Resistivity Mapping Using Inductive Sources

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Abstract

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 a grid located just south of the Temora gold mine in N.S.W. clearly show the effectiveness of the ISR technique in detecting a resistive zone of silicification located unconformably under 10S of conductive cover. 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.

Key words: inductive source resistivity, UTEM, Temora, gold

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 EM16R instrument (Collett and Becker, 1968) and also 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 were in New South Wales, Australia, at Mt. Aubrey (Macnae and Irvine, 1988) and at Temora. 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. A number of other tests were conducted in Canada on the Porcupine-Destor break (Pemberton, 1989; Macnae *et al*, 1989), where the transported overburden is not very conductive and where detected inductive induced polarization (IIP) effects were closely associated with the pyrite present in the immediate vicinity of drilled gold mineralization.

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.

In cases C,D for a resistive dyke whose resistivity contrast to the host is 3:1,100:1 respectively, we can see that the largest anomalies exist where the primary electric field cuts across the dyke, and are much smaller 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

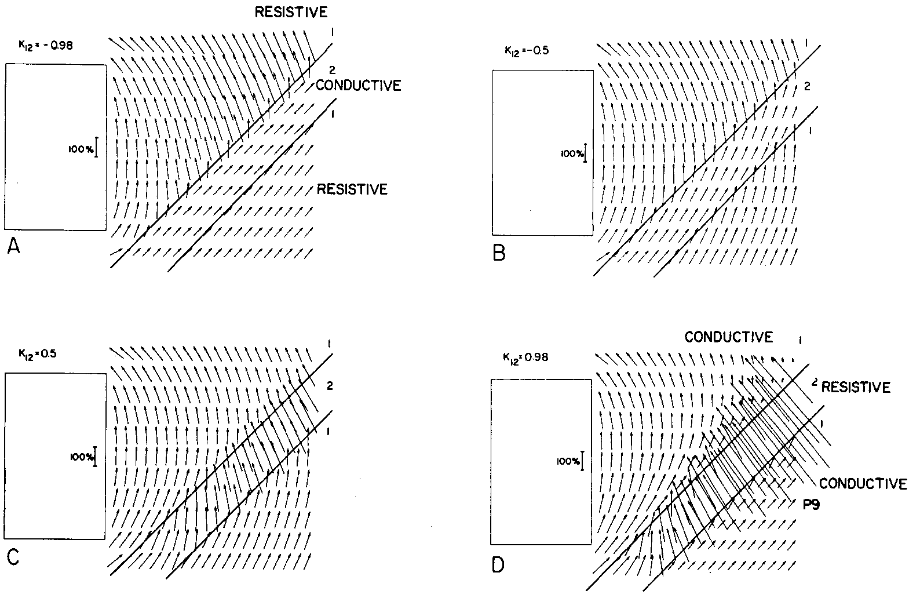

FIGURE 1
Vector plots showing direction and relative amplitude of the ISR response over a dyke striking at an angle to the survey grid. The ratio of conductivity of host to dyke is A: 100:1, B: 3:1, C: 1:3, D: 1:100. The transmitter loop is also shown in each case.

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 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 Pemberton (1989).

Temora Utem Survey

A test survey was conducted using the UTEM system to make ISR measurements over an area located immediately south of the Gidginbung gold mine at Temora, N.S.W. (Figure 2). The gold deposit is located within altered and silicified andesites (Thompson *et al*, 1986). The aim of the survey was to test if

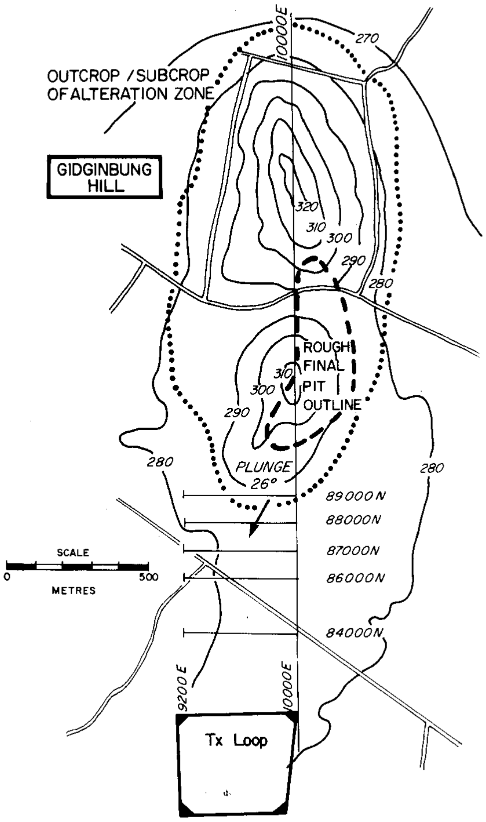

FIGURE 2
Location map for the ISR survey at Temora.

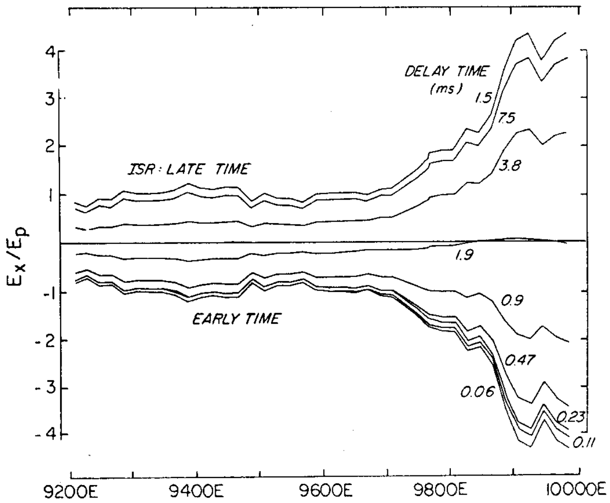

FIGURE 3
Electric field (Ex) data normalized with respect to the calculated primary field (Ep) as a function of delay time on line 8400N.

the zone of alteration and silicification surrounding the economic gold mineralization could be detected under thick conductive cover. Figure 2 shows both the rough outline of the open pit, and the location of the outcrop/subcrop of the surrounding alteration zone as mapped. Sandstones and conglomerates unconformably overly the andesites within which the alteration has taken place. To the south, the alteration zone plunges at about 26 degrees into the host andesites.

A transmitter was laid out to the south, along strike from the deposit as is optimum for the detection of resistive features (Macnae and Irvine, 1988). The along-line component of the electric field (Ex) was measured at 25 m stations using a 25 m dipole. This measurement was made for 10 different delay times on 5 lines each 800 m long as shown in Figure 2. Figure 3 shows an example of the data collected on line 8800N. On this plot we see the symmetry of response from early delay times to late times, reflecting the transition from induced dc current in one direction to that in the reverse direction after the primary ramp current direction reverses. The latest delay time measurement was taken to be the ISR response.

With a time delay of 2.5 ms to the transition through zero amplitude as seen in the Ex data of Figure 3, using a distance of 230 m to the transmitter loop on line 8400N, it is possible to estimate that the average overburden conductance is 10 Siemens. Using drilled depth information, this implies that the sandstones/conglomerates have a conductivity of about 0.1 S/m. The zero transition in Ex is the half-way point in the EM decay. Due to the significant delay of this transition in comparison to the latest sample time of 15 ms, it is not possible from this data to determine if IIP effects are present at Temora.

Figure 4 presents a geological section under line 8800N together with the ISR response measured on surface. Directly over the drilled location of the alteration zone is a broad high in the ISR response. The response however, is not smooth but has narrow peaks located over both the east and west edges of the alteration zone. The top of the alteration zone is shallower to the west, and the associated resistivity peak is as expected somewhat sharper than that to the east. Modelling has not as yet been completed to determine what proporation of the detected response may be due to the topography of the unconformity as opposed to variations within the andesite.

At the line furtherest to the south (Figure 5), the alteration zone is deeper and its boundary not well defined by the limited drilling. The survey line extends only to the west of the drilled zone. In this case, with 110 m to the unconformity and 170 m to the alteration zone, the ISR high is much smoother than that seen on line 8800N. Since the secondary electric field measured using the ISR technique is a potential field, for a narrow source the half-width of an anomaly directly proportional to its depth of burial. For a wide source the anomaly half-width will of course be increased compared to a narrow source.

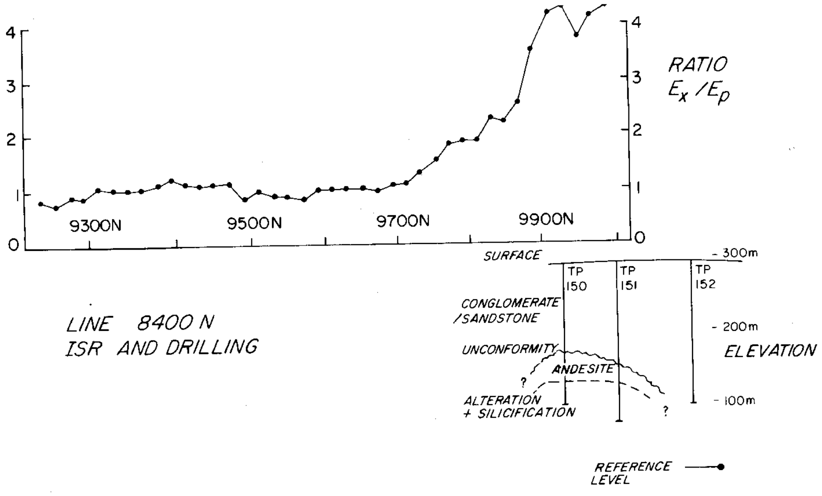

FIGURE 4
ISR response, plotted as the ratio of the Ex component at the latest delay time to calculated primary field Ep, together with the drill section on line 8800N. The geological section was redrafted from a sketch provided by Paragon Resources.

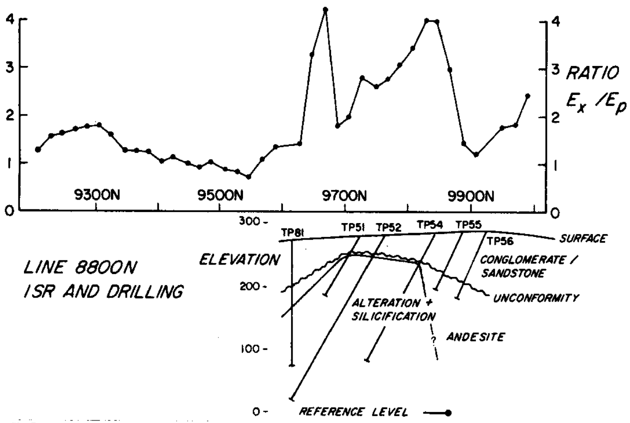

FIGURE 5
ISR and drill section on line 8400N.

Figure 6 presents a contour map of the ISR response over the measured grid. The zone of high readings extends south and east from the mapped outcrop, in the direction of alteration as defined by drilling. A smaller secondary zone of resistivity high is present to the west. For this test survey, only limited coverage was possible, and the survey lines could usefully have been extended further east.

Conclusions

The ISR survey at Temora was particularly successful in outlining a resistive zone of alteration and silicification under 100 m or more of unconformable, 0.1 S/m conductive overburden. In these conductive conditions however, IIP effects are not detectable by the UTEM system.

Acknowledgements

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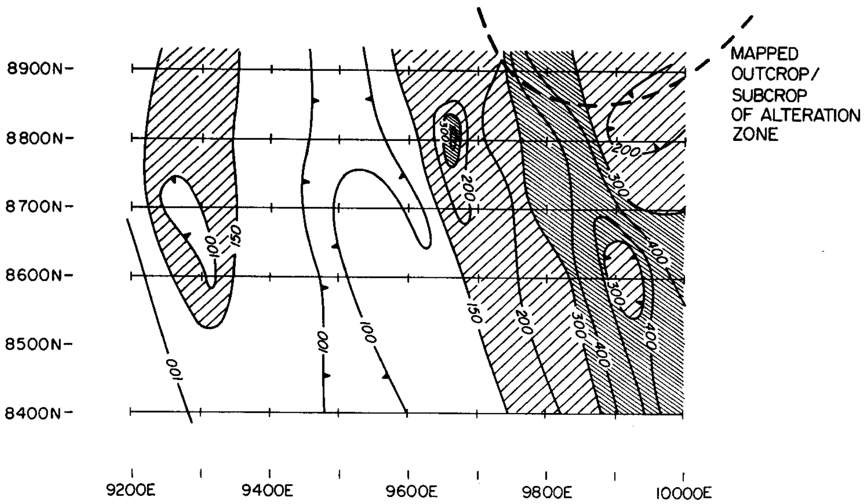

FIGURE 6
Contour map of ISR data over the UTEM survey grid at Temora.