Airborne IP detects only fine-grained minerals when compared to conventional IP

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SUMMARY

Using a thin-sheet model, it is possible to predict Cole-Cole parameters of polarizable materials in the near-surface from airborne EM data. With the high frequency of AEM systems, typically more than 100 times higher than ground IP systems, most conventional IP targets will often not show an AIP response. Very fine-grained minerals, around 0.1 mm in average dimension, are however good sources for AIP responses. In 6 examples from Tasmania and NSW comparing AIP with ground IP, 5 have AIP responses that are not coincident with ground responses, but may detect finer grained minerals in the periphery of the alteration system associated with a mineral deposit.

Key words: Airborne Induced Polarization, electromagnetics.

INTRODUCTION

Macnae (2015) presented a case history from Quebec showing that a surficial thin-sheet model was able to fit Cole-Cole Induced polarization model to AEM data collected with the VTEM system. Investigations presented here compare the theoretical sensitivity of inductive AIP using a concentric loop system operated at 25 or 30 Hz with galvanic ground IP operated at 0.125 Hz. Macnae (2016) and Macnae and Hine (2016) tested this model on VTEM data sets from Tasmania and New South Wales, and showed that allowing for AIP effects greatly improved the error of fit to the data, and provided coherent maps of the Cole-Cole IP parameters chargeability m_{IP}, time constant τ_{IP} and frequency dependence c.

In conventional ground induced polarization (IP), the Newmont standard is one often used where the transmitted current follows an 8 second, 50% duty cycle waveform (van Schoor et al., 2009). The IP parameter measured is obtained from an integration over the last part of the off-time (in mV-s) normalized by the amplitude of the observed step (V) and as a result having units of ms. Typical background chargeabilities are 1 or 3 ms. In frequency domain, a 0.1 or 0.125 Hz transmitter is common, with the phase difference at the fundamental frequency (and potentially phase differences at its odd harmonics if a time-domain transmitter is the current source) used as a measure of IP chargeability. Typical background phases are a few mrads.

METHOD AND RESULTS

Fundamental considerations

Ground IP conventionally uses a galvanic current source and AIP an inductive source at a base frequency 2 or more orders of magnitude greater. It is instructive first to theoretically estimate the degree of correspondence we might expect between ground galvanic (0.125 Hz base frequency) and airborne inductive (25 Hz base frequency) data using an ideal 50% duty cycle waveform for an extensive polarizable target in the near surface. For typical economic sulphide deposits with Cole-Cole frequency dependence of c = 0.3 (Vanhala, 1997), I compare system sensitivity as a function of chargeability m_{IP} and time constant τ_{IP}. The ground system galvanic response is simply given by a Cole-Cole model, ignoring the effects of any overburden cover or surrounding host rock; whereas the AIP response is calculated based on a thin layer (Macnae, 2015).

Using the Cole-Cole model, for a moderately polarizable target in the near surface, we can assume there are no "dilution" effects (Zorin, 2014). Figure 1 shows contours of the observed phase in terms of intrinsic chargeability m_{IP} and time constant τ_{IP}, for the common frequency dependence of 0.3 observed over economic mineralization. Quite clear from the solid contours is that the ground IP with a 0.125 Hz base frequency is sensitive to time constants τ_{IP} from microseconds to days. The AIP system operating at 25 Hz however (dashed contours) is only sensitive to time constants τ_{IP} of 10 ms or less, for this case where the overburden (thin-sheet) conductance is 1 S. While not discussed here, the AIP sensitivity to time constant τ_{IP} is a strong function of surficial conductance as reported in Macnae (2016)

As well as sulphides, IP and AIP effects have been associated with Gold mineralization (Vanhala, 1997, Viezzoli et al., 2015). Most systematic physical property characterizations of IP have focused on the characteristics of economic mineral deposits. Much less can be found on uneconomic deposits and on the general geological background. Figure 4 presents physical property compilations of IP parameters for graphite, base metal sulphides (Hallof and Klein, 1983) and a gold deposit (Vanhala, 1997) from minerals collected in the Northern Hemisphere. Most economic base-metal IP had frequency dependence c close to 0.3, most time constants τ_{IP} were above 1 second, and only a small few are less than 10 ms.

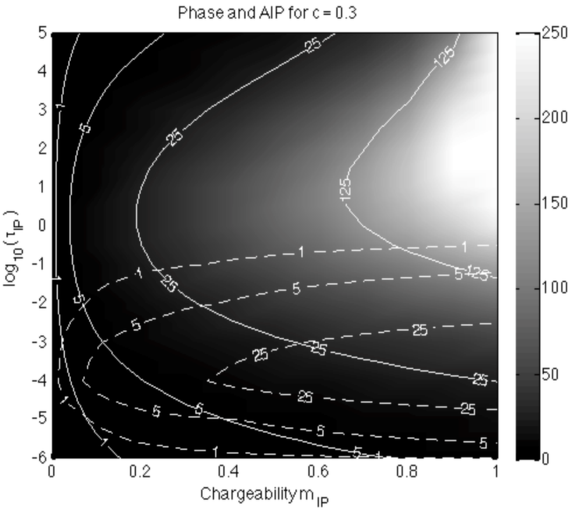

Figure 1: Phase (mrad) for a 0.125 Hz ground IP system (image and solid contours) with ideal waveform AIP response (ppk) as dashed contours for the case of a 1 S thin sheet. The concentric loop AIP does not respond significantly to layers with intrinsic IP time constant τ_{IP} greater than 0.1 secs

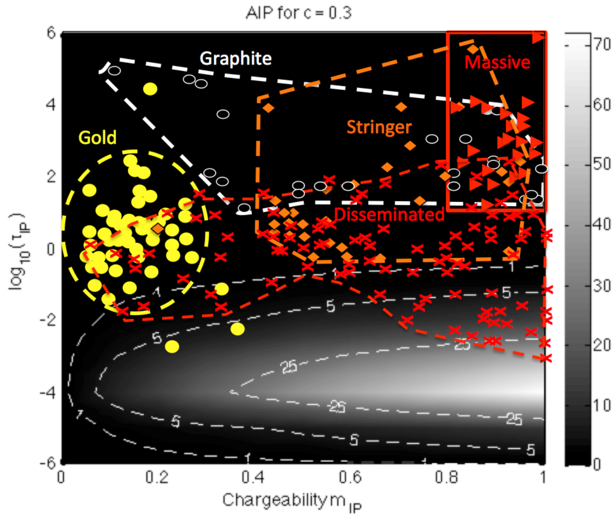

Figure 2: Image of concentric loop AIP sensitivity for a frequency dependence of c = 0.3. Contours are in ppk. Plotted are the results of some 200 Ontario mineral samples from Hallof and Klein (1983) with red triangles massive sulphides, red crosses disseminated sulphides, orange stringer sulphides, black/white graphite and disseminated gold (Vanhala, 1997).

Inspection of Figure 2 shows that almost none of the 300 or physical property parameters over polarizable economic targets would lead to a significant AIP response. The AIP sensitivity is clearly maximum for time-constants shorter than those for economic targets as measured in the laboratory.

Field examples

A VTEM survey was conducted for Macquarie Harbour Mining Ltd. over 6 blocks in the vicinity of Macquarie Harbour, Tasmania in 2010. This survey covered several mineral exploration targets with ground IP responses. The VTEM data was fitted with a polarizable thin sheet model as described in Macnae (2105), using EMFLow style basis functions. The first data fitting experiment tested 13 EM basis functions (near surface thin sheet responses) with 16 AIP basis functions, calculated for all combinations of Cole-Cole parameters m_{IP} = 0.1, c = [0.1, 0.3, 0.5, 0.7] and τ_{IP} = [0.03,0.3, 3, 30] ms. The program used a one-by-one approach, fitting 13 AEM and one of 16 AIP response at a time and storing the residual errors of fit. The IP parameters for the best fit (calculated from a sum square error at later delay times where AIP effects are most evident) were then kept as that best characterizing the response. As shown by Macnae (2105), secondary AIP responses are linear in m_{IP} so that the basis function fitting process predicts a chargeability value for each station. For the main fitting of data, at each fiducial, a set of AIP models was calculated for that conductance, using all combinations of c = [0.3, 0.8], τ_{IP} = [0.03, 0.1, 0.3, 1 and 3 ms]. While 10 possible IP models were fit to the data, most data was fit with c = 0.3, and τ_{IP} = 0.03 ms. The fit to data then predicts chargeability m_{IP}. Figure 3 presents maps of Conductance, Raw data Negatives and fitted Chargeability.

The map of fitted chargeability Figure 3b shows general trends parallel with magnetic (not presented in here) and conductive Figure 3a features. It does however show significant differences from the map of negatives in the raw data seen in Figure 3c, which negatives are sometimes used as a proxy for chargeability. Spatial coherence of the predicted chargeability m_{IP} is excellent, with detailed examination showing that the high chargeabilities are mapped in areas of both high and low conductivity, and as such are unlikely to be an artefact of processing or an inadequate model. The range of fitted chargeabilities m_{IP} extended from about 0.001 to 0.2. Due to small AIP effect and the simplified model, the reliable discrimination of the smallest fitted chargeabilities between say 0.001 and 0.01 is unlikely.

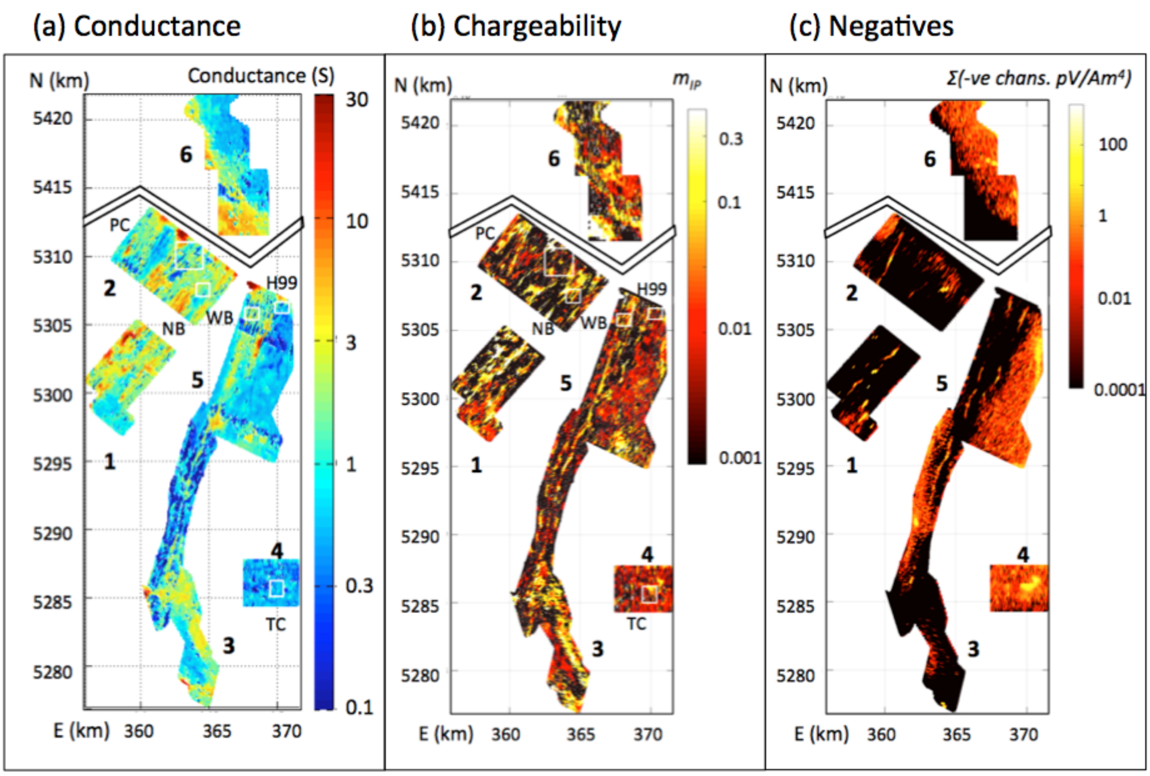

Figure 3. (a) Conductance, (b) Cole-Cole chargeability and (c) sum of negatives in each decay over 6 areas in the Macquarie Harbour area, Tasmania. The northernmost area 6 has been discontinuously hifted south to compact the maps.

Detailed extracts from the chargeability map (Fig 3b) presented on a grayscale image, are shown in Figure 4 for two of the 5 areas, together with an outline of the ground IP anomaly. Immediately clear from these two, and the other 3 deposits not shown in this abstract, is that AIP and ground IP anomalies are not coincident over these 5 economic prospects. This conclusion thatAIP and ground Ip mapped different areas was independently reached by Hine (Macnae and Hine, 2016) based on data collected on several surveys located elsewhere in Australia.

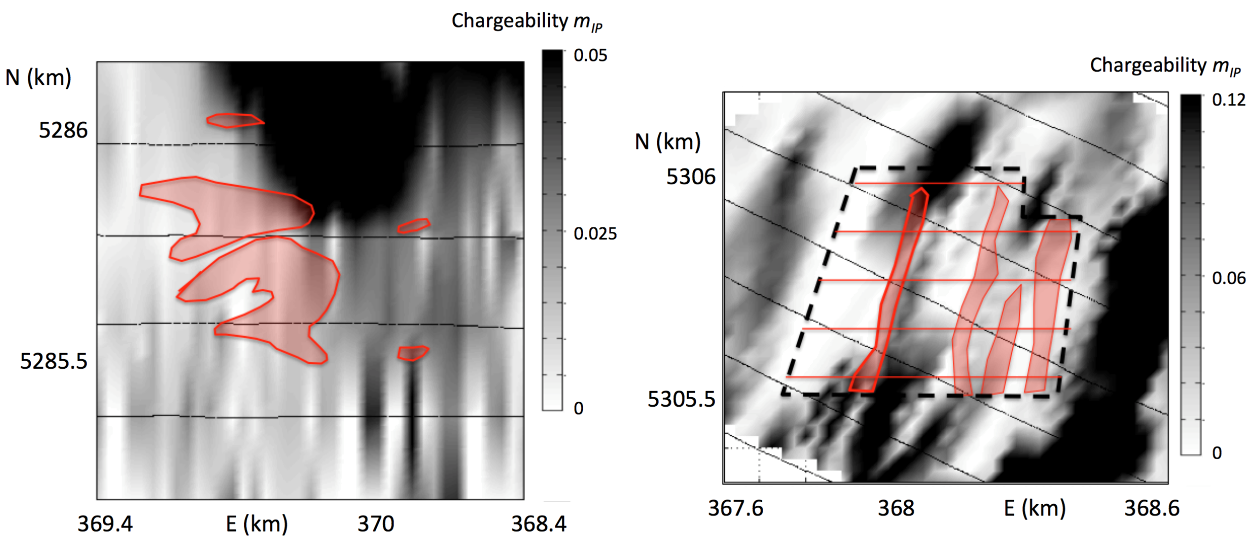

Figure 4: Comparisons between VTEM survey chargeabilities (image in black) and areas of high IP (phase > 34 mrads, shown in red)_ in ground IP data collected with a gradient array. The left plot is for the Thomas Creek prospect (TC) seen on Figure 2 in Block 4, and the right plot covers the West Baylee Prospect area (WB) in Block 5.

It is instructive to refer to the established relationship between grain size and IP time constant. Figure 5 was redrafted from a figure by Vanhala (1997) which shows that in data from economic deposits, time constants < 10 ms arise only when grain radii are less than 1 mm. This laboratory data is generally consistent with a Wong (1979) electrochemical models as shown on the plot. Fine grain mineralization is thus the only expected source of AIP responses in double-dipole configuration operated at 25 or 30 Hz base frequency. Most desirable economic targets have coarser mineralization, and will likely be undetectable in a concentric loop AEM system

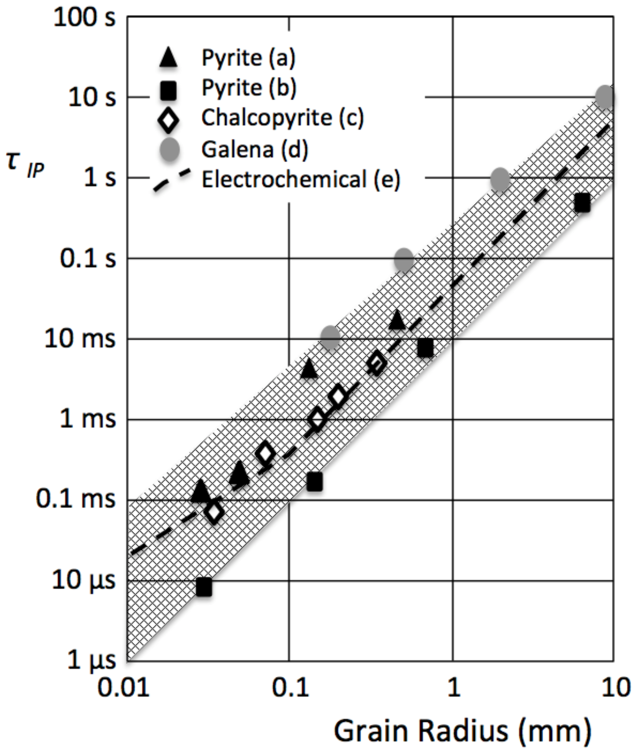

Figure 5: IP time constant increases as a function of grain size as shown. Data plotted compiled by Vanhala (1997) who compared laboratory data with the Wong (1979) electrochemical model.

In all 5 cases in this survey, covering small areas each less than 1 km square, there was inconclusive evidence that AIP responses may partially surround ground IP anomalies. If this observation were to prove common, it might suggest that AIP sees the fine-grained mineralization in the outer regions of an altered sequence, whereas ground IP is more sensitive to the larger grained, longer time constant material of greater exploration interest.

While not justified here, work in AMIRA project P1036 and P1036a has confirmed that to detect AIP responses from typical porphyry sulphides, both a lower base frequency (5 Hz?) and a significant transmitter-receiver separation are required to favour galvanic over inductive responses, and be sensitive to the longer IP time constants of economic deposits.

CONCLUSIONS

Even though the concentric loop geometry is the least sensitive to AIP effects, the low noise levels of AEM systems frequently show such AIP. With AIP sensitivity good enough to detect "background" IP from finer grained minerals, in this Tasmanian survey the data provided very good mapping of low-level IP effects. There was no useful correspondence between AIP and gradient array ground IP. It is likely that most ground IP targets of economic significance would have time constants outside the detectable range of the VTEM or similar "double dipole AEM systems such as SkyTEM or HeliTEM.

ACKNOWLEDGMENTS

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