Presented at:

Geoconferences (WA) Inc.
Kalgoorlie '07 Conference

25-27 September 2007,
Kalgoorlie, Western Australia

KALGOORLIE '07
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GETTING THE MOST FROM YOUR YILGARN EM SURVEY

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Presented by:
GEOCONFERENCES (WA) INC.
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This paper is from the following publication:

BIERLEIN F.P. and KNOX-ROBINSON C.M., (editors), 2007. Proceedings of Geoconferences (WA) Inc. Kalgoorlie '07 Conference, 25-27 September 2007, Kalgoorlie, Western Australia. Geoscience Australia Record 2007/14, 249p.

ISBN (online version): 978-1-921236-21-8 *ISBN (CDROM version): 978-1-921236-52-5* *ISSN: 1448-2177*

GETTING THE MOST FROM YOUR YILGARN EM SURVEY

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Introduction

Electromagnetic (EM) surveys have been used for over 70 years to help locate massive sulphide deposits. Although Canadian designed systems had been used prior to the 1970's, the use of EM in the Yilgarn Craton of Western Australia only really gained traction with the re-engineering of the Russian MPPO1 to produce the Sirotem Mark I. With the introduction of new technology came experimentation and investigation into the best way to use it. By the 1980's the technology was thought by some to be mature and surveys essentially followed a copy book methodology with little variation. Reconnaissance was undertaken using 100m x 100m loops, generally with a central "in-loop" receiver coil and follow up surveys used large fixed loops with multi-component coil readings. Single component down hole probes were developed in the early 1980's and followed by three component tools later that decade. EM surveys using these approaches have been involved in the discovery of over 25 ore bodies in the Yilgarn since 1970.

Meanwhile in Canada, airborne EM (AEM) systems were having similar if not better success, although, as is typical of step changes in technology, the bulk of the deposits discovered with AEM were found early in its development. Unfortunately, these airborne systems did not transfer well from the resistive Canadian Shield to the very conductive Yilgarn Craton, and although thousands of kilometres have been flown with these systems, they have yet to result in an economic discovery in the Yilgarn.

The past ten years have seen significant improvements in all aspects of ground EM systems. Recognition of the weakness of the existing AEM systems has spawned a series of helicopter, time domain EM (TEM) systems, at least one of which appears to have potential to break the AEM hoodoo in the Yilgarn. These new systems challenge the historical "one size fits all" approach to EM exploration and leave geophysicists with a multitude of choices which must be tailored carefully to the target mineralisation style being explored for. While not providing a cook book on using EM in the Yilgarn, this paper aims to give examples of where the new technology should be used and, at the same time, indicates where areas covered previously by EM could now possibly be considered under-explored.

Which system to use?

The choice of EM system will depend on the style of target and its expected depth. These two parameters can be combined to produce two end members to a spectrum of target types with regolith or base of weathering hosted targets at one end and bedrock targets at the other.

Regolith targets

These include kimberlites and lamproites, lateritic nickel and palaeochannels for uranium, gold or groundwater exploration. They also include geotechnical investigations such as leaking tailings dams and mapping contaminant plumes.

The conductivity profile of kimberlites can be quite variable and depends, amongst other things, on the host rock type, the groundwater salinity and the depth of weathering. They are, however, generally electrically distinct from their hosts and thus pose a good target to EM systems, in particular those EM systems that provide good, near surface resolution. AEM when combined with magnetics can be used to follow up positive indicator geochemistry for kimberlitic targets and help to narrow down the areas of interest. Small footprint, helicopter systems provide the best airborne platform for these targets in environments like the Yilgarn. Figure 1 shows contours of resistivity from a Dighem survey flown over the Melita 2 kimberlite dyke, southwest of Leonora, discovered by DeBeers. The kimberlite produced no magnetic response, even to detailed ground magnetics.

The smectite clays mined in many Yilgarn nickel laterite deposits are generally conductive and thus provide a contrast for EM systems. The ore bodies are often quite patchy and thin and thus not ideal AEM targets. They do, however, provide clear targets for small loop shallow ground EM surveys.

Considerable energy has been expended recently in locating paleochannel- or playa-hosted uranium deposits in the Yilgarn. Most of this effort has been focused on outcropping calcrete bodies which show up in airborne radiometric data. It takes less than a metre of soil cover to mask this radiometric response, indicating that there are likely to be considerable reserves of uranium in calcrete remaining in the Yilgarn. Although not exclusive to paleochannels,

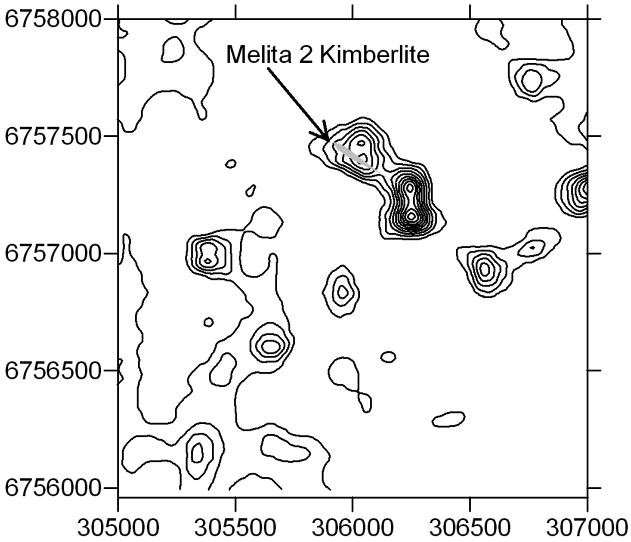

Figure 1. Contours of resistivity from 56 kHz Dighem data over the Melita 2 kimberlite (shown in grey stipple). Data courtesy of DeBeers.

there are likely to be significant amounts of calcrete or carbonaceous material contained within paleochannels in the Yilgarn, particularly those forming part of the playa lake chains. Where these paleochannels cut through a weathering profile or even deeper into bedrock, they will generally have a conductivity contrast with their surroundings. This can be enhanced if the channel contains porous material holding greater amounts of water than the surrounding rock. In the Yilgarn, this water will generally be saline and the paleochannel will be seen as a conductor. Paleochannels form good targets for all AEM systems with good near-surface resolution.

EM can also be used within the regolith to accurately map subcrop topography. This is best done with hybrid EM methods such as Sub Audio Magnetotellurics (SAM). This technique maps the electromagnetic field generated by current channeling. Of particular interest to gold explorers is channeling along depressions in the subcrop produced by deeper weathering over structures.

Bedrock targets

The use of EM in the search for massive sulphides is well documented, and although it was recognised that not all sulphides were conductive (notably sphalerite), it was not generally acknowledged until recently, that some sulphides could be too conductive to be detected. Although well established in theory, the prevailing wisdom, and perhaps more importantly, the lack of any viable alternative, meant that in the last century all conductive targets were explored for using the same EM systems, often using the same parameters. The development of sensitive magnetic sensors and full waveform receivers in the past ten years has changed this.

At the end of the last century the most popular EM systems used a small multi-turn coil receiver to measure the rate of change of the secondary magnetic field generated by an alternating and repetitive transmitter signal. Geophysicists refer to this as dB/dt where B is the magnetic field and t is time, the prefix d indicates the difference. Over the time range measured in conventional surveys the dB/dt response increases as the conductance, which is the product of conductivity and size, increases. However, a point, called the inductive limit, can be reached beyond which the dB/dt response decreases to a point in the extreme where no response is recorded over an excellent conductor. Figure 2a shows a set of ideal decays for a dB/dt response with increasing conductance represented by increased darkening of the solid lines. The thick dashed line represents the background response from the ground without the conductor buried in it. As the conductance increases, the maximum response decreases and the point at which the decay sits above background moves later in time. In Figure 2b, the same parameters are produced for a B field system.

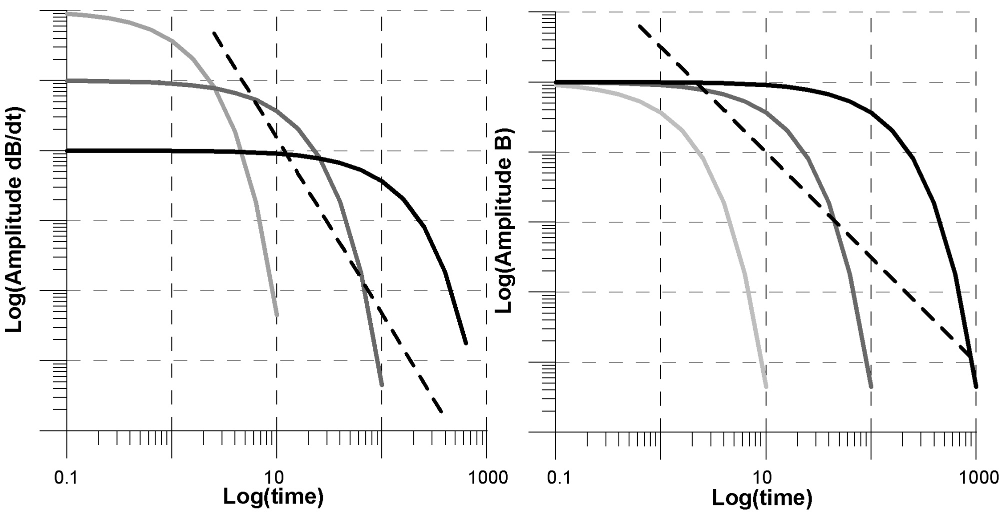

Figure 2. Ideal response for three conductors of increasing conductance (grey = low, black = high), superimposed on the background response from the ground (thick dashed line). (a) for a dB/dt system, (b) for a B field system.

Not only does the point at which the response from the conductor dominates occur earlier in time, it also has a higher amplitude making it easier to resolve from background noise. Nickel sulphide ore, which is generally a mix of pentlandite and pyrrhotite, can be an excellent conductor and would tend towards the darker line in these decay plots. In 1975, geophysicists at the University of Toronto developed the UTEM system to get around this problem. Although it used a coil to measure a voltage, as do the dB/dt systems, the transmitter waveform was modified to transform this to a B field, or magnetic, response. As with the earlier Canadian AEM systems, UTEM has been responsible for several discoveries in the resistive Canadian Shield and even in the moderately resistive parts of eastern Australia, (e.g Hellyer). Unfortunately, however, its high base frequency and the conductive cover throughout the Yilgarn meant that it was ill suited to exploration there. Clearly, a new approach was needed for nickel exploration. If the coil sensor measuring dB/dt could be replaced by a magnetometer measuring B, not only would the response of very high conductance bodies be readily measurable, good conductors would be visible earlier in time than a dB/dt response. This would give it a better chance of being seen above the background response from the conductive ground and before the amplitude of the secondary fields fell below the background noise level thus potentially allowing shorter reading times and thus more productive surveys.

What was required was a magnetic sensor which could operate at very high frequencies (kHz range). The first technology that offered this prospect spawned from superconductor research. Superconductors are devices that have zero or negligible resistance, enabling them to be used to manufacture very sensitive measuring tools. To date, physicists have only been able to make these work at very low temperatures, so they have had to be cooled, generally with liquid helium (-268.9°C, 4K) or nitrogen (-195.79°C, 77.36K). These superconductors have been cast into special sensors known as SQUIDs or Superconducting Quantum Interference Devices and used to make, amongst other things, highly sensitive magnetometers. Two SQUID based sensor systems were developed almost in parallel: Anglo American, using commercial German technology, worked on a Helium cooled SQUID, considered a low-temperature device. CSIRO developed a "high temperature" version using liquid nitrogen as the coolant. Unfortunately, these sensors have a long way to go before they are "off the shelf" items and are therefore currently very expensive. While these giant leaps in physics were being taken by the superconductor scientists, incremental improvements in old technology were also occurring. The fluxgate magnetometer invented in 1941 and used for mineral and oil exploration up until about 30 years ago, when it was replaced by the proton precession magnetometer, had steadily improved in performance. Although it currently has higher noise levels than either of the SQUIDs, it costs a small fraction of the price. Figure 3 shows a comparison of the bench noise levels of the four kinds of sensors discussed here. Real noise levels measured in the field will be higher, particularly at higher frequencies, however the relativities remain. The abscissa on this plot is frequency which we can think of as the inverse of time, which is the measurement space used by most EM systems of interest to Australian mineral explorers. Thus, at low frequencies or late times the B field sensors are quieter than the coil sensor and SQUIDs are significantly quieter than fluxgates. Despite the higher noise levels, the considerable price difference has meant that most EM crews exploring for massive nickel sulphides in the Yilgarn today use fluxgate sensors to measure the B field response. Additionally, the only B field down hole tools available use fluxgates. The use of B field sensors over areas previously covered with dB/dt sensors has been a humbling experience for geophysicists as areas which appeared to have nothing of interest produce high priority anomalies. Figure 4 shows a comparison of coil dB/dt data and Fluxgate B field data over a recently discovered (as yet confidential) nickel ore body in the Yilgarn. The mineralisation is about 200m below the surface. Apart from the different sensor, the survey equipment and geometry used were identical; that is, a 100m inloop, 2 turn transmitter and Smartem receiver. A black shale dipping to the right is evident in both data sets at station 1000. However, the mineralisation, which parallels it at station 750, is really only evident as a twin peaked anomaly in the B field data. The coil data have decayed to noise before the response from the massive sulphide dominates over background.

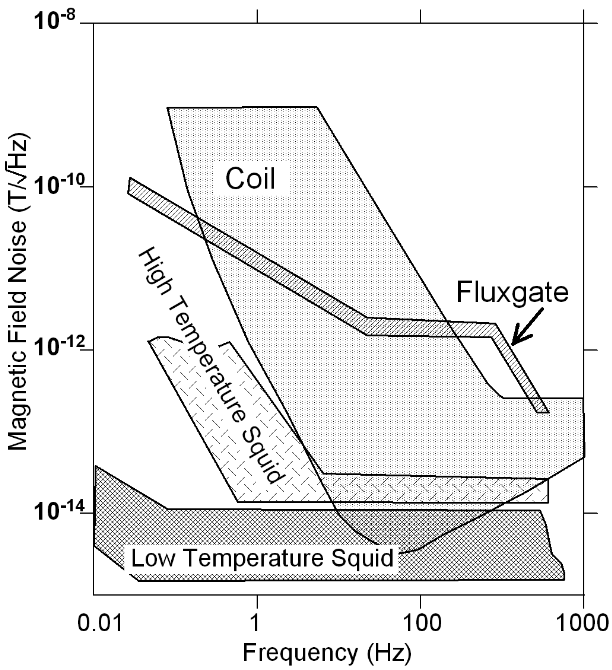

Figure 3. Bench noise comparison between four different kinds of EM sensors.(after Foley and Lesley 1998).

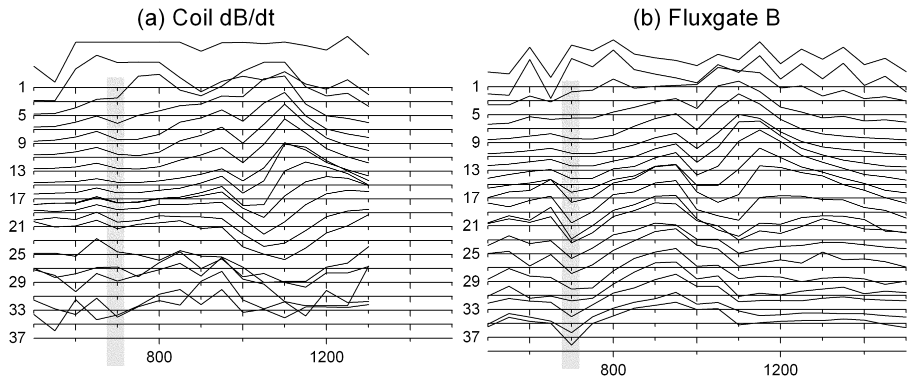

Figure 4. Comparison of dB/dt and B field data over a recently discovered nickel orebody in the Yilgarn. Each trace is scaled independently and only every second window is displayed. The top of the mineralisation is highlighted by the grey stipple at station 750

Whilst Anglo American and CSIRO were working on SQUIDs, Western Mining Corporation (WMC) took another approach and designed a dB/dt system with very low noise levels, enabling WMC to record much later in time than conventional systems. This system is called the GeoFerret and is now operated by BHP Billiton and Mithril. The low noise levels are achieved by using multiple sensors in a distributed array which could be left to record data for a much longer period than was practical with conventional single receiver systems. Unfortunately, the use of distributed arrays is only beneficial with fixed loop surveys, which, because of the conductive overburden in the Yilgarn, are often a poor choice of geometry except for the final drill target definition, implying that another system has generated the anomaly for follow up. Until recently the system used dB/dt sensors, which did not solve the inductive limit problem discussed previously.

Of course not all the developments in EM systems were ground based. The lack of success experienced by the fixed wing time domain AEM systems in conductive environments and over small highly conductive targets, and the poor penetration of the helicopter based frequency domain systems, lead a number of groups to independently develop their own time domain helicopter AEM equipment. These include Normandy's HoisTem (now slightly modified and called RepTem), Newmont's NewTem, Aeroquest's AeroTem, Geotech's VTEM and the University of Aarhus' SkyTem, to name a few. RepTem, VTEM and SkyTem are currently flying in Australia. All these systems appear to have better penetration than the older frequency domain helicopter systems and achieve better resolution for small shallow targets than the fixed wing systems. However, only VTEM appears to penetrate to sufficient depths to be of use in modern base metal exploration in the Yilgarn. As much as they have improved, none of the airborne systems are a replacement for, or even come close to, the resolution and depth of penetration attained by ground based systems. Figure 5 shows a comparison between stacked profiles of ground data and two AEM systems over the Nepean nickel deposit southwest of Kalgoorlie. Superficially, it appears that all systems record an anomalous response over the deposit. However, the bulk of the EM response, particularly in the airborne examples, comes from the adjacent shale rather than the thin massive sulphide ore body. The ground EM data were acquired with a Slingram array, which produces a low, flanked by highs, whereas the HoisTem and VTEM systems use an In-loop configuration which produces a twin peaked anomaly over a steeply dipping conductor. In this example, the Nepean orebody dips at 85 degrees to the left, so the left hand peak would be expected to be stronger than the right in all arrays. The ground system starts to see the mineralisation around window 13 (~2 msec) and loses it in noise around window 29 (~30 msec). HoisTem really only has a fleeting glimpse of the mineralisation around window 13 (~2 msec), which would be hard to pick without knowing where to look. The VTEM system starts to break apart the mineralisation response around window 25 (~3 msec) and continues to get a recognisable response until the last window at ~9 msec. Although the ground systems provide superior data, the airborne platforms do provide a cost effective way of covering a large area fairly quickly and perhaps finding the "easy" shallow targets. Additionally, because airborne surveys have a minimum line length of at least 3km (longer for fixed wing systems), the area covered is usually larger than that which would be considered prospective and targeted by ground systems. This effect can result in serendipitous discoveries (e.g. Kidd Creek).

Several of the AEM contractors are marketing B field systems. However, this practice is a little misleading in that these systems are actually recording dB/dt and integrating the waveform to recover B. Although in theory this is acceptable, in practice it does not produce the same, or as good as a result as measuring B directly, particularly with the relatively high frequencies used in AEM. Unfortunately, the B field sensors discussed above are sensitive to movement

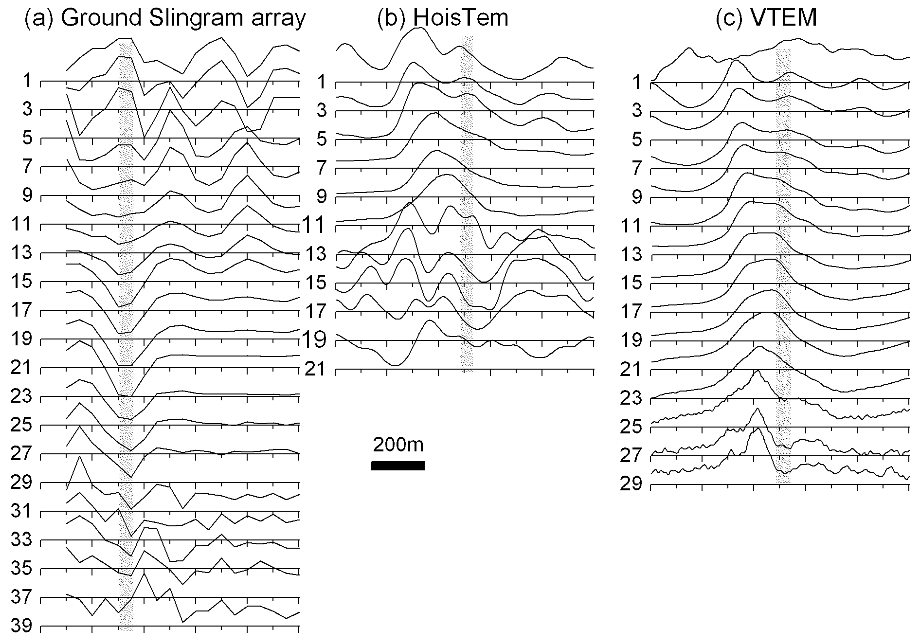

Figure 5. Comparison of ground and airborne responses over the Nepean nickel deposit. Each trace is scaled independently and only every second window is displayed. The top of the mineralisation is highlighted by the grey stipple. Data courtesy of Focus Minerals.

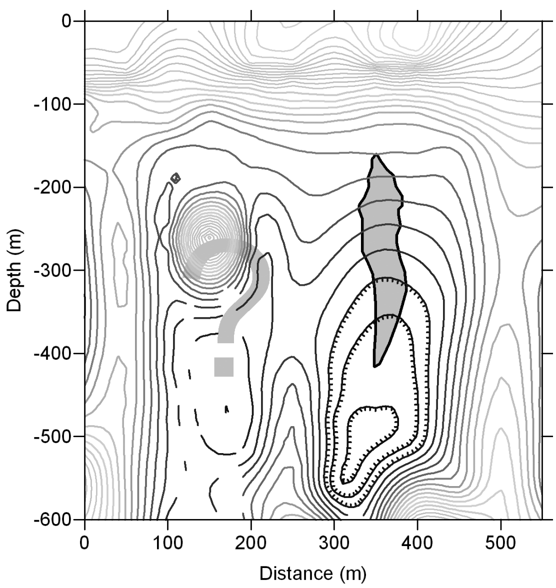

Figure 6, Conductivity depth section through the Juno M10 ore body, showing the known ironstone in grey. Contours are shaded from black (low) to grey (high). Data courtesy of Excalibur Mining.

and could not easily be used on an airborne platform. One solution currently under development for ground based systems uses a very fast sampling Caesium Vapour magnetometer to measure the total field response. Adaptation of this to an airborne platform may be the breakthrough needed to acquire true B field AEM data, which will improve their target detection ability significantly.

Another bedrock target style which has received very little attention as a prospective EM target is a resistor buried in a conductive host. Figure 6 shows a conductivity depth image (CDI) section, generated from a ground in-loop EM survey, through the Juno M10 orebody at Tennant Creek in the Northern Territory. The ironstone hosting the orebody, as defined by drilling, is shown in grey around station 375. Although shown closed in this figure, the ironstone is open at depth because of a lack of deep drilling. It coincides with a prominent conductivity low on the CDI interpreted to be due to silica and dolomite within and surrounding the ironstone. It should be noted that the dolomite halo around the ironstones is often much larger than the ironstone. This pattern has been observed over several of the copper poor ironstones at Tennant Creek, while the copper-rich orebodies have a response similar to that observed around station 150. This target awaits drilling.

Acknowledgements

I would like to thank my colleagues at SGC assisted in providing examples and improving the manuscript, DeBeers, Focus Minerals and Excalibur Mining for providing the data allowing me to present the their data.

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