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Archean Gold Exploration with ISR

An case history at Windjammer prospect on the Porcupine-Destor fault

Updated from the paper "Detecting Resistive Zones with the Inductive Source Resistivity Method:Updated Windjammer Case History" by James Macnae, Brian Groves, Stephen Conquer and Patrick McGowan,1989 SEG Meeting,Dallas,TX and "Doing Inductive Source Resistivity in the Winter: A New Development" by Patrick McGowan (1990)

Archean Gold Exploration with ISR

In electromagnetic (EM) exploration for conductive targets, measurements of the magnetic component or its time derivative have received more theoretical attention and practical application than have measurements of the electric component. However, the electric component can be shown to be particularly useful in the search for resistive zones not usually detected by the magnetic component. Normalized measurements of the surface voltage differences caused by the constant current induced at late time by the UTEM transmitter are called "Inductive Source Resistivity" or ISR measurements.

Data collected on the Windjammer property grid located straddling the south branch of the Porcupine Destor fault clearly show the effectiveness of the ISR technique in detecting a resistive zone of silicification. Due to the relatively slow falloff of the electric field from an inductive source, the technique is ideal for the rapid exploration of large areas.

Introduction

In geophysical prospecting, the use of electric field measurements from an inductive source has not received much attention in published literature. Combinations of E and H fields are used to calculate apparent resistivities from distant source systems, for example at VLF frequencies in the EM-I6R instrument (Collett and Becker, 1968) and in the magnetotelluric and controlled source audio-frequency magnetotelluric methods (Vozoff, 1985). These remote source techniques do not ,however, consider the E field data independently of the H field data.

The first detailed studies of the application in geophysical prospecting of electric fields from a local, ungrounded, controlled source transmitter to geophysical prospecting were performed at the University of Toronto. This was during the development of the UTEM system as described by Lamontagne (1975), Macnae (1981) and West et al (1984). When the UTEM 3 system became commercially available in 1981, its immediate applications were in conductor search for base metal and unconformity uranium deposit exploration, for which H field data alone were required. The geological requirement for a geophysical method capable of detecting resistive zones only became evident with exploration interest for epithermal gold deposits during the mid 1980"s, where associated alteration and silicification is commonly resistive.

In 1987 and 1988, several surveys were conducted which measured electric fields from the inductive UTEM source, and which successfully detected silicification associated with gold mineralization. Two test surveys in New South Wales, Australia, at Mt. Aubrey (Macnae and Irvine, 1988) and at Temora (Macnae et al, 1989) showed the effectiveness of the ISR method in detecting resistive zones beneath conductive cover. The Temora case showed a large response from a zone 140m deep under lOS of unconformable conductive overlying rocks. Modelling results (Macnae, 1981) confirm that the ISR technique is particularly effective in the exploration for steeply dipping resistive features, as the transmitter/target coupling is essentially unaffected by horizontal conductive cover.

Inductive Source Resistivity

The basic theory of ISR is given in Macnae (1981). Conceptually we can regard UTEM as a system which transmits alternating linear current ramps through an ungrounded loop. These ramps of constant slope create, through induction, a constant primary electric field vortex which circles around the loop. For a horizontal transmitter with unit current slope, the strength of this primary electric field is a function of geometry only and is independent of horizontal conductivity structure due to layering or overburden. The primary electric field thus induces a current system in the ground, whose local density is given by the product of conductivity and electric field, according to $J = \sigma E$. However, this steady state current takes time to establish, and while it is building up (dJ/dt non zero), there will be changes in dB/dt (measurable with a coil sensor). Thus the electric field reading will only reflect the true ISR when dB/dt has decayed to zero.

When the circulating electric field crosses any conductivity boundaries, local charge accumulations result which create secondary fields measurable at surface. Figure 1 presents the calculated total electric fields for a thick dyke for various dyke/host conductivity contrasts. The length of each electric field vector is normalized to the calculated primary field; this corrects for the falloff of amplitude with distance from the transmitter loop. Close to the transmitter loop, the general circulation of the electric field can be seen.

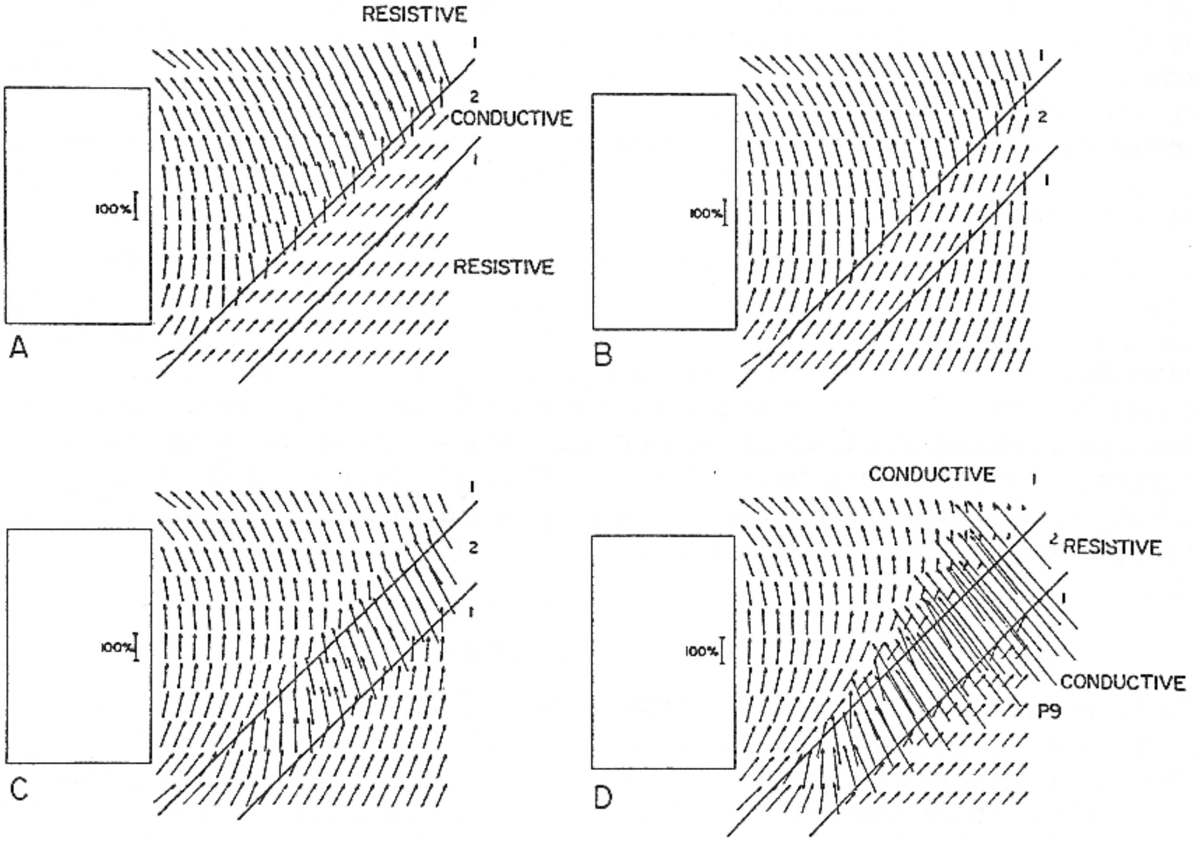

Figure 1: Vector plots of ISR response over conductive (top) and resistive (bottom) dykes. Dyke-to-host conductivity contrasts are (counterclockwise from upper left): 100:1, 3:1, 1:3, 1:100

In cases C,D for a resistive dyke with a resistivity contrast to the host of 3:1,100:1 respectively, we see the largest anomalies where the primary electric field cuts across the dyke, and much smaller anomalies at the bottom left of each plot where the primary field is approximately parallel to the dyke. In contrast, conductive dykes have distinct anomalies, which are much smaller in amplitude and tend to be parallel to the dyke rather than perpendicular to it.

It is interesting to note that because the primary electric field is divergence free, charge accumulations at boundaries are unable to cancel its tangential component, and a substantial electric field must exist behind the conductive dyke. Macnae (1981) has shown that the amplitude of this field behind the infinite dyke is exactly half that of the total primary field expected over a half-space. With a galvanic source (grounded current electrode), virtually no electric field would be present behind a very conductive dyke extending to surface. In layered situations, since the primary electric field from a horizontal transmitter is also horizontal, no charge accumulations (and hence no ISR anomalies) are created. This is of considerable advantage in prospecting over areas with thick overburden or a heavily weathered layer, as the source-to-target coupling is unaffected by overlying horizontal conductivity. The inductive source is thus far more effective than a galvanic source in causing currents to flow behind large conductors or under overburden. In those cases where the EM response shows a rapid decay, it may be possible to detect "Inductive Induced Polarization" or IIP effects, as is discussed in Macnae (1981) and in Pemberton (1989).

Windjammer Geology

In general the Windjammer property is underlain by an interbedded sequence of sediments and volcanics of Archean age (Figure 2). The rocks form a steeply south dipping, southwesterly striking series of units where a tops up configuration is indicated. The geological interpretation of some northerly dipping sections is local flexure. The geology of the property is known only from drilling, as there are no outcrops. Drilling has been locally extensive, concentrated in two areas where gold mineralization has been discovered.

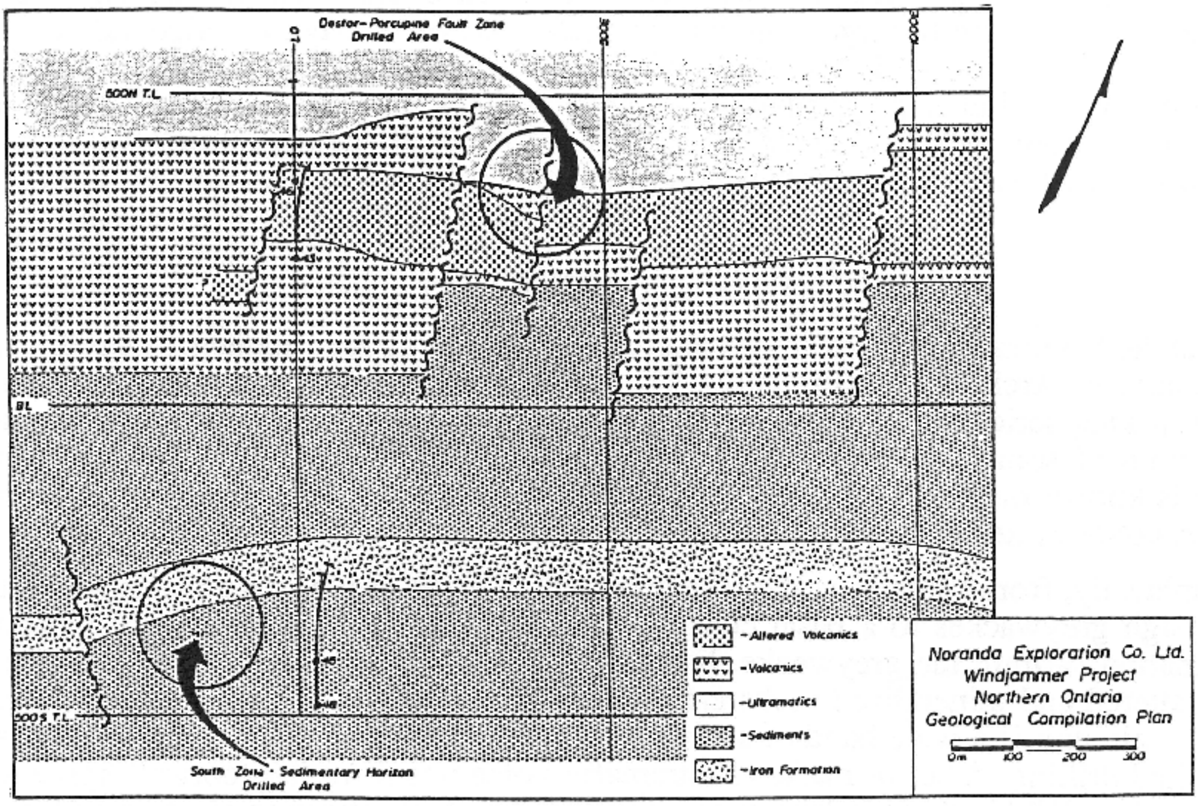

Figure 2: Geological compilation of the Windjammer Property, Matheson, Ontario.

Stratigraphically, from south to north, a sedimentary horizon grades from mafic (chloritic) tuffs through greywackes to a basal conglomerate and finally to an oxide facies banded iron formation. Within the greywacke, basal conglomerate and iron formation a zone of variably altered and mineralized rocks are present that is gold bearing (The South Zone). The next main unit is a wide band of sediments, assumed to be dominated by greywackes from limited drilling. A set of mafic to ultramafic volcanics form the footwall horizon of the greywackes. Within these volcanics several sections of silicification and fuchsitic-to-sericitic alteration have been observed, and these alteration zones locally host anomalous to economic gold values (North zone).

The sedimentary volcanic sequence is the host of numerous structures dominated by faults. The most important of these is the Destor-Porcupine Fault, which from Timmins to Amos (Quebec) is spatially associated with numerous gold mines. This fault is not so much a single fault plane as a wide zone of faulting. The most southerly branch of the fault zone crosses the northern part of the Windjammer property. Numerous cross faults are known to exist, some of which have been seen in drill core while others are inferred from regional and local magnetic surveys. On a regional scale, gold mineralization tends to exhibit a north-easterly trend and match breaks in magnetic anomaly continuity.

The results of a ground magnetic survey are presented on Figure 3. The most prominent magnetic highs are the iron formation to the south, and a zone of ultramafic volcanics to the north and east of the North Zone.

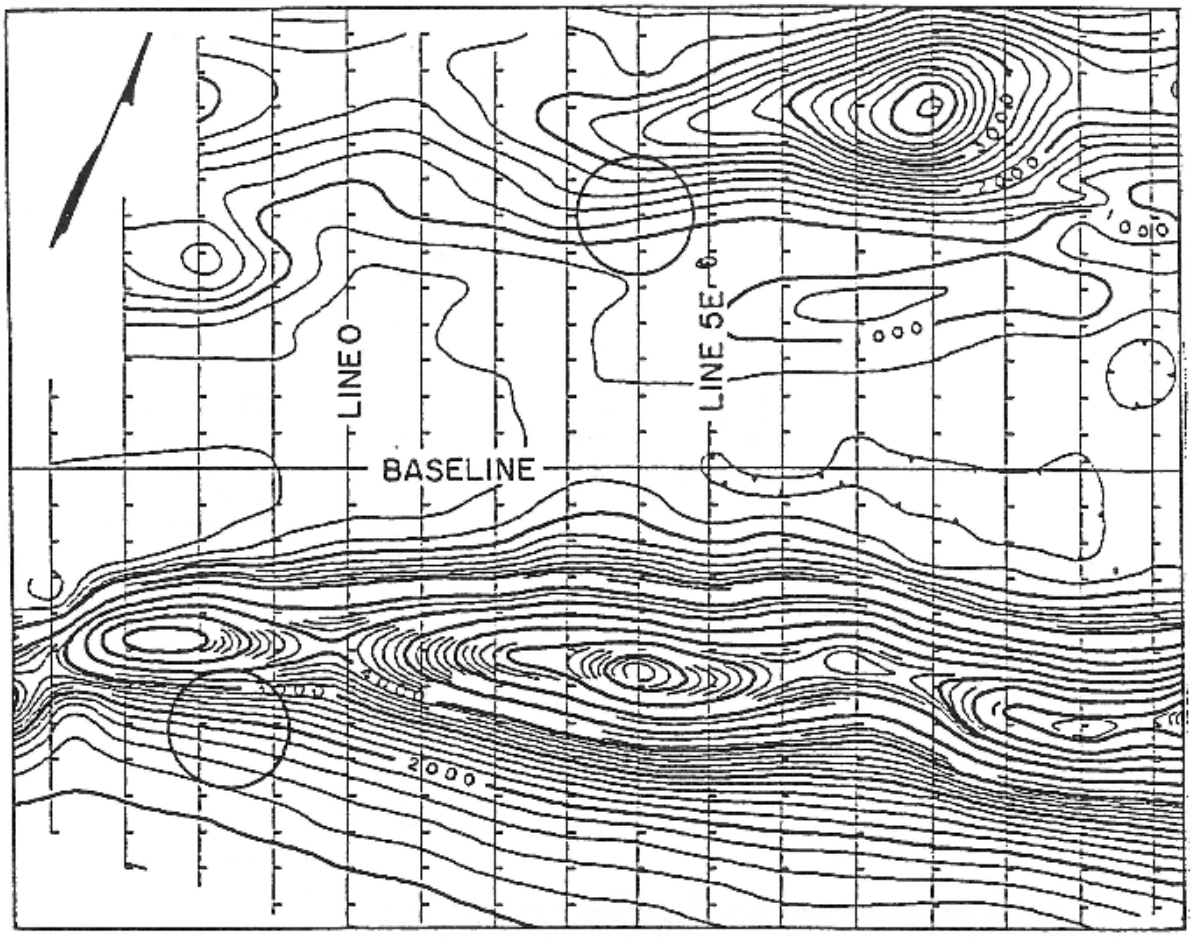

Figure 3: Contours of ground magnetics, Windjammer Property (the circles refer to the areas highlighted in Fig. 2).

Resistivity mapping of Windjammer

A conventional IP and Resistivity survey was performed at Windjammer using the pole dipole array, the results of which on line 0 are shown in Figure 5. The 50m of glacially transported overburden necessitated the use of a large (5Om) dipole separation leading to fairly low lateral resolution in this data. The overburden is evident as a near-surface resistivity and chargeability low. To the south, the iron formation shows as a clear resistivity low and chargeability high; while to the north no clear response is associated with the alteration.

The UTEM survey over the property was conducted in three segments at different times. A total of four transmitter loops were laid out for test purposes at different locations, both along and across strike from the gold mineralization. The data shown here used transmitter loops along strike located east or west of the grid. Figure 4 shows profiles of eight time samples of the received waveform using a 25m electric dipole oriented along the survey line (Ex). The transmitter loop was lying to the east of the survey line, some 800 metres away. The responses cluster together at late time (the ISR response); but can be seen to show the effects of electromagnetic induction in the overburden as a time-varying response in the earliest time channels. In this data, the iron formation is seen as a narrow low in the electric field, and the alteration as a distinct ISR or resistivity high.

In an effort to see how well data collected from different transmitter loops compared, line 7E was surveyed from both a transmitter loop to the east and also from one to the west. The data showed that while the lateral variation of response was virtually identical, the observed total amplitude was different by 20% between the two surveys. To equalize amplitudes for the contour plot, the data from the east loop were scaled by a factor of O.S. This variation can be attributed to regional variations in the circulating current system.

Figure 5 is a colour contour map of the late time electric field response or ISR. The data for this survey were collected using a single transmitter loop lying to the west and covered the same ground as the two previous surveys. The uniform coverage from a single loop solved the problem of level shifts between data sets as discussed above.

Over most of its length, the iron formation shows as an ISR low, lying on the southern flank of the sediments. The eastern extension of the iron formation is not well known from drilling. However, the ISR data would suggest that it either changes resistivity markedly towards the east or veers southward.

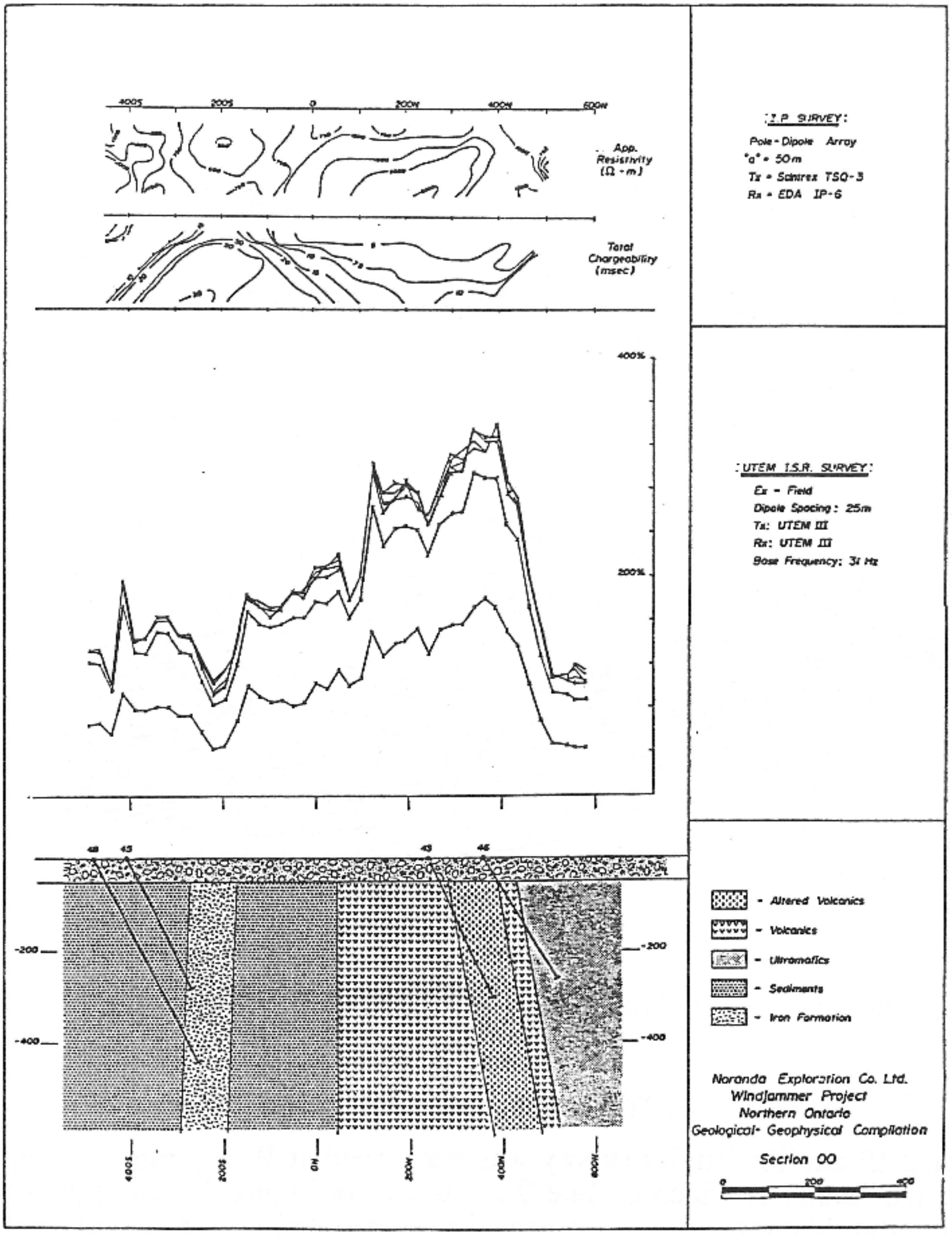

Figure 4: Conventional IP and dipole-dipole resistivity (top), UTEM ISR and e-field decay (centre) compared to geology (bottom)

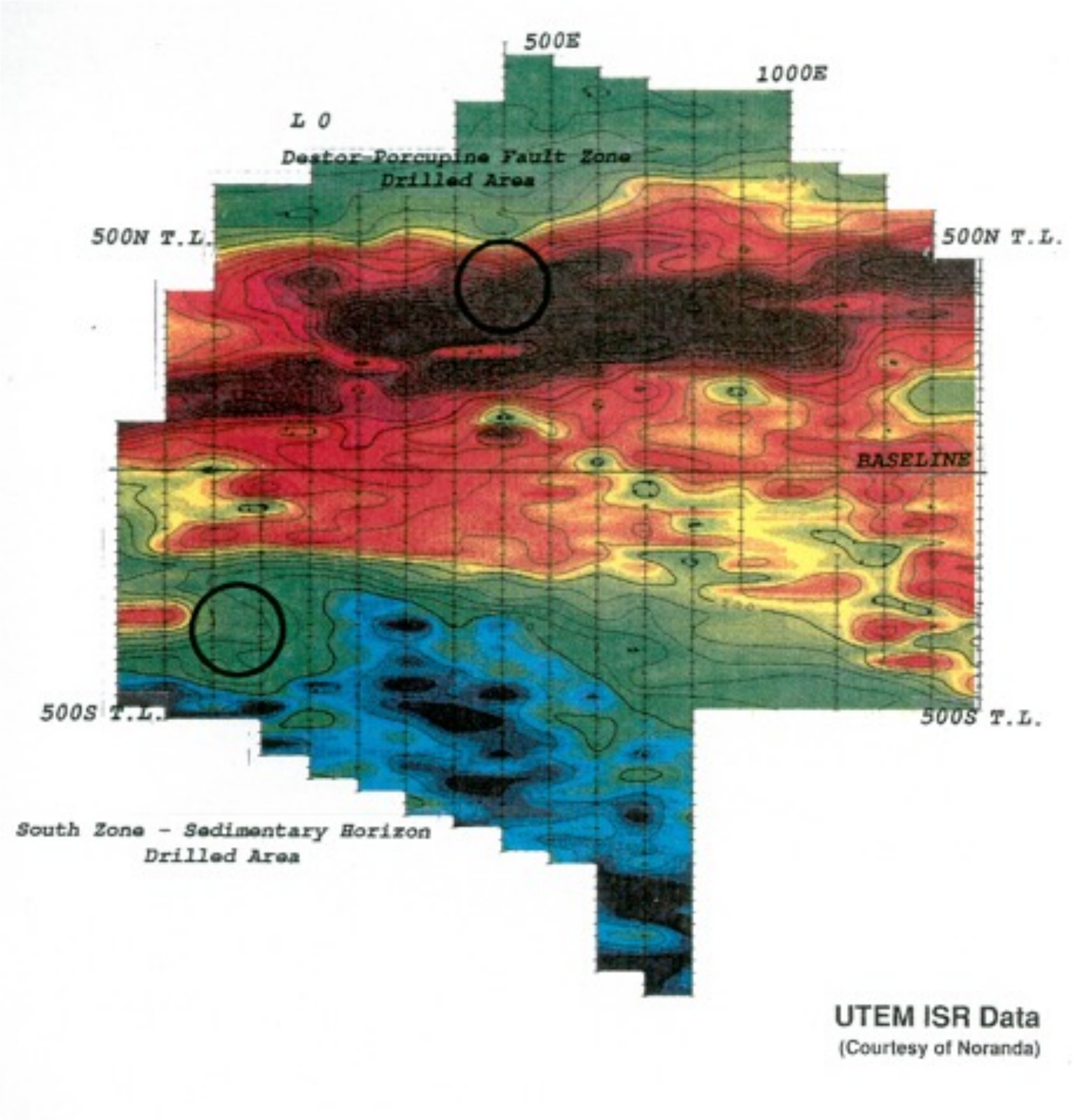

Figure 5: Contoured ISR data. The circles located the areas highlighted on Figure 2 and 3.

The alteration zone to the north associated with the Porcupine-Destor Break is clearly defined as a resistivity high. Faults and their accompanying offsets are well mapped; note the offset at line 0, and between lines 2E and 5E. The drilled gold mineralization occurs in an area where there is a coincidence of a pronounced ISR high with breaks in magnetic response and known faults.

Since horizontal layering produces no ISR response, the variations of ISR will primarily map bedrock resistivity variations; although lateral variation in overburden resistivity will have some effect. Surveying in this mode is rapid, with 4-8 km of line being read per day depending on factors such as access. The location of the transmitter loop can be several kilometres from the survey grid, allowing for a choice of layout depending on ease of access.

Conclusions

ISR is successful at mapping basement resistivity variations under a considerable thickness of overburden. With an appropriate choice of transmitter location, resistive zones can be easily mapped even with an inductive source.

Acknowledgements

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Appendix: Comparing Inductive Source Resistivity in Summer & Winter

Conventionally, the UTEM ISR technique has relied upon a grounded electric dipole as the sensor at the receiver. Despite the high (10 M-ohm) impedance of the UTEM receiver, surveying in the winter has posed to be more difficult due to to the inherent contact problems of frozen ground and snow cover. Capacitative electrodes have been developed and tested over the Windjammer gold prospect near Matheson, Ontario. The results of this survey compare very well with those obtained in a summer survey using grounded electrodes.

Two surveys, one in summer and one in winter, were carried out over the Windjammer gold prospect. The results from the survey on line 0 are shown here. Line 0 was first surveyed (25m stations) in summer using a 25m dipole comprised of conventional grounded electrodes and then surveyed a second time in winter using capacitive electrodes (same 25m dipole). The snow cover was about 1.5m (4 feet) thick for the winter survey. Surveying was done in both near freezing (-5°C) and very cold (-30°C) conditions with the same results. The same transmitter loop location was used for both the summer and winter surveys.

The capacitive electrodes were about 2.25m (7 feet) in length, had a diameter of 8cm (3.5 in) and weighed approximately 12kg (25 lb.). Care was taken to lay the electrodes in the snow in the same manner at each station as the depth of burial and contact area were found to affect the signal significantly. However, the survey was able to proceed at more or less the same production rate as the summer survey.

The results from line 0 are shown in Figure A-1 (on the following page) for both the winter and summer surveys. The base frequency in both cases was 30.974 Hz, and the data are continuously normalized. It is clear that the survey results are more or less identical. Subtle differences in the decay at late time (channels 1 - 5) may be noticed and at early times (channels 8 and 7), but the two surveys are remarkably similar. The Inductive Source IF (IIP) effects observed in the sum mer data (see Macnae, et al.) are not as obvious in the winter data. This may be explained in the fact the the IP sources may be affected by the frozen, near-surface conditions.

Conclusions

Capacitive electrodes for the UTEM system may be employed to collect ISR data in both winter and summer. The effects interpreted in the summer to be due to IIP may not be as reliably measured. Nevertheless, the advantages of good winter access will open up a much wider variety of terrain to cost effective resistivity mapping using the ISR method and UTEM"s capacitive electrodes.

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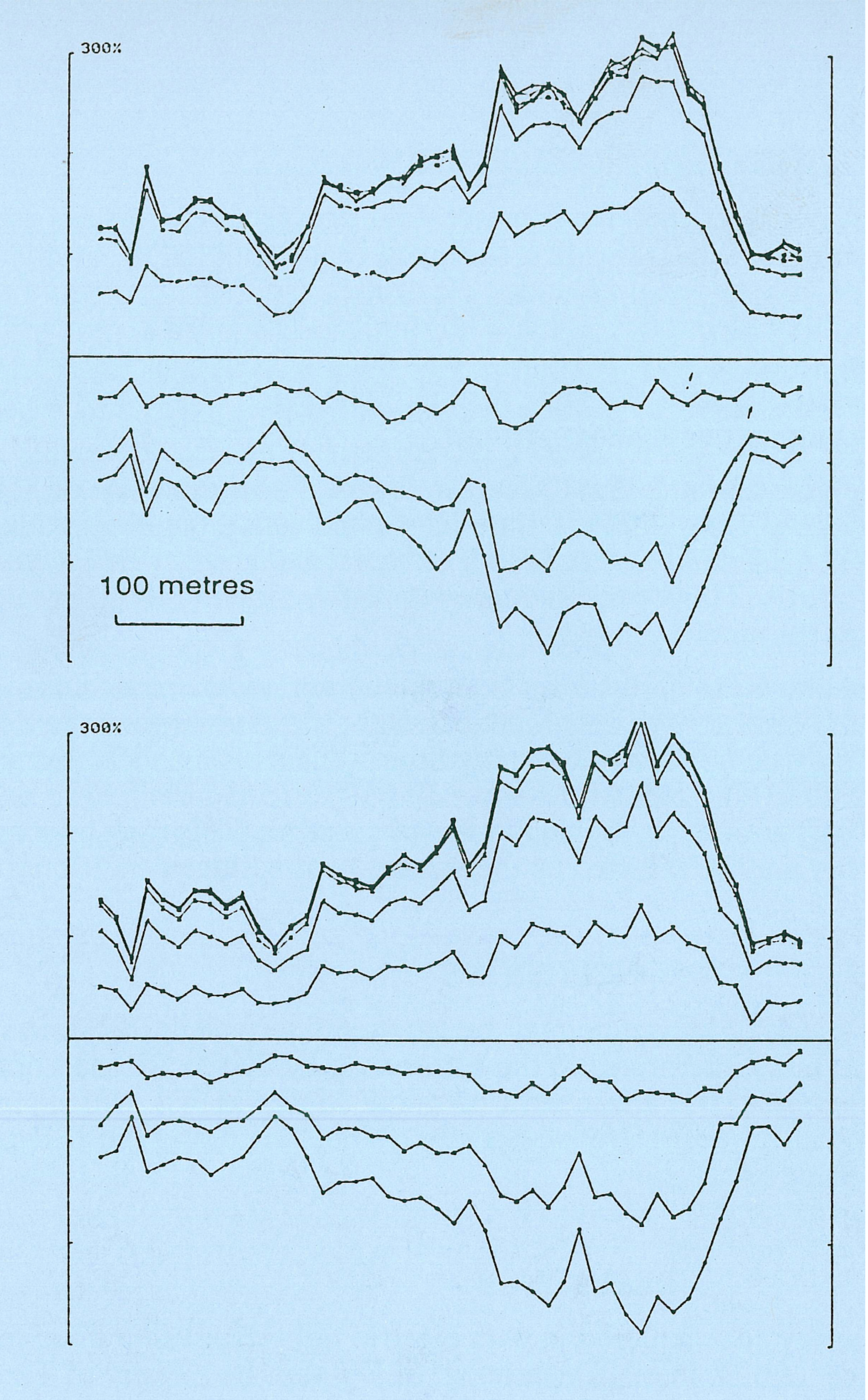

Figure A-1: Line 0 UTEM ISR data collected in the summer (top) using conventional, grounded electrodes and in the winter (bottom) using capacitative (non-contacting) electrodes.