Electrical Methods for Ore Body Delineation

Mwenifumbo, C.J.[1]

1. Geological Survey of Canada, Ottawa, Ontario, Canada

ABSTRACT

Most ore bodies are structurally complex, highly deformed and faulted. Therefore, the determination of the ore body geometry, even after expensive definition drilling, is often difficult. Electrical and electromagnetic methods have been used successfully to detect and delineate conductive ore bodies, both on the surface and underground. The present paper focuses on the use of cross-borehole electrical methods in ore body delineation, primarily the mise-à-la-masse or applied potential method. Borehole mise-à-la-masse measurements are carried out by placing a current electrode in a conductive zone and measuring the resulting potential field distribution in one or more other boreholes. Current is channelled through conductive zones connected to the current source, and therefore, the measured voltages reflect the geometry of the conductor.

The Geological Survey of Canada has carried out mise-à-la-masse studies over a number of deposits to delineate ore bodies. This paper presents four field examples of the application of the mise-à-la-masse method in ore body delineation. The first example is from the Victoria graphite deposit and illustrates the use of the technique to provide some information for mine planning. The second example illustrates the use of the method for mapping the orientation of conductive gold-bearing alteration zones at the Hoyle Pond gold deposit. The third example is from the Redstone nickel deposit and illustrates how the mise-à-la-masse technique was used to establish the down-dip extension of the nickel mineralisation. In the final example, from the Stratmat deposit, borehole mise-à-la-masse measurements were used to resolve the structural relationship between two massive sulphide zones that were originally thought to be connected near the surface. In these studies, the mise-à-la-masse method provided significant data that have been used to refine the deposit models, providing better ore reserve estimates.

INTRODUCTION

Ore deposits are often structurally deformed, offset by faults and generally consist of a number of ore lenses. They are also complicated by changes in ore deposition surfaces and/or pinching out of ore lenses. Accurate definition of ore lenses for mine planning is, therefore, often difficult. In the case of conductive massive sulphide deposits, borehole electrical and electromagnetic (EM) methods have been successfully applied to delineate and interpret the structure of ore deposits. These methods have been used to detect and accurately locate ore boundaries, to determine ore body size and orientation, and to correlate ore intersections between boreholes.

There are several variants of borehole electrical and EM surveying methods for ore body delineation. These include single-hole, surface-to-hole, hole-to-surface, and hole-to-hole measurements. The single-hole measurements are the standard resistivity/conductivity logs that are used to define ore boundaries. They also provide in situ resistivities/conductivities of ore and host rocks that serve as constraints in the design of hole-to-hole survey techniques and in the interpretation of the acquired data, e.g., electrical and EM tomographic inversions. The surface-to-hole (current electrodes or EM transmitters on the surface and measurements in the borehole) or hole-to-surface (current electrodes or EM transmitters in the boreholes and measurements on the surface) methods are generally utilized to determine the direction towards better mineralisation or to detect offhole conductors and hence guide subsequent drilling. The hole-to-hole or cross-borehole resistivity and EM methods are mainly used for imaging conductive targets between boreholes. These measurements, combined with the geological data, provide information that is used to develop a better understanding of the ore body geometry.

Borehole EM methods are not covered in this paper. Here we present only one of the borehole electrical methods, the mise-à-la-masse (or applied potential) method. This is a galvanic resistivity method that involves directly energising an ore intersection to determine its orientation, and size, and to establish its continuity with intersections in other boreholes. Four field examples are presented of the application of the mise-à-la-masse method in ore body delineation. These examples illustrate how problems in structural relationships and orientations of ore intersections can be solved.

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THE MISE-À-LA-MASSE METHOD

The mise-à-la-masse method has been extensively and successfully applied to detailed mapping of massive sulphide ore bodies with high electrical conductivity (e.g., Parasnis, 1967, Witherly, 1986, Reed, 1991). More recently, the application of the mise-à-la-masse method has been extended to the mapping of fracture zones (relatively poor conductors compared to massive sulphide ores) to evaluate areas for possible radioactive waste disposal sites (Jamtlid *et al.*, 1982).

Electrode configuration

Mise-à-la-masse measurements are carried out by placing a current electrode in the conductive zone of one borehole and measuring the resulting potential field distribution in one or more other boreholes. The other return current electrode is located, on surface, a large distance from the survey area (essentially at infinity). Figure 1 shows the two electrode configurations that can be used in hole-to-hole mise-à-la-masse measurements; the potential and the potential gradient arrays. With the potential array, one of the potential electrodes is fixed at a distance from the measurement hole (remote reference electrode placed effectively at infinity). The other potential electrode is moved along the measurement hole continuously or incrementally. In the potential gradient arrangement, the potential difference is measured by a mobile potential dipole in the borehole. The current electrode setup is the same for both modes of operation. Although most measurements are carried out in the potential mode, the potential gradient data provide some characteristic features for quantifying the geometrical parameters of the conductive structures, (e.g., estimation of the inclination and width of the conductors under study (Mwenifumbo, 1980)). Potential gradients can, however, be computed from the potential data if the measurements are taken at small sample intervals. Continuous potential or potential gradient measurements are carried out with the Geological Survey of Canada (GSC) logging system. Logging speeds are usually 3, 6, or 9 m/minutes with data acquired every second, giving measurements every 5, 10 or 15 cm, respectively.

Presentation and interpretation of the data

Both mise-à-la-masse potential and potential gradient logs are analyzed. The gradient data are computed from the potential measurements using the Savitzky-Golay least squares derivative operator (Madden, 1978). The mise-à-la-masse potential and the derived potential gradients are plotted for each source location. All the values are normalized with respect to the current intensity in order to facilitate comparison of the amplitudes of the observed measurements for different source locations with different energising current intensities. The potentials are expressed in volts/ampere (V/A) and the potential gradients in millivolts/ampere-metre (mV/A.m).

For an electrically isotropic medium, the equipotential surfaces resulting from a buried current source are concentric about the source. In such a situation, cross-borehole electrical data will indicate maximum potential amplitudes or zero-crossover points in the gradient data, at a point in the measurement hole which is closest to the source. When a current electrode is placed in a conductive zone, the current tends to focus along the conductor, and observations in a hole that intersects the energised conductor will show a potential maximum or zero-gradient across the intersection. This intersection is not necessarily at the shortest distance from the source. In the case of a simple, single conductor, the peak-to-peak amplitude separation on the gradient data gives a rough estimate of the width of the conductor. The gradient data provide more accurate information on conductor axis location, conductor width and resistivity variations along the borehole than do the potential data. Figure 2 shows an example presentation and interpretation of depth-

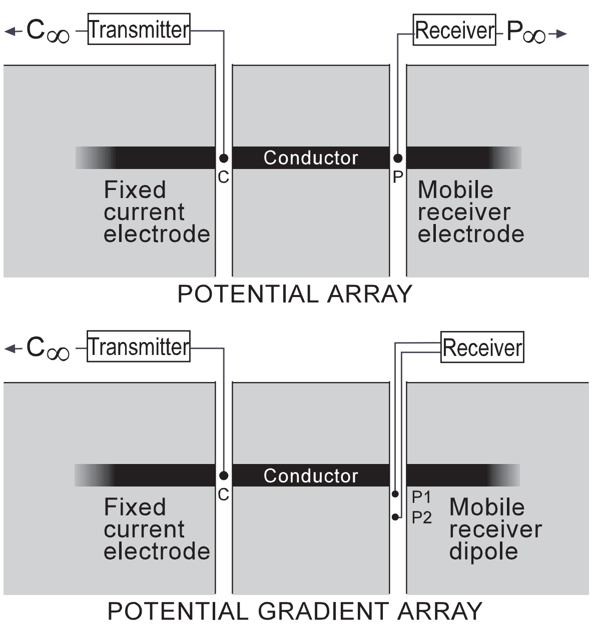

Figure 1: *Electrode configurations in borehole mise-à-la-masse potential and potential gradient measurements.*

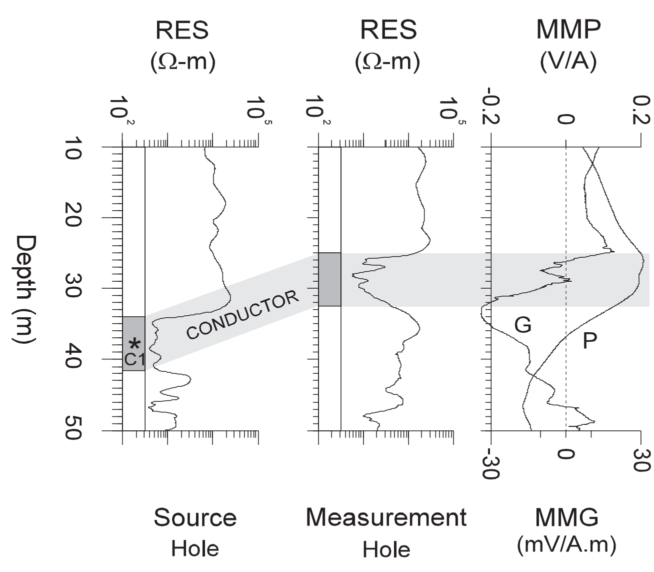

Figure 2: *Field example showing the use of mise-à-la-masse potential (MMP) and potential (MMG) gradient measurements to establish continuity of conductive zones between boreholes. RES = resistivity, P = potential; G = gradient.*

profile cross-borehole mise-à-la-masse data. The resistivity logs indicate low resistivities across the conductive zones in the two holes that are to be studied. With the current electrode placed in the source hole at C1, a high on the potential log is observed in the measurement hole directly across the conductor intersection indicating electrical continuity between the two zones. The dominant current flow path between the holes occurs along the shaded zone. This is determined from the maximum amplitudes on the potential log (MMP) and the zero-crossover point on the gradient log (MMG). In this example the boreholes are drilled vertically, and therefore the depth scale on the logs represents the true vertical depths.

VICTORIA GRAPHITE DEPOSIT, SMITH FALLS, ONTARIO

Extensive mine development drilling at the Victoria Graphite deposit indicated that graphite mineralisation consisted of a number of high-grade graphite ore lenses within a broad graphitic horizon. Some of these zones could be mapped on the surface from the trenches. Planning for a small scale open pit graphite mining operation required an accurate understanding of the connections of different high-grade graphite zones between different drillholes in order to maximise the ratio of ore-to-waste rock during mining operations. This information could be not be accurately obtained from the definition drillhole geological data alone because multiple intersections of graphite ore lenses could not be easily correlated between holes. In several cases there were ambiguities in the interpretation. Mise-à-la-masse measurements were made at the deposit to provide some additional information on the deposit structure and interrelationships between the different graphite ore lenses and to improve ore boundary definition.

Geological setting

The Victoria Graphite deposit lies within the Grenville geological province of the Canadian Shield. The lithology intersected by drillholes comprises Precambrian marbles and paragneisses that are cut by quartz-feldspar pegmatites. Graphite mineralisation occurs disseminated in the highly silicified marbles and paragneisses. Graphite within marbles generally occurs uniformly, and concentrations range from trace to massive seams, with graphite ranging from fine to coarse flakes. It also occurs as contact metasomatic graphite in marble and in pegmatites. Graphite is often seen to be cut off by pegmatites making hole-to-hole correlation difficult.

There are several graphite zones at the deposit. Borehole geophysical logging and mise-à-la-masse measurements were carried out at the Main Zone identified as conductor D (also known as the D-zone) from ground geophysics. Figure 3 shows the D-zone as outlined by a surface horizontal loop EM survey. This broad graphitic horizon comprises several high-grade graphite lenses that pinch and swell along strike, and are cut by pegmatites.

Results and discussions

Figure 4 shows two holes, D45 and D11, intersecting graphite lenses. The high-grade graphite ore lenses are clearly delineated on the resistivity log for hole D11 as low resistivity zones within relatively resistive host rocks. The problem presented in this situation is that one graphite zone is intersected in D45 whereas D11 intersects two zones. The objective then is to determine which of the two graphite zones in D11 is connected to that in D45. When the graphite zone in D45 is energised by placing a current electrode in it, potential measurements in D11 show a potential maximum across the upper graphite intersection. This graphite zone is interpreted as being connected to the zone in D45. The lower graphite zone shows a lower, flattened potential interval across it, characteristic of

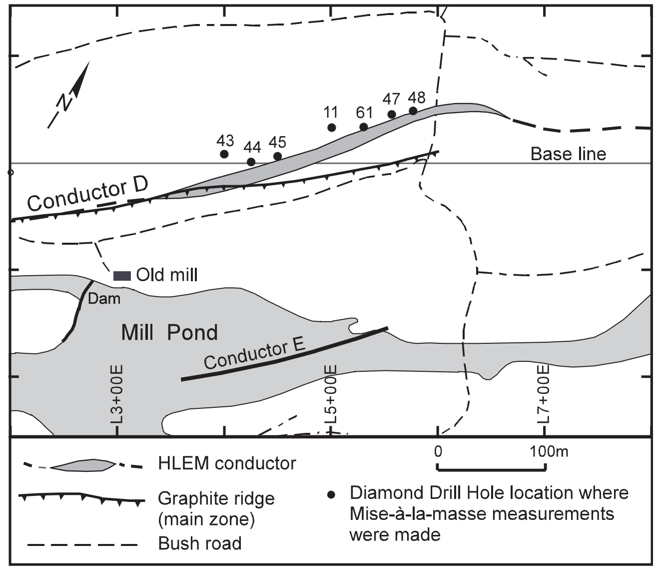

Figure 3: *The D-zone, Victoria Graphite deposit, and location of holes where mise-à-la-masse measurements were made.*

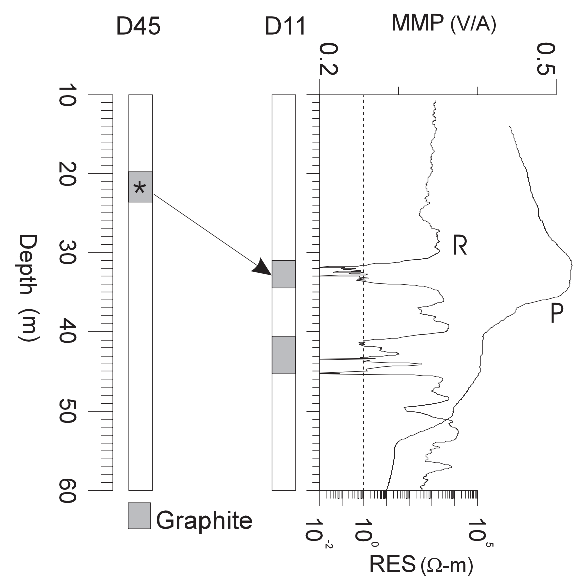

Figure 4: *Resistivity and mise-à-la-masse potential logs from D11 with the current source located in the graphite zone in D45. A potential maximum across the upper graphite intersection indicates electrical connection with the energised zone in D45. The lower graphite zone shows a lower, flattened potential interval across it, characteristic of the response of an isolated conductor.*

the response of an isolated conductor lying in proximity to a charged one (Mwenifumbo, 1980).

Figure 5 shows a more complex geological situation with several high-grade graphite intersections in D47 and two intersections in D48. The holes are 10 m apart. With current sources located at three graphite intersections in D47, potential measurements were successively made in D48. The potential responses for the three current source locations are virtually the same and show a potential maximum, coincident with, but broader than the upper graphite intersection. This suggests a wide graphite zone close to the borehole intersection. High-grade graphite ore lenses pinch and swell along the strike. The lower graphite zone in D48 is not connected to any of the three energised zones in D47. To reduce ambiguities in the interpretation, reciprocal measurements were made. The graphite zone in D48, across which the potential maximum was observed, was energised and measurements were made in D47. Graphite zones 1 and 3 have the same peak potential amplitudes suggesting that they are both in electrical continuity with the current injection point in D48. This is a typical mise-à-la-masse response of a single conductive zone in one hole in electrical continuity with two zones in another hole. Graphite zone 2 is isolated from the upper and lower zones. The interpretation of the dominant current flow paths is represented by arrows.

The overall interpretation of the mise-à-la-masse measurements in the D-zone is given in Figure 6. The interpretation from the geological data, indicated as grey shaded sections, shows some pronounced departures from the mise-à-la-masse interpretations shown as hatched zones. Because the conductivity variations are highly dependent on graphite grade, electrical continuity between high-grade graphite zones is a fairly positive indication of connectivity between zones. Information from the mise-à-la-masse measurements made a significant contribution to planning the mine development at Victoria Graphite deposit and was useful in deciding where to start open pit mining. The eastern part of the D-zone between D11 and D48 (Figure 6) was selected for the initial open pit mining operations.

HOYLE POND GOLD DEPOSIT, TIMMINS, ONTARIO

Geological setting

The Hoyle Pond gold deposit, located about 18 km northeast of Timmins, Ontario, occurs within the Abitibi greenstone belt. Gold mineralisation is found in carbonate alteration zones, known as 'gray zones', within a uniform sequence of magnesium-rich tholeiitic basalts. The zones are structurally controlled and are characterized by in situ brecciation and a strong schistosity in their centres.

Figure 7 shows the geology and structure of section 101,307E of the Hoyle Pond Gold deposit. The holes intersect about 20 m of glacial overburden, regolith and magnesium tholeiitic basalt flows. The alteration zones identified in the drill core are displayed along the boreholes as black areas. Note the geological interpretation of the presence of alteration zones in areas where they were not identified on the drill core (zone A, hole H80-24). It is clear from the interpretation that even with this number of closely spaced boreholes, the correlation of the alteration zones between the holes is a difficult task. Resistivity logging and hole-to-hole mise-à-la-masse measurements were carried out in holes H80-14 and H82-04 to delineate alteration zones and to determine their relationships between holes.

Results and discussions

Figure 8 shows the alteration zones and the resistivity log acquired in H80-14. Resistivity lows coincide with the majority of the alteration zones which makes the resistivity log useful for detecting and delineating these zones. There are a few low resistivity zones that do not correspond to any of the mapped alteration zones (e.g., at 110 m and between 310 and 325 m). These zones may correspond to alteration zones narrowly missed or not identified in the drill core. The resistivities for most of the alteration zones vary between 10 000 and 1000 hm-m, except for the alteration zone between 260 and 330 m which has apparent resistivities lower than 100 ohm-m. The resistivities of the unaltered basalt are around 100 000 ohm-m.

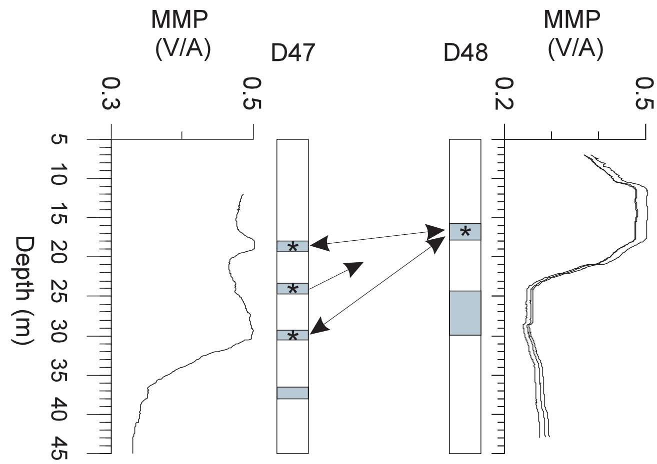

Figure 5: *Mise-à-la-masse data acquired between D47 and D48, illustrating a more complex problem. The potential responses in D48 for current sources at three graphite intersections in D47, are virtually the same. Reciprocal measurements show that, of the three energised graphite intersections, two of them are in electrical continuity with the upper zone in D48.*

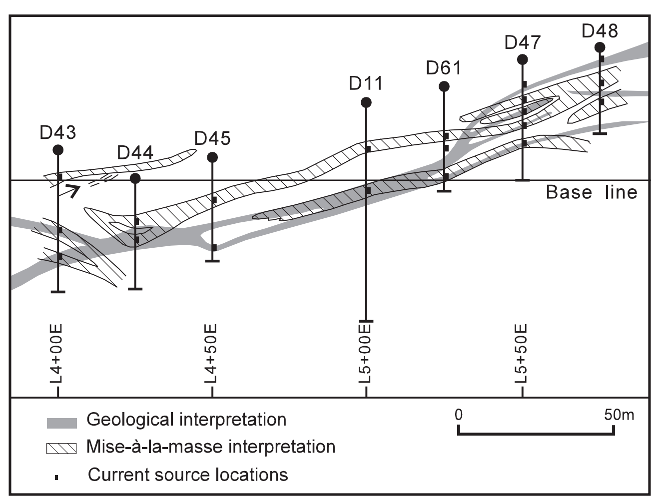

Figure 6: *Plan view showing a comparison between the geological and mise-à-la-masse interpretations of the D-zone.*

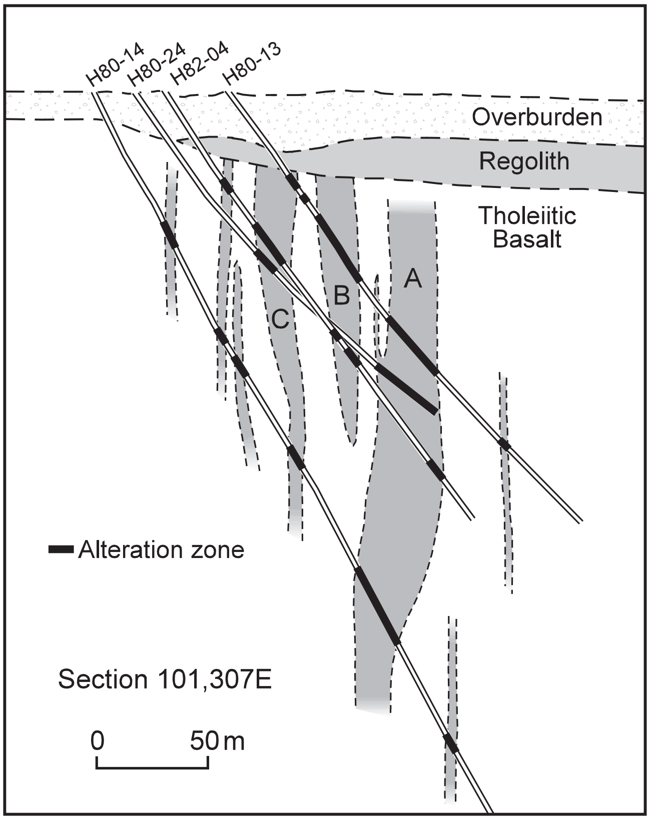

Figure 7: *Geological cross-section along grid line 101,307E, Hoyle Pond Deposit. The alteration zones identified in the drill core are indicated as black shaded zones.*

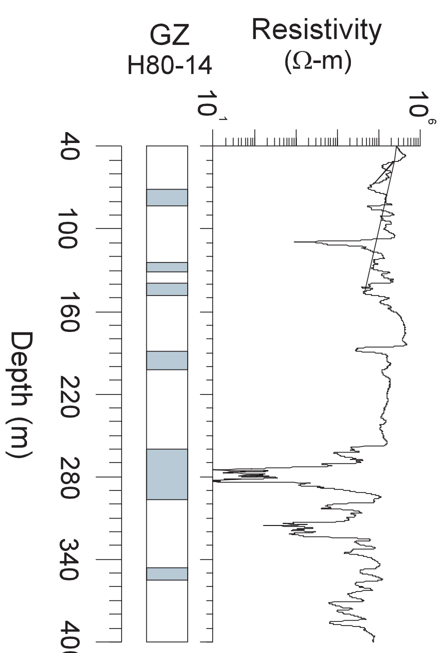

Figure 8: *Resistivity log acquired in H80-14. GZ = alteration zones or gray zones.*

Figure 9 shows mise-à-la-masse potential and derived potential gradient logs acquired in H80-14 with current electrodes implanted at three different alteration zones in H82-04. C1-Log, C2-Log and C3-Log represent data acquired with the current electrodes at C1, C2 and C3, respectively, in H82-04. The C1-Log shows maximum potential amplitudes and a zero-crossover point in the potential gradient at approximately 110 m. No alteration zone was mapped at this depth but the resistivity log (Figure 8) indicates a fairly conductive zone at this depth. Electrical continuity is, therefore, indicated between the alteration zone at C1 in H82-04 and the low resistivity zone at 110 m in H80-14.

The C2-Log shows high potentials between 140 and 150 m that coincide with two alteration zones. The dominant current flow axis is located at approximately 143 m (zero-crossover point in the gradient data). The C3-Log indicates that the alteration zone at C3 is connected to that intersected at approximately 360 m in H80-14. It is interesting to note the abrupt step-like change in potential at approximately 320 m, above which the potentials are fairly low and flat. The alteration zone at approximately 220 m in H82-04 is well isolated from that between 260 and 320 m in H80-14, contrary to the interpretation inferred from the drill core log (see Figure 7).

In all of the above observations, the location of the potential maximum showed large displacements from the location of the points along the observation hole that have the minimum distance from the current sources. This indicates significant current channeling along the more conductive paths. Figure 10 shows the overall interpretation from

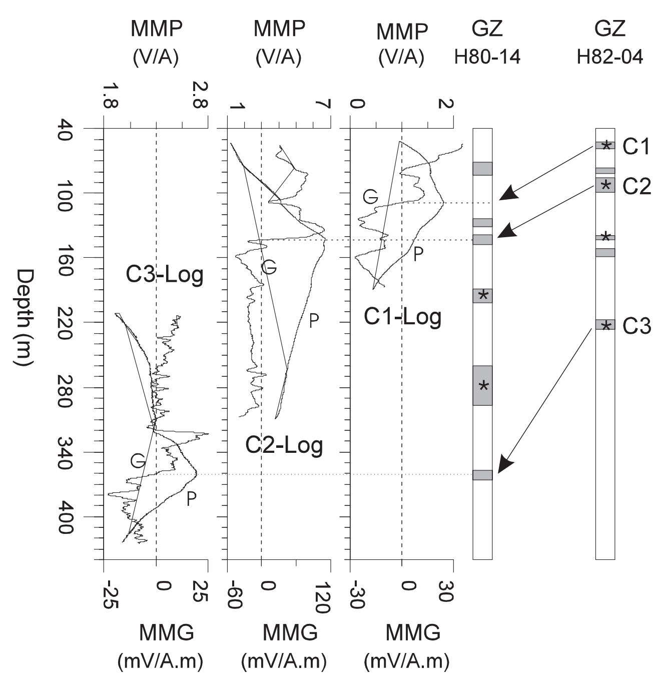

Figure 9: *Mise-à-la-masse potential and gradient data acquired in H80-14 with the current electrodes in H82-04. C1-, C2- and C3-Logs represent measurements with the current electrodes at C1, C2 and C3, respectively. The arrows between the geologic columns represent the dominant current flow path.*

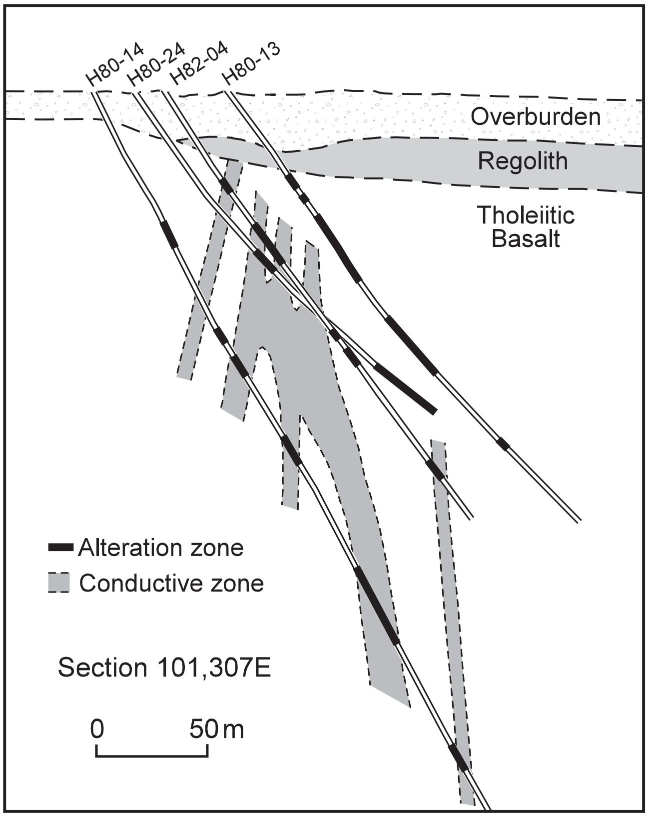

Figure 10: *Conductivity structure between H82-04 and H80-14 interpreted from the mise-à-la-masse and resistivity logs.*

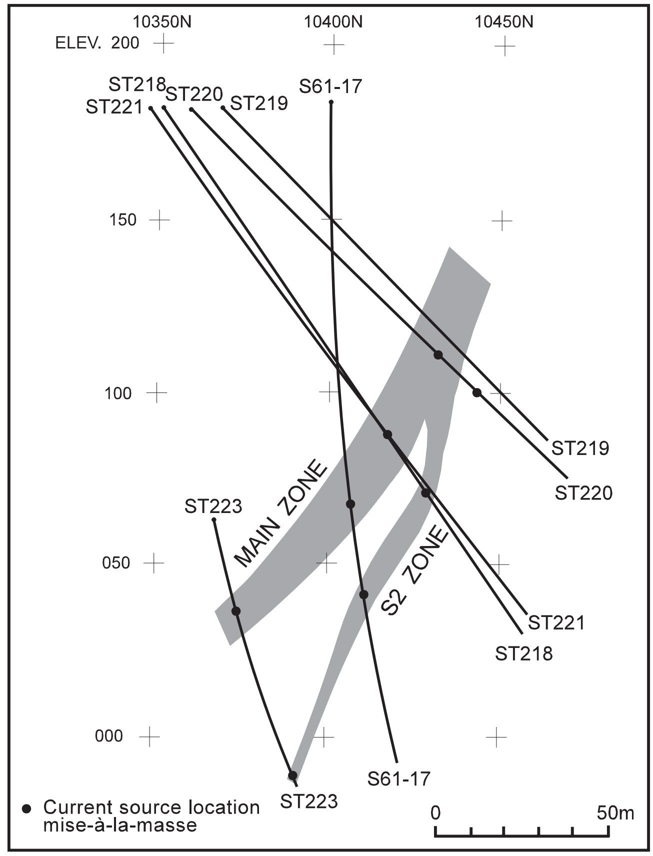

Figure 11: *Geological cross-section of the Stratmat deposit (unpublished data, courtesy Noranda Exploration Ltd.).*

resistivity logs and the mise-à-la-masse observations between H82-04 and H80-14. This is a qualitative interpretation of the conductivity structure between the two holes and is derived from dominant current flow paths determined by joining zero-crossover points in the gradient data with their respective energising current source locations. Theoretical modeling of the structure may provide a more realistic geometrical interpretation. The most dramatic difference between the geological (Figure 7) and geophysical (Figure 10) interpretation is the orientation of the alteration zones. Alteration zone A in H80-14 (Figure 7) is electrically connected to zone C. It appears that there are two sets of alteration zones which may represent two stages of fracturing and alteration. A more complete picture on the conductivity structure between the holes along this section could have been obtained by studying the alteration zones in other holes (H80-24 and H80-13).

STRATMAT DEPOSIT, NORTHERN NEW BRUNSWICK

Geological setting

The Stratmat massive sulphide deposit is located about 2 km north of the Heath Steele mine and 40 km southwest of Bathurst, northern New Brunswick. The deposit is underlain by a package of predominantly felsic volcanic and metasedimentary rocks of the Tetagouche Group. The favourable horizon is repeated by folding, and massive sulphides are believed to be concentrated in the fold closure areas. Most of the boreholes at the deposit intersect volcanic tuffs, mafic dykes, gabbro, argillite and massive sulphides. The deposit is dominated by pyrite-chalcopyrite mineralisation near the surface and grades into sphalerite-galena mineralisation at depth.

Figure 11 shows a cross-section of the deposit with two massive sulphide ore lenses; the Main zone and the S2 zone. The geological interpretation indicates that the two lenses are connected near the surface. Boreholes ST219 and ST220 did not intersect sulphide mineralisation corresponding to the S2 zone. A wide spectrum of geophysical data have been collected at this deposit by the GSC. The geological and structural picture of the deposit has been considerably enhanced as a result of this work. Mise-à-la-masse measurements were undertaken to provide some additional information to investigate the interpretation of the two ore lenses. Current sources were placed at several locations within the low resistivity zones in several holes (Figure 12) to determine if the two massive sulphide ore lenses are connected.

Results and discussions

Figure 12 shows the mise-à-la-masse potential measurements in ST220 for current sources located in ST218 at the two massive sulphide zones. The resistivity logs acquired in both holes are also presented and

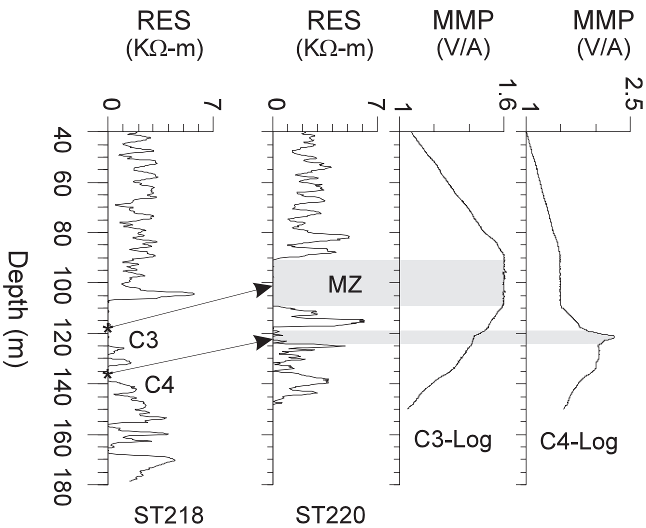

Figure 12: *Mise-à-la-masse measurements acquired in ST220 with current sources in ST218. The C3- and C4-Logs represent potential-depth profiles with electrodes at C3 and C4, respectively. MZ = Main zone.*

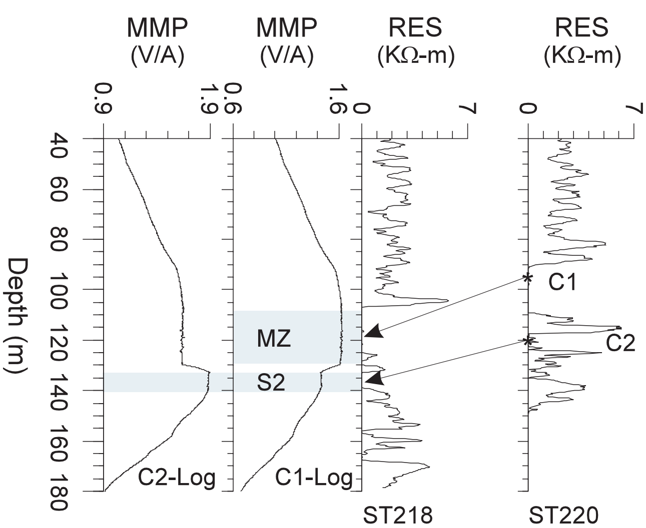

Figure 13: *Mise-à-la-masse measurements acquired in ST218 with current sources in ST220. The C1- and C2-Logs represent potential-depth profiles with electrodes at C1 and C2, respectively.*

show low resistivity across the two lenses in ST218. In ST220 the Main zone is clearly delineated on the resistivity log. There is also an indication of the extension of the S2 zone below the Main zone (the low resistivity zone between 118 and 124 m). With the current source in the

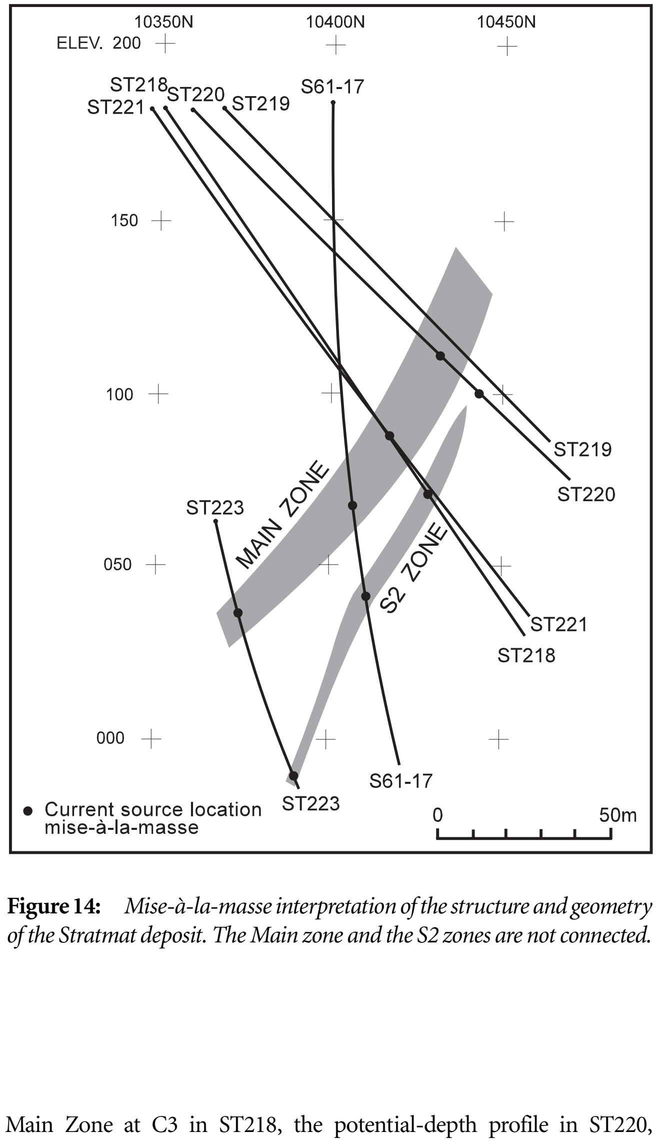

Figure 14: *Mise-à-la-masse interpretation of the structure and geometry of the Stratmat deposit. The Main zone and the S2 zones are not connected.*

Main Zone at C3 in ST218, the potential-depth profile in ST220, C3-Log, shows a potential high across the Main Zone indicating electrical connection between the two zones. A flat potential plateau is observed across the relatively low resistivity zone below the Main zone. With the current source in the S2 zone at C4 in ST218, the potential-depth profile, C4-Log, indicates that the S2 zone extends close to ST220 but is not connected to the Main zone.

To check for reciprocity and confirm that the two ore zones were isolated, current electrodes were placed in the Main zone in ST220 and at the low resistivity zone below. Potential measurements were made sequentially in ST218. The data from this survey are presented in Figure 13. The potential-depth profiles (C1-Log and C2-Log), again indicate that the two ore lenses are isolated and are not connected below ST220 as interpreted from the geological data.

Figure 14 shows the interpretation of the ore deposit geometry from all of the mise-à-la-masse measurements. The Main zone and the S2 zone, previously shown to be connected between ST218 and ST220 (Figure 11) were determined to be electrically isolated and therefore not structurally connected. This interpretation of the Stratmat deposit has currently been adopted as the working model.

REDSTONE NICKEL DEPOSIT, TIMMINS, ONTARIO

Geological setting

The Redstone nickel deposit is located approximately 20 kilometres southeast of Timmins, Ontario. The geology of the deposit consists predominantly of magnesium rich komatiitic ultramafic rocks of the younger Tisdale Group and felsic volcanic rocks of the older Deloro Group. Nickel sulphide mineralisation occurs at the contact of a sequence of hanging wall ultramafic rocks and foot wall felsic volcanics. Mineralisation also occurs entirely within the footwall felsic rocks and also within the hanging wall ultramafic volcanics. Nickel mineralisation consists of pentlandite and millerite. Other associated sulphides include pyrrhotite, pyrite, and chalcopyrite.

Previous hole-to-surface mise-à-la-masse measurements, carried out on the R-zone at the Redstone nickel deposit by Utah Mines Limited (Witherly, 1986), successfully outlined the deposit and indicated its strike extent, dip and plunge. Several holes were drilled for exploration purposes. One of the holes drilled to test the down-dip extension of the R-zone (TN-11), intersected massive nickel sulphides well below the depth that was projected from the structural information on the shallow part of the known R-zone. Figure 15 shows the problem posed by this new mineral intersection. The basic question that needed to be answered was whether the mineral intersection in TN-11 was an extension of the shallow ore body or whether it was a separate and isolated mineral intersection. Because the geological data was not conclusive, a follow-up drilling program preceded by a mise-à-la-masse survey to answer this question was discussed. The GSC carried out hole-to-hole mise-a-la-masse measurements in order to provide some answers to this problem.

Results and discussions

Figure 16 shows mise-à-la-masse measurements between TN-10 and TN-11. The nickel sulphides in both holes are fairly conductive relative to the host rocks. Mise-à-la-masse potential measurements were made in TN-11 with current sources in TN-10 placed at the two sulphide intersections, C3 and C4. Two potential highs were observed around 800 and 870 m in TN-11. The lower potential high around C2 coincides with the Ni zone suggesting electrical continuity with that in TN-10. No mineralisation was intersected around the upper potential high and resistivity logs (not shown) do not indicate low resistivities at these depths in TN-11. A conductive zone may be present between TN-11 and TN-10, that is not close enough to TN-11 to be detected on the resistivity logs. There is also a fairly significant change in resistivity at this location, which is at a contact between a diabase dyke and the ultramafic. To check for reciprocity, potential measurements were made in TN-10 with current sources placed in TN-11 at C1 and in the mineralisation at C2. The mise-à-la-masse responses for the two current source locations confirm the electrical continuity of the conductive zones between the two holes. The interpretation of the mise-à-la-masse data (Figure 16) shows that the R-zone in TN-10 is connected to the nickel sulphide intersection in TN-11. There is also a possible conductive path above the mineralisation. These

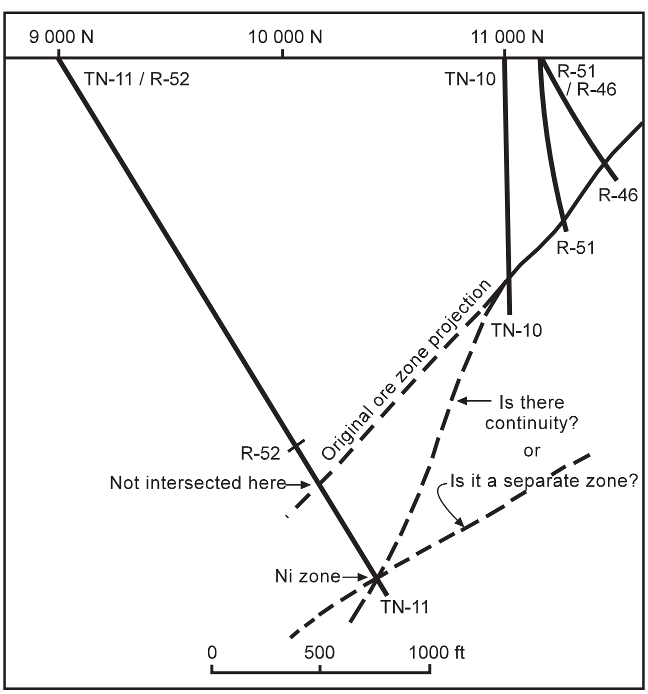

Figure 15: *Geological problem presented at the Redstone nickel deposit, Timmins. Borehole TN-11 intersected nickel sulphides at a much greater depth than predicted by projecting the deposit orientation from the near-surface R-zone.*

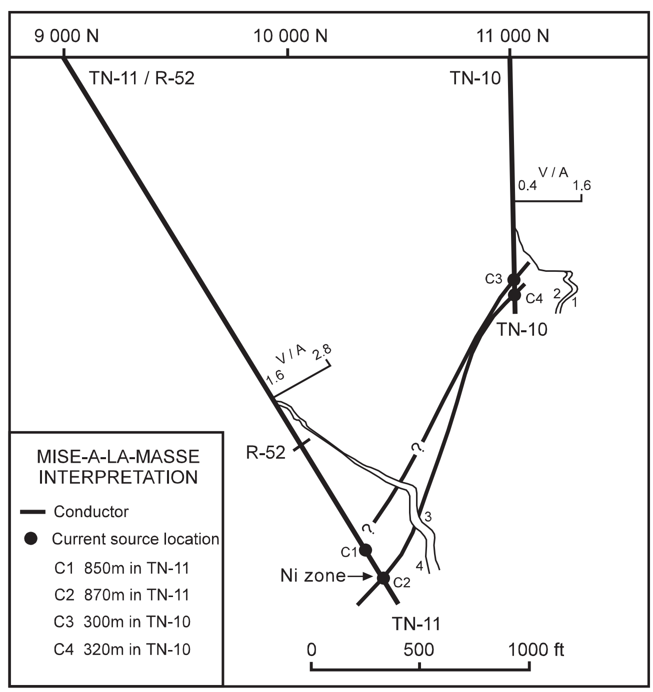

Figure 16: *Interpretation of the mise-à-la-masse data between TN-11 and TN-10. Electrical continuity was established between nickel mineralisation in the two holes.*

data provided a strong case to justify the proposed follow-up drilling program to evaluate the mineral potential between TN-10 and TN-11. Subsequent drilling between TN-10 and TN-11 confirmed the down-dip extension of the R-Zone deposit to hole TN-11. The ore reserve estimates were substantially increased as a result of these surveys.

CONCLUSIONS

Borehole mise-à-la-masse surveys at the Victoria graphite deposit were successfully used to correlate high-grade graphite zones between holes. These data were used in the planning of a small scale open pit graphite mining operation that required an accurate understanding of the connections between different graphite zones in order to maximise the ratio of ore-to-waste rock during mining operations. At the Hoyle Pond gold deposit, the mise-à-la-masse measurements were successful in hole-to-hole correlation of gold-bearing, relatively conductive carbonate alteration zones. The limited mise-à-la-masse measurements between two holes indicated that there were two possible orientations of the alteration zones, one nearly vertical which is concordant with the primary structures (foliation and brecciation) within the basalts and another one which cuts these primary structures. The axis along the intersection between these two orientations of the alteration zones proved to have the best gold values.

Mise-à-la-masse measurements at the Stratmat massive sulphide deposit were used to resolve the structural relationship between two massive sulphide zones that were originally thought to be connected near the surface. At the Redstone nickel deposit, mise-à-la-masse measurements established electrical continuity between sulphide mineralisation intersected in two widely spaced boreholes and directed the drilling of a follow-up program to determine the down-dip extension of the deposit. Subsequent drilling after the mise-à-la-masse survey, confirmed the mise-à-la-masse findings, increasing the ore estimates significantly.

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