Time domain spectral IP results from three gold deposits in northern Saskatchewan

Ian Johnson and **Blaine Webster**, JVX Ltd., and
Ron Matthews and **Steve McMullan**, Cameco

ABSTRACT

Time domain spectral Induced Polarization (IP) data from the Tower, Jojay and Laurel Lake gold deposits in northern Saskatchewan are presented. The resistivity data shows both resistivity lows (due to fault, shear or alteration zones) and resistivity highs (due to silicification) in the area of the deposits. The high resistivity zones suppress and distort coincident IP responses, calling for high quality surveys and special care in interpreting the IP data.

Electromagnetic methods are not effective in locating the deposits. This is due, in part, to masking by conductive cover. The Jojay Lake deposit has a strong magnetic response. A more indirect magnetic association is seen for the Tower Lake deposit. The Laurel Lake deposit has no magnetic signature. Magnetic data are useful in defining structure in all cases.

All three deposits are outlined in the IP survey results. IP anomaly amplitudes from the pole-dipole array are from two times (Tower and Laurel Lake) to six times (Jojay Lake) background values. Gradient array IP anomalies are of less amplitude. The spectral time constant is short for the Tower and Laurel Lake deposits and long for the Jojay deposit. This implies that the metallic sulphides in the Jojay deposit are more interconnected than those of the other two deposits.

INTRODUCTION

Induced polarization/ resistivity surveys are commonly used in gold exploration programs in the Canadian shield because the IP method is effective in detecting disseminated metallic sulphides which are often found associated with gold. Other common geophysical survey methods such as magnetics, VLF and EM are not generally capable of direct detection of disseminated sulphides.

Keywords: Exploration, Gold deposits, Induced polarization (IP) methods, Tower Lake deposit, Jojay Lake deposit, Laurel Lake deposit, Spectral IP.

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Since the introduction of the IP method in the 1950s, it has undergone continuous improvement. The most recent improvement is the development of time domain receivers which sample the full decay and record it in digital form. This results in a more complete measurement of the response which permits analysis and enhancement of data quality and the derivation of anomaly parameters which characterize the measured decay. This extension of conventional time domain IP methods is called spectral IP, a term first introduced by Pelton *et al.* working in the frequency domain(1). Spectral IP surveys are attractive because they allow the possibility of discriminating between IP responses which have similar amplitudes but are due to dissimilar geologic targets. The discrimination can be important in the selection of IP anomalies for follow-up.

Time domain spectral IP survey results are presented over three known gold deposits in northern Saskatchewan—Tower Lake, Jojay Lake and Laurel Lake. The surveys were initiated and supported by Cameco—A Canadian Mining and Energy Corporation (formerly the Saskatchewan Mining and Development Corporation—SMDC) and were carried out by JVX Limited using the Scintrex IPR-11 receiver and attendant spectral analysis software.

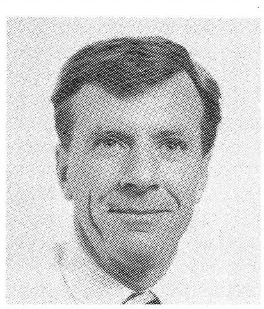
Time Domain Spectral IP

In conventional time domain IP/resistivity surveys, the chargeability is recorded as an average of the residual voltage after shut-off of an interrupted square wave. In spectral IP, the receiver samples the decay at a number of time periods, thus defining the shape of the decay. Each measured decay can then be analyzed for curve shape characteristics using simple models. The model most commonly used is the Cole-Cole model(1), originally developed by Pelton *et al.* for the analysis of frequency domain IP data. This model is defined by four parameters. They are:

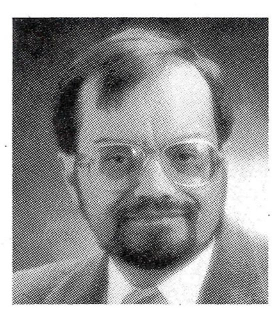
1. R—the resistivity in ohm-meters
2. m—the chargeability amplitude in mV/V
3. tau—the time constant in seconds
4. c—the exponent (dimensionless).

These parameters are independent physical properties of the subsurface. Conventional chargeability (or per cent frequency effect or phase if working in the frequency domain) is a mix-

Ian Johnson received a B.Sc. in geophysics from the University of Western Ontario in 1968 and a Ph.D. in geophysics from the University of British Columbia in 1972. On graduation, he worked for Paterson, Grant and Watson Ltd. From 1978 to 1986, he worked in the surveys division of Scintrex Ltd. in Toronto. He is currently a consulting geophysicist working in areas of resistivity/IP and helicopter borne surveys.



Blaine Webster received a B.Sc. in geophysics from the University of British Columbia in 1970. He joined Inco in Sudbury in 1971 where he worked until 1979. Between 1979 and 1983, he was manager of ground and drillhole surveys for the Toronto office of Scintrex Ltd. He founded JVX Ltd. in 1983. The company has performed a variety of services including contract geophysical surveys and regional and property geological and geophysical studies. Included are more than 200 time domain spectral IP surveys.



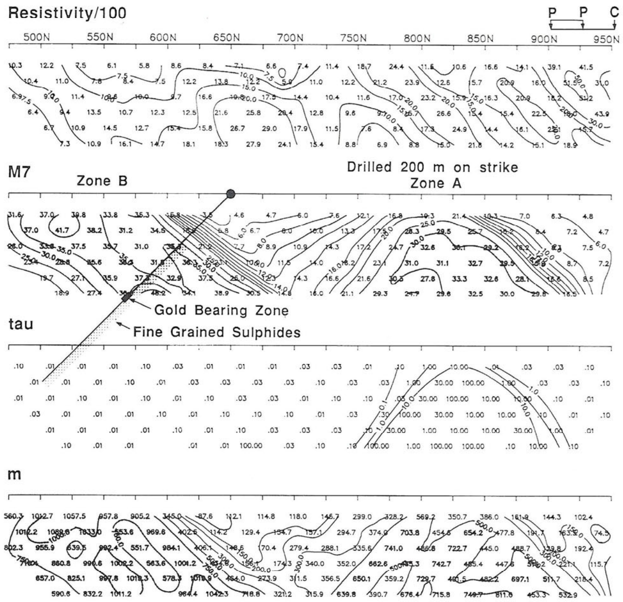


FIGURE 1. Time domain spectral IP results from a pole-dipole survey (dipole spacing = 25 m) near Chibougamau, Quebec. Shown in pseudosection form are the apparent resistivity/100, the eighth slice chargeability (labelled as M7 according to IPR-11 protocol-taken from the 690 to 1050 ms window), time constant and chargeability amplitude (m). Traverse direction is from right to left.

ture of the more fundamental properties m, tau and c.

In practice a suite of master decay curves is built up assuming a range of values of c and tau[2]. Measured decays are compared to these curves. The best agreement yields the spectral parameters m, tau and c for each dipole. As with resistivity and conventional IP, the spectral parameters are presented using normal pseudosection plotting conventions.

The derived spectral parameters are used to supplement the conventional IP/resistivity survey results. Pseudosections of apparent resistivity and one chargeability slice are often the basic presentation from profile type surveys. Ten slices are recorded by the IPR-11 receiver. The eighth slice located between 690 and 1050 ms after shut-off is commonly plotted. IP anomalies are picked from the chargeability pseudosections. The spectral parameters are also presented in pseudosection form so that they may be correlated with the IP anomalies.

The parameters m and tau are the most useful in separating anomalies with similar resistivity and chargeability characteristics. The chargeability amplitude m is related to the volume per cent metallic sulphides (although there is no convenient quan-

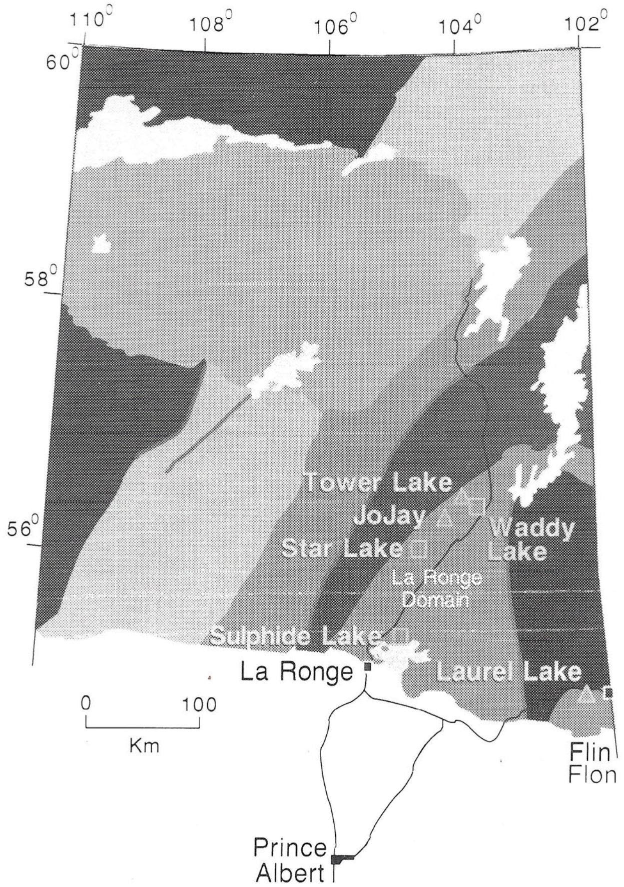
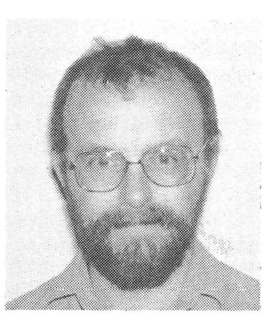


FIGURE 2. Regional geologic map of northeastern Saskatchewan showing the position of the Tower Lake, Jojay Lake and Laurel Lake deposits.

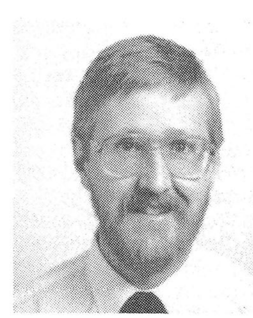
titative relationship between m and the volume per cent polarizable material). The time constant is related to grain size and commonly varies from 0.01 to over 100 s. Finely disseminated sulphides should give a short time constant. Interconnected or more massive sulphides should give a long time constant. The exponent c is a measure of the uniformity of grain size and varies from 0.1 to 0.5. A c value of 0.5 suggests a single polarizable source. Smaller c values imply a mixture of sources. These concepts from Pelton *et al.*[1] are the starting point for interpreting spectral IP data. They will be refined and improved as more experience with the spectral IP method is gained.

An example of the use of spectral IP surveys for gold exploration is shown in Figure 1[3]. Two distinct, but similar,

Ron Matthews received a B.Sc. in physics from the University of Exeter in 1970, and a Ph.D. in geophysics from the University of London, England, in 1976. On graduation, he joined Hunting Geology and Geophysics as a geophysicist. He has worked for Noranda Exploration Ltd. and Geoscource in Dublin, Ireland, and in 1978 joined Cameco (then the Saskatchewan Mining and Development Corporation — SMDC), based in Saskatoon. He is currently senior geophysicist with Cameco. His primary area of interest is mining geophysics with particular emphasis on electromagnetic methods.



Steve McMullan received a B.Sc. in honours earth science from the University of Waterloo in 1980. On graduation, he joined Uranerz Exploration and Mining Ltd. as a geophysicist involved in exploration for uranium in Saskatchewan and the Northwest Territories. From 1983 to 1988, he was employed as a geophysicist with Cameco (then the Saskatchewan Mining and Development Corporation — SMDC), based in Saskatoon where he worked on exploration for uranium as well as gold and base metals in the La Ronge and Flin Flon areas. He is currently a geophysicist with the Geological Survey of Botswana.



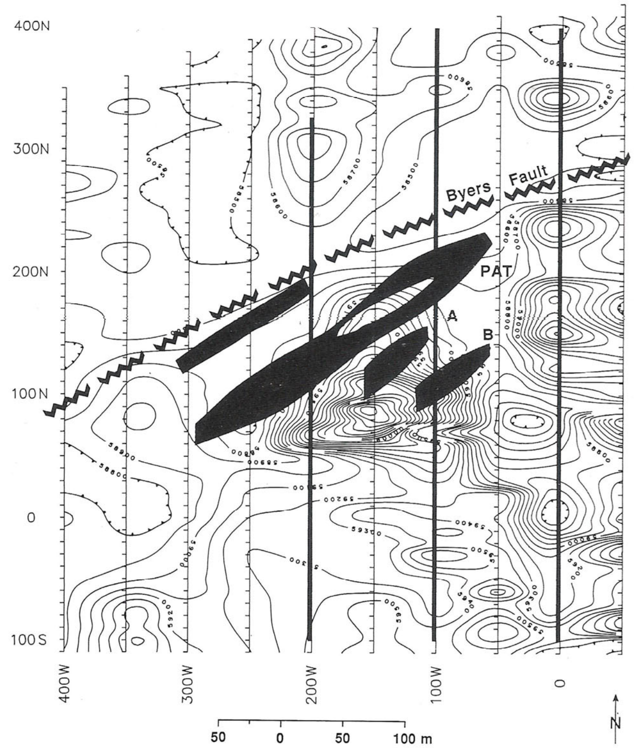


FIGURE 3. Contoured magnetic map for the Tower Lake area. Minimum contour interval = 100 nT. The shaded areas outline the mineralized zones (labelled A, B and Pat). Lines of pole-dipole survey coverage are highlighted.

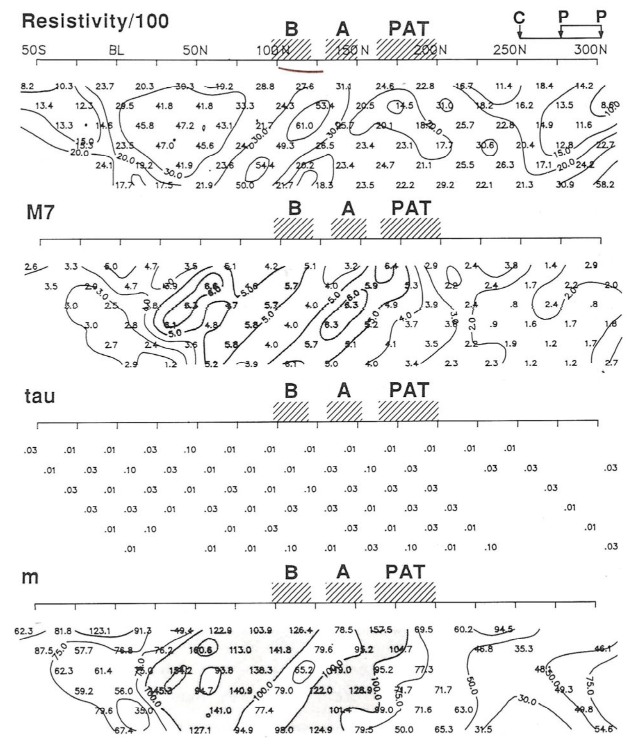


FIGURE 4. Contoured pseudosections of the spectral IP/resistivity results for line 1+00 W of the Tower Lake grid. Shown are the apparent resistivity in ohm-m divided by 100, the eighth slice chargeability (M7) in mV/V, the time constant (tau) in seconds and the chargeability amplitude (m) in mV/V. The B, A and PAT mineralized zones are indicated. Traverse direction is from south to north. Areas of M7 greater than 5 mV/V and m greater than 100 mV/V have been shaded.

IP/resistivity anomalies are seen in the pseudosections of apparent resistivity and chargeability. The time constants are generally short (i.e. 0.01 to 0.1 s) for the anomaly to the left and long (i.e. 10 to 100 s) for the anomaly to the right. Both anomalies have been drilled. The anomaly showing the short time constants was confirmed to be caused by fine grain disseminated sulphides. The long time constant anomaly was found to be caused by more coarse-grained sulphides. Economic gold was found in association with the fine grained sulphides whereas only small amounts of gold were found in the area of the long time constant IP anomaly.

Time domain spectral IP is beneficial for reasons additional to that of source discrimination. The analysis provides a measurement of data quality which can be used by the operator to improve survey procedures. The analysis can be used to separate signal from instrument or geologic noise. In very resistive areas, for example, potential electrode cable effects may produce false chargeability highs, particularly at early times. Inductive coupling effects may give problems in conductive areas. Spectral IP allows the identification and separation of decays which are of interest from those which are noise related.

Regional Setting of the Tower Lake, Jojay Lake and Laurel Lake Deposits

Figure 2 shows the location of the deposits relative to the regional geology of northeastern Saskatchewan(4). The area is underlain by Proterozoic metasediments, metavolcanics and intrusives of the La Ronge Domain. Paleozoic sediments lie to the south and west and the Athabasca Basin is located to the northwest.

Current gold exploration in northern Saskatchewan has focussed on known gold showings and their immediate surroundings in the Central Metavolcanic Belt of the La Ronge Domain, particularly in the Sulphide Lake, Star Lake and Waddy-Tower Lakes areas. The Jojay Lake deposit is located approximately 8 km north of the Star Lake mine. Most gold deposits in this area are structurally controlled and are hosted by quartz veins. Controlling structures may be shear zones (Jojay Lake), or late regional fault structures such as the Byers Lake fault (Tower Lake)(4). Another major auriferous area is located in the Flin Flon-Amisk Lake area in the Flin Flon Domain. Gold occurences (e.g. Laurel Lake) in the West Channel of Amisk Lake are characterized by quartz-vein systems surrounded by extensive alteration haloes of carbonate, sericite and silica(4).

Tower Lake Project

The Tower Lake Project is a gold exploration joint venture operated by Golden Rule Resources Ltd. in partnership with Goldsil Resources Ltd. and Cameco. The project is located approximately 170 km northeast of La Ronge, Saskatchewan. Geologic reserves of the Tower East deposit are 1.36 million tonnes at 3.4 g/tonne gold (1.5 million short tons at 0.1 oz/ton). Definition diamond drilling of the deposit is currently in progress.

Geology

The project is located within the Central Volcanic Belt of the La Ronge Domain which hosts most of the major gold occurrences in the La Ronge area. The Tower East deposit is hosted by quartz diorite of the Brindson Lake pluton and is associated with the regional Byers fault system. Gold is associ-

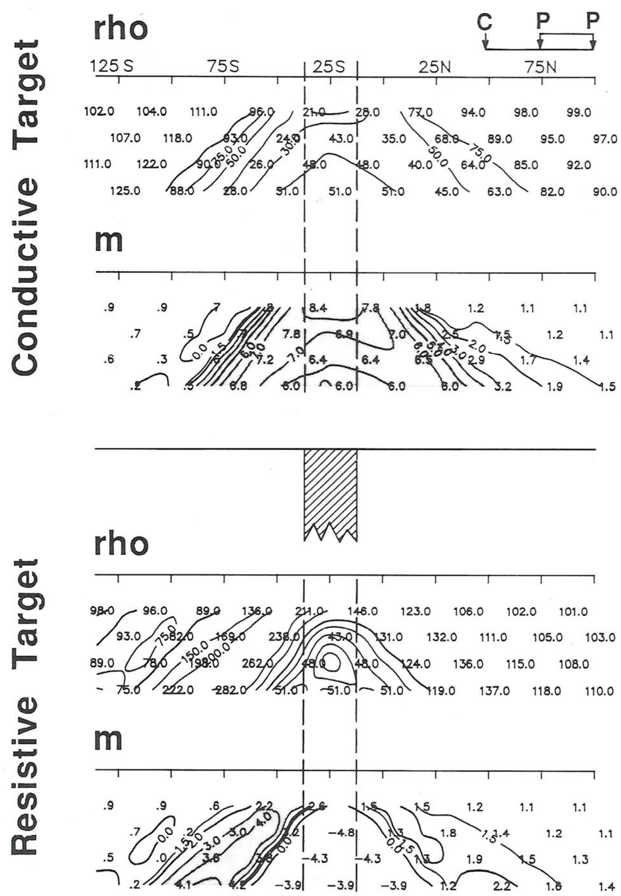


FIGURE 5. Theoretical resistivity/IP pseudosections for a vertical tabular body at surface. Results are for a pole-dipole array traversing from left to right. The host medium has a resistivity (rho) of 100 and a chargeability (m) of 1. The tabular body has resistivities of 10 and 1000 respectively and a chargeability of 10 (all units are relative). Areas with chargeabilities greater than 3 have been shaded.

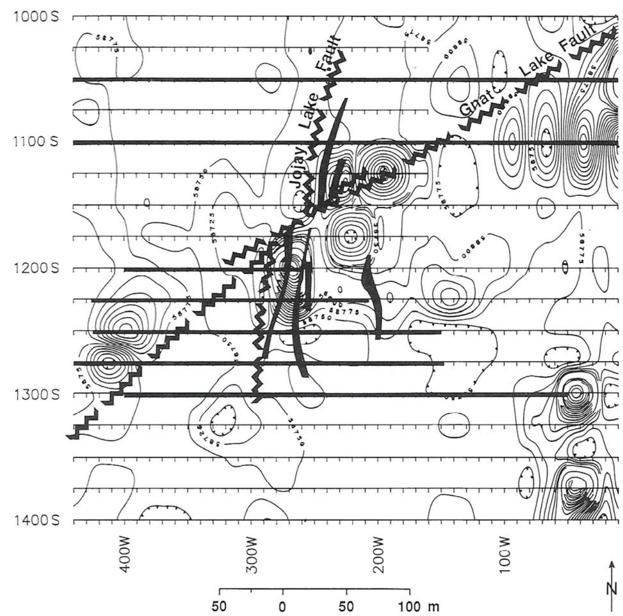


FIGURE 6. Contoured magnetic map for the Jojay Lake area. Minimum contour interval = 25 nT. The shaded areas outline the mineralized zones. Lines of pole-dipole coverage are highlighted.

ated with pyrite which occurs most commonly as pervasive fine-grained disseminations and stringers[5]. An increase in gold concentration with an increase in pyrrhotite has been noted in some cases.

Gold content varies directly with pyrite concentration and occurs as fine-grained inclusions in pyrite with a few grains intergrown with calcite/quartz microveining. Pyrite concentrations vary between 1% and 5% in the mineralized zone. The pyrite mineralization occurs as fine-grained disseminations and stringers as well as clusters of coarse-grained euhedral crystals. The occurence of minor amounts of fine-grained chalcopyrite typically marks areas of higher grade gold values (visible gold). The mineralized zones are 10 m to 40 m wide and are covered with a variable thickness of sandy boulder till and minor glaciolacustrine clay.

Geophysical Setting

The Tower Lake deposit is outlined on the contoured magnetic map in Figure 3. The minimum contour interval is 100 nT. The Byers fault which marks the contact between mafic volcanics to the north and quartz diorite intrusive rocks to the south is seen as a break in the isomagnetic contours. IP/resistivity surveys were conducted over lines 0, 1 + 00 W and 2 + 00 W. The pole-dipole array with six dipoles and a dipole spacing of 25 m was used.

The geophysical signature of the deposit is that of a weak IP response. There is no direct electromagnetic response associated with the deposit. The deposit has an indirect magnetic response.

IP Survey Results

The IP/resistivity results for line 1 + 00 W are shown in contoured pseudosection form in Figure 4. South of station 0 + 25 S bedrock responses are masked by conductive lake sediments. Mineralization in the Pat, A, and B zones correlate to a broad low resistivity zone of apparent resistivities less than 3000 ohm-m and anomalous M7 chargeabilities in three zones from 0 + 25 N to 2 + 00N (5.5 to 6.5 mV/V with background values of 1 to 4 mV/V). A local resistivity high at stations 1 + 25 N to 1 + 50 N may indicate an area of silicification. The Byers fault is interpreted at 2 + 25 N and is characterized by a 125 m wide zone of low chargeabilities.

The lower two pseudosections show the spectral time constant and chargeability amplitude. Plot positions with no data are where the IP decay has been judged too noisy for reliable determination of spectral parameters. As most of the spectral data has been plotted, the IP survey is judged to be of good quality.

The time constant is consistently short in the area of the deposit indicating a fine-grained texture. The chargeablility amplitude may be used to locate areas of highest metallic sulphide concentrations. The pseudosections show three chargeability anomalies. These correspond to the three mineralized zones when allowance is made for a shift of approximately one dipole spacing between the chargeability high and the causative body, i.e. the IP anomaly is located one dipole spacing before the target. This positional shift may be explained by the model results shown in Figure 5. Theoretical apparent resistivities and chargeabilities for a pole-dipole array passing over both a conductive-chargeable and a resistive-chargeable body are shown. These results have been calculated by the computer program IPNDIKE from Urquhart Dvorak Ltd. The algorithm is from Hanneson[6].

Figure 5 illustrates how the chargeability anomaly is cen-

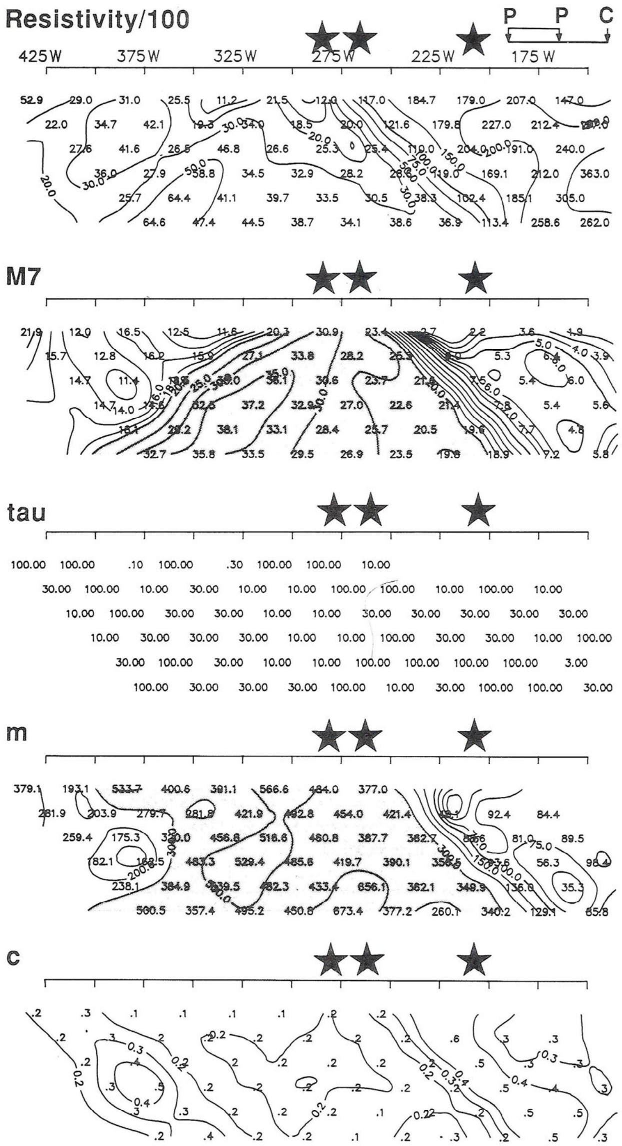


FIGURE 7. Stacked pseudosections for the pole-dipole survey on line 12+50 S over the Jojay Lake deposit. Shown are the apparent resistivity in ohm-m divided by 100, the chargeability in mV/V (M7), the time constant in seconds (tau), the chargeability amplitude in mV/V (m) and the exponent (c). The location of the deposit is shown. The chargeability pseudosections have been shaded for M7 values greater than 20 mV/V and m values greater than 300 mV/V.

tered over the target when it is more conductive than the host. For a resistive target, however, the resistivity and IP anomalies are shifted and distorted and of less relative amplitude. This result applies to the Tower Lake data. The gold and disseminated sulphides are associated with more resistive zones of silicification. The higher resistivities are probably due to lower porosities. This behaviour is important when interpreting pole-dipole IP survey results for gold in a resistive environment.

Jojay Lake Project

The Jojay Lake Project is a gold exploration joint venture operated by Cameco in partnership with Claude Resources Ltd. and Shore Gold Fund Inc. The Jojay deposit is located approximately 150 km northeast of La Ronge, Saskatchewan. The deposit is within the Central Volcanic Belt of the La Ronge Domain. Geologic reserves of the Jojay deposit were 284 100 tonnes at 9.1 g/tonne gold (313 200 short tons at 0.26 oz/ton) following the winter 1987 program. The deposit is open below a depth of 250 m and is currently being considered for development.

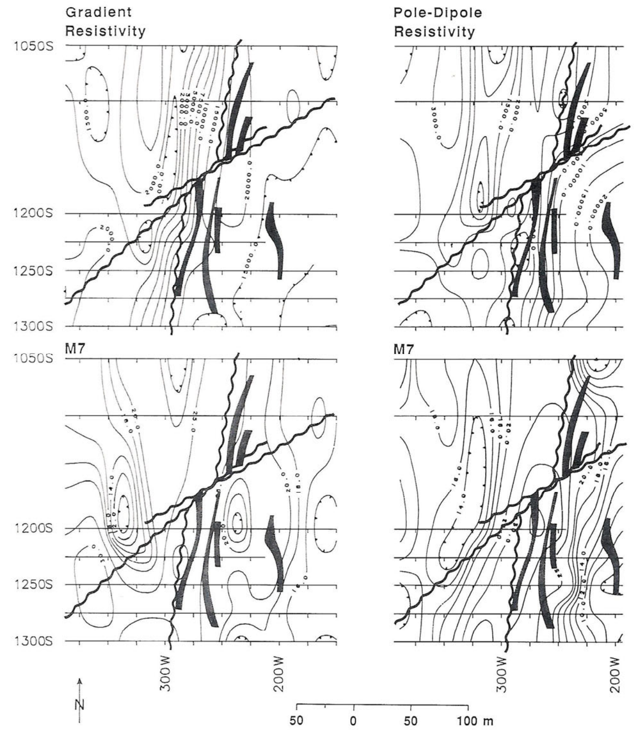


FIGURE 8. Contour plan maps of the apparent resistivity and chargeability (M7) from the pole-dipole and gradient surveys over the Jojay Lake deposit. Values from the second dipole of the pole-dipole data have been used.

Geology

The deposit is hosted by intermediate to mafic volcanics close to the fault contact with clastic metasediments. Pyrrhotite, pyrite, galena, sphalerite and quartz occur in a quartz-carbonate vein stockwork which is structurally controlled(7). Metallic sulphides range from 0 to 15% and average 2% of the rock volume. The deposit is 0.5 m to 10 m wide and is covered by 0 to 10 m of sandy boulder till.

Geophysical Setting

The deposit is outlined on the contoured magnetic map in Figure 6. The minimum contour interval is 25 nT. The Gnat Lake fault is seen as a break in the isomagnetic contours. The Jojay Lake fault marks the contact between clastic metasediments to the west and mafic to intermediate volcanics to the east.

IP/resistivity surveys were carried out using both gradient (dipole spacing = 25 m) and pole-dipole (six dipoles with a dipole spacing of 25 m) arrays. As gradient surveys are often two to three times less expensive than pole-dipole surveys, they are sometimes initially used to establish the regional IP/resistivity character of an area. Profile surveys are then carried out to provide detail in areas of interest.

The geophysical signature of the deposit is a strong magnetic anomaly together with a strong IP response. Electromagnetic surveys are dominated by surficial conductivity.

IP Survey Results

The apparent resistivities and chargeabilities obtained for the pole-dipole survey are shown as contoured pseudosections

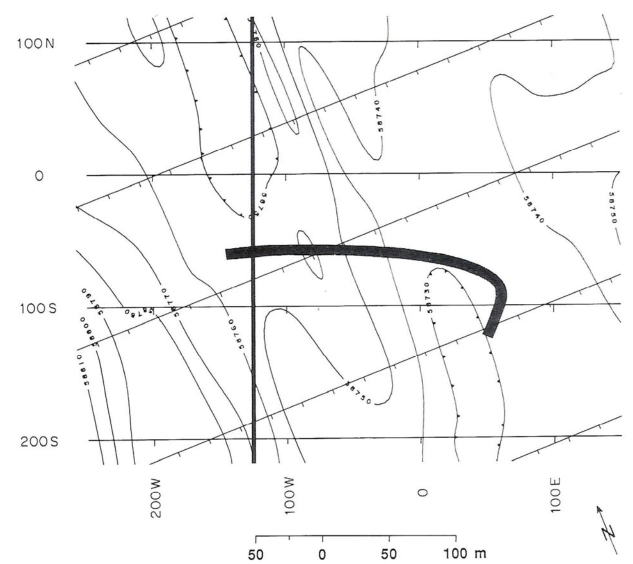


FIGURE 9. Contoured magnetic map for the Laurel Lake area. The minimum contour interval is 10 nT. The shaded area outlines the deposit. The line of pole-dipole coverage is highlighted.

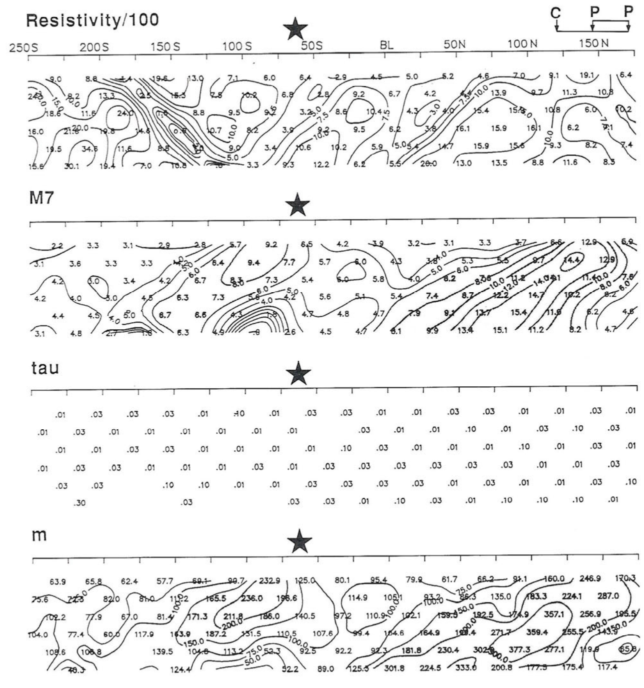


FIGURE 10. Stacked pseudosections for line 1 + 25 W over the Laurel Lake deposit. Shown are the apparent resistivity in ohm-m divided by 100, the eighth slice chargeability in mV/V (M7), the time constant in seconds (tau) and the chargeability amplitude in mV/V (m). The location of the deposit is shown. Traverse direction is from south to north. Chargeability anomalies of 6 mV/V or greater (M7) and 150 mV/V or greater (m) have been shaded.

in Figure 7. The mineralized zones are indicated. The resistivities are low (2000 to 5000 ohm-m) in the area of the Jojay fault ralative to the volcanics to the east which have resistivities greater than 20 000 ohm-m. The resistivities to the west of the Jojay fault are of the same order as those seen in the area of the fault. This may be due to the overburden cover which consists of swamp and muskeg.

The M7 chargeability pseudosection is dominated by a strong response which correlates with the mineralized area. IP response amplitudes are from 25 to 35 mV/V with background values of 5 mV/V. The IP anomaly does not separate the mineralized zones. This is expected given that the array spacing is twice their separation. The mineralized zone near station 2 + 00 W is of limited extent and does not significantly add to the total reserves of the deposit. As metallic sulphides are limited, there is no coincident IP/resistivity response.

The long time constant values imply coarse-grained sulphides. This may be an oversimplification as it is not clearly supported by the geology. The change in time constants from those seen at Tower Lake does, however, suggest some geological difference, although a better explanation for the difference is lacking. Physical property studies in both areas should give a basis on which to better interpret the spectral IP data.

The chargeability amplitude data suggests that there may be significant concentrations of metallic sulphides to the west of the Jojay fault. The spectral c value is included for completeness. In theory, a high c value suggests a single target whereas a low c value suggests that a mixture of polarizable sources is present.

The pole-dipole and gradient data are presented as contour plan maps in Figure 8. Both datasets show a low resistivity zone located west of a strong chargeability anomaly over the deposit. The gradient array appears to have provided a reliable picture of the regional resistivity and IP character. The pole-dipole results, however, give better resolution and a larger relative anomaly amplitude for the IP response which corresponds to the deposit.

Spectral parameters may also be derived from the gradient array data. The results are usually less reliable because the array is less focussed on one polarizable source. This is observed in this case where the average c value for line 12 + 50 S is 0.19 for the gradient array compared to 0.26 for the pole-dipole array. The time constants for the two arrays are in total disagreement east of the Jojay fault. The gradient array time constant is short (.01 to 1 s) whereas the pole-dipole array time constant is long (30 to 100 s). The pole-dipole time constants are more reliable in view of the higher c values.

Laurel Lake Project

The Laurel Lake deposit is part of the Amisk Lake project operated by Cameco in partnership with Husky Oil. The deposit is situated on Missi Island within Amisk Lake approximately 25 km southwest of Flin Flon, Manitoba. It is located within the Amisk Group volcanics which hosts all of the major base metal deposits in the Flin Flon area. Geologic reserves of the Laurel Lake deposit are 255 800 tonnes at 15.1 g/tonne gold and 75.7 g/tonne silver (281 970 short tons at 0.44 oz/ton Au and 2.21 oz/ton Ag) (press release, January 27, 1988). Underground exploration of the deposit started in the spring of 1988 as part of an economic feasibility study.

Geology

The deposit is hosted by quartz-feldspar porphyry, which forms part of an interpreted intrusive-flow complex. The mineralization appears to be synvolcanic in origin. Metallic minerals include pyrite, tetrahedrite, chalcopyrite, sphalerite and galena, which occur as disseminations and veins in a broad sericite alteration zone[8].

Gold occurs as fine specks of free gold in and along intergranular boundaries between sulphide grains. The sulphides occur as veins, stockworks, disseminations and irregular masses. Mineralization occurs in discrete sub-zones which are distinguishable by their dominant ancillary sulphide species. Sulphide concentrations vary from 10% to 30% of rock volume in a zone 1 m to 2 m wide. The overburden cover varies from 0 to 20 m in thickness and consists of glacio-lacustrine clay and boulder till.

Geophysical Setting

The outline of the deposit is shown on the contoured magnetic map in Figure 9. This outline is a much simplified view of what is a complex network of mineralized veins. The area was surveyed with the gradient array. Selected lines were also surveyed using the pole-dipole array. Electomagnetic and magnetic surveys have not been effective in outlining mineralization although they have been useful for regional mapping. The most useful survey for outlining the deposit directly has been IP/resistivity.

IP Survey Results

The spectral IP/resistivity results for line 1+25 W are presented in Figure 10. The mineralized zone correlates with a well-defined chargeability high with M7 anomaly amplitudes of 6 to 9 mV/V with background values of 3 to 4 mV/V. A resistivity low with apparent resistivities from 300 to 1000 ohm-m from stations 1+25 S to 0+75 N may outline the zone of alteration which contains the deposit. The chargeability high which maps the deposit coincides with higher resistivities. This could be interpreted as a region of silicification. The shape and location of the IP/resistivity anomalies are consistent with the model results shown in the lower half of Figure 5. The IP/resistivity anomaly to the north of the deposit has been drilled and an additional vein system has been discovered.

The time constant is uniformly short over the entire survey line. No significant difference in the texture of the polarizable material has been detected and the deposit appears to be associated with fine-grained material. The IP dataset is of good quality as most of the spectral results have been plotted. The chargeability amplitude data defines the target zone somewhat better than the M7 results. The chargeability amplitude anomaly is four to five times background.

Gradient surveys were conducted in two directions. The chargeability high seen in the pole-dipole survey which correlates with the deposit was also noted in the gradient IP data. The mineralized zones can be traced out using the gradient array although individual anomalies are less distinct.

Conclusions

Time domain spectral IP/resistivity surveys were conducted over three known gold deposits in northern Saskatchewan. In all cases the deposits were seen as chargeability highs. IP anomaly amplitudes varied from weak (Tower Lake), through moderate (Laurel Lake) to strong (Jojay Lake). The spectral data (time constant and chargeability amplitude) were most useful in the Tower Lake area where the conventional IP response was weak. This illustrates the usefulness of the spectral IP method in providing more diagnostic and better quality IP data needed to better select anomalies for follow-up. In all cases, the interpretation of the spectral parameters would benefit from access to more extensive model results and physical property studies.

The apparent resistivity data mapped the faults and alteration zones as resistivity lows. Local resistivity highs (often within the resistivity lows) may indicate areas of silicification and, hence, areas more promising for gold mineralization. High resistivities may also be responsible for a reduction in the amplitude and a distortion of IP anomalies. The intrepretation of pole-dipole IP data must make allowance for these effects.

The gradient array IP surveys gave somewhat mixed results. They have proved to be a useful method for establishing the regional character of an area and locating areas for follow- up.

There is no consistent magnetic signature to the deposits. Magnetic anomalies in the Jojay area are probably due to high concentrations of pyrrhotite. This association is not as apparent in the Tower Lake area and is absent in the Laurel Lake area. Electromagnetic methods are not useful for direct detection because the deposits are associated with disseminated sulphides which are normally only detectable using IP methods. The EM survey results are also strongly influenced by variations in conductive overburden.

Acknowledgments

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