HCP anomaly and a negative VCP anomaly indicating the presence of induced magnetization.

The TEM measurements revealed relatively resistive responses at the sounding done in the centre of the island and conductive responses extending to relatively late times at the sounding done in the northwest. The decay at the second site has an exponential decay constant of 0.11 ms.

Core susceptibility measurements

As part of our study magnetic susceptibility measurements were made on core from a drill hole intersecting the Duport deformation zone using a Scintrex SM-5 susceptibility meter. Geological descriptions were made of the core and petrographic examination of selected intervals was conducted. Figure 9 shows the magnetic susceptibility and lithology. The highest susceptibility values, of around 0.2 SI are observed in a schistose basalt unit. In the remainder of the core there is poor correlation between the susceptibility values and lithology. The results show one interval of 10 m length in which the susceptibility had a value of around 0.1 SI and other zones of about the same length with susceptibility values of 0.02 to 0.05 SI.

Figure 9 also shows gold assay results from the same drill hole. Highest gold values occur at the upper (northwestern) margin of the high susceptibility zone at the upper margin of the schistose basalt unit.
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Figure 9. Susceptibility values measured on core from drill hole 05-01. Three closely spaced readings were taken at each measurement depth and all have been plotted. The figure also shows the results of gold assays on the core.

Magnetic Modelling

The ground magnetic data from line 50 S and the adjacent line of airborne magnetic data (located approximately 10 m to the southwest) were fitted using a simple block model in order to understand the basic magnetic divisions at the deposit. The objective of the modelling was to reproduce the main features of the ground and airborne data on line 50 S rather than to fit the data completely, and the resulting model is therefore only a coarse representation of the true magnetic structure.

The magnetic model was loosely constrained by the known geology (Figure 5), the susceptibility observations (Figure 9) and the along-strike extent of features in the airborne and ground data (Figures 6 and 7). It consists of 6 blocks striking at Az034o (Figure 10) all with their top at the ground surface. The key parameters of the blocks are listed in Table 1 and Figure 11 shows the model in cross-section and the fit to the data.

<table>
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<tr>
<th>Block</th>
<th>Width (m)</th>
<th>Dip (°)</th>
<th>k (SI)</th>
<th>J (A/m)</th>
<th>Dir</th>
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<td>70</td>
<td>0.1</td>
<td>0</td>
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<tr>
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<td>8</td>
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<td>0.7</td>
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<td>0.3</td>
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Block 1 consists of a 2D rectangular prism and is required to fit the linear anomaly in the airborne data in the southeast of the island. The dip of this block is not well constrained but it appears to be more shallow than the dip of the other blocks.

Figure 10. Location of the top of the blocks in the magnetic model.

Figure 11. Cross-section of magnetic model and the fit to the observed ground and airborne magnetic data. Modelling was done using POTENT.

The remaining blocks were assigned a strike length of 50 m on either side of the data profile so as to match the observed strike of the anomalies. In order for the blocks to have the observed large effect on the ground data and much smaller effect on the airborne data it is necessary that they have a limited depth extent. A value of 100 m was assigned. In order to match the anomaly shapes these blocks require a dip of 75° to 90°.

Block 2 is needed to fit the large positive anomaly observed in the ground data and requires either a susceptibility of 0.7 or a combination of smaller susceptibility and remanence parallel to the present field. Blocks 3 and 5 were necessary to fit negative anomalies on the ground profile. Block 3 required a strong remanent magnetization in the reverse direction to the present field in order to fit the -5000 nT anomaly adjacent to the large positive anomaly. As well as fitting the negative anomaly in the ground data this block produces the negative
deflection in the airborne data. The remaining Blocks, 4 and 6, can fit the data using either remanent or induced magnetization and are not as well constrained as the other blocks.

**INTEGRATION**

**Conductivity signatures in HEM and ground responses**

The airborne EM data provide evidence of enhanced conductivity in the northwest corner of Cameron Island, e.g., as shown by the positive 56,000 Hz quadrature response in this area (Figure 6). The EM31 results show that the enhanced conductivity occurs within narrow (< 10 m width), steeply-dipping zones rather than being broadly distributed. The EM31 data also detect narrow zones of enhanced conductivity that are not easily observed in the airborne data e.g. midway along the northwestern shore of Cameron Island. The southeast of the island has low conductivity.

The EM31 vertical dipole reading is larger than the horizontal dipole reading in areas of enhanced conductivity suggesting that the conductivity decreases near the surface, possibly due to weathering of sulphides in the rocks. The observed decay constant for the TEM measurement can also be related to a conductivity. Assuming a plate model for the enhanced conductivity with typical plate dimension, \( L \), the time constant \( \tau \) will be given by:

\[
\tau = \frac{\mu_0 L}{10} \quad \text{Eq. 1}
\]

(e.g., Nabighian & Macnae 1990). With a value of \( L=100 \text{ m} \) the observed decay of 0.11 ms corresponds to a conductivity thickness product \( \sigma L \) of \( \approx 8 \text{ S} \) and assuming an average plate thickness of 10 m the decay corresponds to a conductivity of 800 mS.m\(^{-1} \). This value is much higher than observed in the quadrature EM31 responses on Line 150. However, it is quite consistent with the 10 ppt and 20 ppt in-phase HCP and VCP anomalies observed on Line 150 (Figure 8). Based on the modellings shown in Figure 2 these values correspond to apparent conductivity of 300 mS.m\(^{-1} \) and 400 mS.m\(^{-1} \) respectively.

Full modelling of the HEM responses should provide some additional general constraints on the conductivity structure of Cameron Island but as the width of the conductive features is much less than the flight height, 2-D or 3-D modelling will be required.

**Magnetic signatures in HEM and ground responses**

The geophysical results suggest the large-scale magnetic anomaly in the southeast of the island is due to induced magnetization. Measurements of susceptibility of surface samples from this part of the island gave relatively constant values of \( \approx 0.065 \text{ SI} \) (Cook 2006). These values are slightly less than the 0.1 SI determined for Block 1 in the magnetic modelling (Table 1).

The EM in-phase response also provides estimates of the susceptibility. Examination of Figure 2 indicates that the 40 ppt positive HCP in-phase response observed in the southeast of Cameron Island corresponds to an apparent susceptibility of around 0.3 SI. The 80 ppm (0.08 ppt) decrease observed in the 900 Hz in-phase response in the southeast of the island corresponds to an apparent susceptibility of 0.04 SI. The EM31 in-phase response appears to overestimate the susceptibility but still provides a clear indication of the presence of strong induced magnetization. The results are based on only three EM31 readings and the higher values of susceptibility estimated form these may reflect local variations in the magnetic mineral content.

The geological cross-section in Figure 5 suggests the schistose basalt unit lies approximately 60 m away from the Stevens Island diorite. In the magnetic model Block 2 lies a comparable distance from the Block 1 which is coincident with the Stevens Island diorite. This observation along with the measurements of high susceptibility in the schistose basalt in core samples suggests that the large positive anomaly in the ground magnetic data is due to induced magnetization in the schistose basalt unit. Some support for this conclusion comes from the EM31 in-phase data. On Line 100 (Figure 8) there is a small in-phase anomaly and separation of HCP and VCP in-phase responses in the vicinity of the magnetic anomaly (e.g., Figure 8). The susceptibility required for Block 2 in the magnetic model is 0.7 SI and exceeds the values measured in the schistose basalt which are around 0.2 SI. The EM31 in-phase results also support a lower value for the susceptibility of this block. The results suggest that the magnetization may be explained by a combination of induced and remanent effects.

The two remanent magnetization dominant blocks in the magnetic model, Blocks 3 and 5, are spatially correlated with enhanced conductivity suggesting the presence of a reasonable abundance of a remanent-causing mineral such as pyrrhotite.

**Geological interpretation**

The magnetization in the southeast of Cameron Island is interpreted to be due to the presence of magnetite in the mafic intrusive rock. Petrographic analysis of samples form the surface of Cameron Island indicate that magnetite comprises up to 5% of the rock and occurs along grain boundaries as well as disseminated through clinopyroxene pseudomorphs (Cook 2006, Figure 12). Comparison of Figures 3 and 6 shows that the region of strong magnetization does not extend across the whole outcrop area of the Stevens Island diorite. The observations suggest that the magnetite content has resulted, at least in part, from an episode of alteration spatially associated with the Duport deformation zone.

The geophysical results indicate a susceptibility of 0.07 to 0.1 SI for the magnetic unit. For the typical relationship between susceptibility and magnetite content (e.g. Clark & Emerson 1991) the observed susceptibility corresponds to 2-3% magnetite content. This result is in quite good agreement with the petrographic observations. With less than 5% magnetite in the rock there will be minimal enhancement of the electrical conductivity and typical relationships between metallic mineral content and conductivity (e.g. Keller 1987) suggest the conductivity would be less than 10 mS.m\(^{-1} \). This result is consistent with the EM31 observation of low conductivity in the southeast of the island.

Figure 12 shows a photomicrograph of the schistose basalt unit. Magnetite is a significant component of this rock, typically being present in the 5 to 15% range. In samples from the core the magnetite was typically fine grained (0.005 to 2 mm) but in the surface sample shown in Figure 12 it is present in the form of larger grains (up to 8 mm in size) which are...
sometimes mantled by finer grained magnetite, chlorite, and calcite. The sulphide content of this rock is typically less than 3% (Cook 2005). The petrographic observations are consistent with the schistose basalt exhibiting strong induced magnetization. A 10-15% magnetite content is expected to correspond to a susceptibility of 0.4-0.6 SI in quite good agreement with the value of 0.7 determined for Block 2 in the magnetic modelling. The lower values (~0.2 SI) of susceptibility measured in the schistose basalt core samples, along with the variation in grain size between the subsurface and surface samples suggests there may be some spatial variation in the magnetite content and susceptibility of this unit.

**CONCLUSIONS**

The integrated airborne-ground-core geophysical study completed at Cameron Island has helped understand the relationship of the airborne geophysics with geological features. The results show that the relatively broad airborne EM and magnetic anomalies in the northwest of the island are associated with a series of narrow zones of enhanced magnetization and conductivity. The integration of the core susceptibility measurements helps relate the strong ground magnetic anomaly to a schistose basaltic unit containing abundant magnetite. A broader zone of induced magnetized rocks in the southeast of Cameron Island correlates with the northwest part of the Stevens Island diorite and the enhanced magnetization observed may be associated with magnetite alteration in these rocks.

Previous studies have shown the value of a comprehensive surface and core magnetic measurement program to exploration and mine development (e.g. Coggon 2003). The present study has been based on only one core but suggests there may be value for such an approach at Duport. The results suggest the occurrence of gold at the margin of the schistose basaltic unit and indicate that this unit has a characteristic induced magnetic anomaly. If the gold was deposited during an alteration event that removed magnetite and formed pyrite and pyrrhotite the margin of the narrow induced magnetic anomaly will form a valuable geophysical target. Additional magnetic measurements on core samples and increased understanding of the alteration history at the site will help assess this approach.

The EM results at Cameron Island reveal the presence of conductive rocks and the enhanced conductivity is interpreted to be due to increased pyrrhotite abundance. The existing data suggest that these conductors do not correlate with gold occurrence. However, the results from the present study do show that EM surveys play a useful role for examining the magnetic response, and in particular providing a method for discriminating between induced and remanent magnetization.

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