The use of the ''floating'' S-plane for effective interpretation of airborne TEM data

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SUMMARY

B-field TEM data due to a pulsing ground loop and collected with a DJI 600Pro hexacopter with MagArrow magnetometer as well as helicopter borne VTEM d**B**/dt data was modelled with the 'floating' S-Plane interpretation technique. The former stems from the Flat Mine North copper deposit and the later was recorded at the Hondekloof nickel occurrence, both in South Africa. Since interpretation routines for B-Field recordings are not well known the main objective of our research was to develop a single procedure for the interpretation of B- and dB/dt airborne TEM data. For the drone survey a transmitter (Tx) loop 1000x800 m^2 in size, on the ground and a MagArrow magnetometer below the drone was used as receiver to record both the magnetic and TEM variations. Soundings were recorded both inside and outside the Tx loop (up to ~500 m from all sides) and are 15m apart resulting in a total of about 1000 TEM soundings. After digital separation of the magnetic and electromagnetic field components a modified method for calculating the apparent longitudinal conductivity $S\tau$ (Stau) was applied. Firstly, the parameters of an equivalent conducting S-plane with longitudinal conductivity at a fixed depth, are determined. Then the theoretical emf curve was calculated for known parameters of the "floating" plane. To comply with the conditions of the near zone, the calculation of theoretical curves was carried out for the in-loop configuration but simulated by using Tx loops with smaller dimensions. Then $S\tau$ as a function of depth H was calculated according to the well-known usual technique and converted into a resistivity voxel showing possible deeper ore bodies.

For the VTEM data at Hondekloof the classical method of calculation $S\tau(H)$ was used, taking into account the excess of the transmitter-receiver configuration above the ground. At the site, exposed ore bodies are reflected in zones of increased longitudinal conductivity. Numerous anomalies have been identified, possibly associated with unexplored reserves of nickel ores.

Keywords: drone, airborne TEM, S-plane copper and nickel deposits

INTRODUCTION

During the first two decades of the 21st century transient airborne electromagnetic surveying became widespread. Presently we are witnessing the development of a new branch of electromagnetic exploration with the use of airborne TEM surveying by drone. Drones, also referred to as Unmanned Aircraft Systems (UAS), Unmanned Aerial Vehicles (UAV) or Remotely Piloted Aircraft (RPA), signify pilotless aircraft. The UAS technology has several advantages over a conventional airborne platform to collect geophysical data such as resolution, accuracy and cost but off-course presently have limited endurance and weight carrying capabilities. In comparison to ground surveys a drone can collect hundreds of thousands of sounding points in 2-3 days, weather permitting.

Airborne TEM have brought with them new problems in processing and interpretation of the data. Although the primary processing is today quite well established the modelling algorithms for a 1D inversion for every sounding can still take a long time and only visualize along the flight lines. This is too time consuming an approach to be used for a quick interpretation. Then heterogeneities in the upper part of the subsurface section can mask conductive bodies because changes in flight altitude can drastically change the amplitude of signals. In contrast to drone surveying neither a helicopter nor a fixed wing can fly at the same constant altitude above surface and changes in flight altitude can result falsely or in not identifying a conductive object. All this must be taken into account when creating a general interpretation/modelling algorithm.

We have carried out experimental work using a 50% duty cycle pulsing ground loop and a DJI 600Pro copter with a Geometrics MagArrow magnetometer suspended below sampling at 1 KHz to collect B-field decay TEM values. This data as well as dB/dt measurements from a VTEM (GETECH) survey were interpreted with the 'floating' S-plane method based on a modification of the Stau ($S\tau$) technique. The 'floating' technique also subdivides a subsurface section into a certain number of layers, but only identifies the conductive ones together with their depths.

The specifications of the drone and

magnetometers are given by Smit et al. (2022) and are outside the scope of this abstract.

INTERPRETATION VIA MODIFICATION OF THE CALCULATION OF APPARENT LONGITUDINAL CONDUCTANCE Sτ

The so-called method of differential transformation of emf signals into curves of apparent longitudinal conductance as function of time and depth was proposed by Sidorov and Tikshaev (1970) The Sτ method has certain advantages. Its use allows determining the conductance of the section and determining the depth where Sτ increases noticeably. Usually increasing conductance is associated with the presence of a low resistive object (bodies and/or layers) in the section.

According to Smythe's (1950) regardless of the position of the observation point at each moment in time, the amplitude of the potential vector Ax (and, accordingly, Bz and emf e(t), will be equal to the amplitude of a certain “floating” conductive plane lying at a depth h with conductivity S equivalent to the total longitudinal conductivity of the entire section up to depth h. Dividing up the transmitter loop in small segments AB we have for a dipole (or a short electric line AB):

$$Bz=(I\mu/4\pi r^2)\ (1/[r^2+4m^2]^{3/2)}), \qquad (1)$$

$$e(t)=(IABQ/4\pi Sr^3)(1/[r^2+4m^2]^{3/2)})=KF(m)/S, \qquad (2)$$

where I is an electrical current (in A), Q is the effective surface area of the receiver loop (in m^2), *r* is the distance between of center of AB and the observation point M, $\mu=4\pi 10^{-7}$ H/m is the magnetic permeability, z_0 is distance between the S-plane and M, $m=z_0/2r+h/r+t/\mu Sr$, $K=IABQ/4\pi r^3$.

Note that the St method can only be used for the ‘near’ zone condition, while with our setup we use either a big loop around which we integrate along small segments AB or if use is made of a long grounded line AB we integrate along the line and as the airborne receiver position Q can be a significant distance removed from AB it is then more likely to correspond to the transition zone between the ‘near’ and ‘far’ zone.

The parameters of the “floating” plane at each sounding are determined as follows:

1. After separating the ambient magnetic field and the TEM signal, the smoothing of the TEM signals to suppress noise;
2. From eq.2 the emf contains two unknowns S and m, while Bz contains only m. The transformation of the emf into Bz is performed by numerical integration, taking into account the additional time sequence;
3. Comparing the calculated values Bz with theoretical ones for the same setup (with fixed h, we get the parameters of the “floating” plane m(t) at each time;
4. Now for a given function m(t) we calculate the theoretical curve Bz for a new setup, i.e. for a small loop-in-loop configuration (AB=25 m) located on the ground (z_0=h).
5. Differentiating the theoretical Bz with respect to time t we obtain e(t) for “floating” plane as a function of m(t)
6. Subsequent smoothing of the emf signals.
7. Transformation of the signals into the Sτ(H), according to (Sidorov V.A. Tikshaev V.V., 1970). The depth of the “floating” plane can be calibrated using available drilling data. However many years of experience in using the St method shows that in most cases the empirical formula H(t)=0.5mr can be applicable.

RESULTS AND DISCUSSION

O’KIEP. RESULTS OF DRONE TEM.

The Flat Mine North (FMN) Cu ore body is one of many that constitutes the O'Kiep Cu district in extreme northwest South Africa. The FMN mine closed in 1995 due to low Cu prizes. Cu bearing sulphides occur in lumpy noritic intrusives in highly resistive granitic-gneissic basement material and are characterized by low or reduced resistivity values for larger Cu orebodies and TEM IP effects when disseminated. Figure 1 shows a 3D geo-electric model constructed from a TEM survey measuring the B-field decay and data collected with a 1kmx1km single loop transmitter with 75A, 50% duty cycle, 250ms on 250ms off waveform. The dipole moment was 750 000 Am^2. The receiver was a Geometrics MagArrow magnetometer hanging 4m below a DJI 600Pro hexacopter recording at a 1 KHz rate. The B-field data was not conducive to being modelled directly with a plate-like algorithm (Barnett,1984, Smit et al.,2022) and converted from B-field to dB/dt for ‘floating’ S-Plane modelling. On the northern side of the model, the conductive body is dipping as clearly seen and confirmed by numerous historic boreholes that discovered the copper body in the distant past. However the results indicate better conductors below the previously mined ore and show that previous drill holes without the foresight of geophysics stopped too short. These better conductors’ start at a depth of 350m plus and show that if they are not due to geology containing graphite could signify much better ore at depth going down another 350m. It also shows the deep penetration advantage of recording the B-field.

HONDEKLOOF. RESULTS VTEM USING HELICOPTER.

Historic VTEM data conducted by GETECH at the Hondekloof Ni occurrence site in extreme central western SA was made available to us for re-valuation of the data. The total number of soundings were about 330,000. The sounding density was 5m along flight lines, 25m between flight lines. The highly conductive nickel sulphides occurrences are confined to a ring-sharped structure surrounding a highly resistive granite–gneiss dome. Figure 2 shows a 3D resistivity model (ρ=H/S) where the colour bar displays the log of the resistivity and. areas of low resistivity are shown in blue. The massive bodies of Ni sulphides have a resistivity of 1Ohm.m and less.

Because of clear TEM IP evidence it is believed that some resistive zones are associated with the presence of disseminated NiS particles, which are also of exploration interest. In these sections, the TEM curves are distorted by the effects of induced polarization.

CONCLUSIONS

The data from both the drone B-field survey carried out at FMN (O'Kiep) and at the Hondekloof site that was surveyed according to the classic helicopter VTEM technique measuring db/dt, the modified Stau method was applied for interpretation of the TEM data. New potential reserves of copper at FMN and nickel deposits at Hondekloof were discovered at two sites in South Africa. The total number of TEM points in both sites are 1000 and 330,000, respectively. Full preparation and calculation of files for visualization of flight line subsurface sections for 143 profiles took 8 hours on an off the shelve i5 laptop (for the Hondekloof site).

As a result, three-dimensional images of geo-electric sections of the study area were constructed by gridding across flight lines. All available boreholes agree with the 3D geo-electric construct which show the potential of extra ore beyond that encountered in the boreholes.

REFERENCES

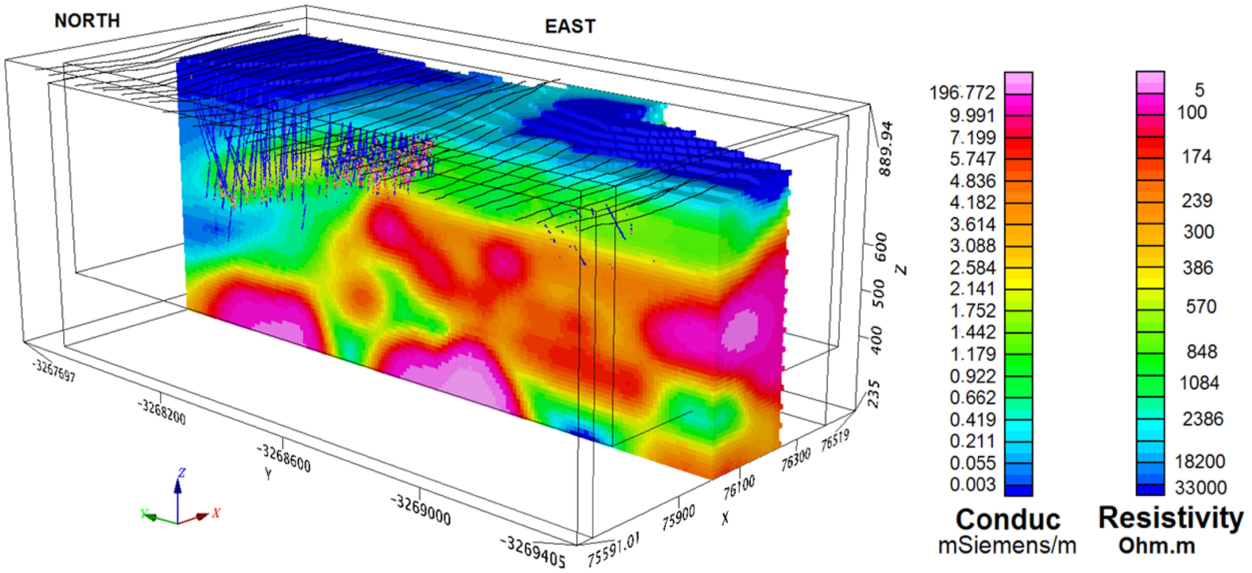
Barnett CT (1984) Simple inversion of time domain electromagnetic data. Geophysics 49(7):925–933. https:// doi. org/ 10. 1190/1. 14417 38

Sidorov VA, Tikshaev VV (1970) Interpretation of transient electromagnetic signals registered in near zone. Exploration Geophysics, M. Nedra. 42: pp.45-54 (in Russian).

Smit JP., Stettler EH, Price ABW, Schaefer MO, Schodlok MC, Zhang R (2022) Use of drones in acquiring B-field total-field electromagnetic data for mineral exploration. Mineral Economics doi:10.1007/s13563-021-00292-1.

Smythe VR 1950 Static and Dynamic Electricity. McGraw Hill Book Company Inc.

e 1: 3D geo-electrical model, Hondekloof Ni occurrence.



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gure 1: 3D geo-electrical model, Flat Mine North O’Kiep

Figure 2: 3D geo-electrical model, Hondekloof Ni occurrence.