Superparamagnetic effects in EM surveys for Mineral Exploration

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SUMMARY

Superparamagnetic effects in soil and rock cause responses in a variety of EM survey types that are routinely used in mineral exploration surveys. The identification of these effects can be difficult and the response may be very similar to that from targeted base metal orebodies. Identification of these effects in TDEM datasets is critical for prioritising ground follow-up of targets and failing to correctly identify SPM anomalies frequently leads to inaccurate inversions, misdirected field work, and unnecessary, deep drill holes. As signal-to-noise ratios in acquisition systems increase, SPM effects will become an increasingly common issue in both airborne and ground EM surveys.

This paper presents examples of SPM responses in data collected with the latest airborne, ground, and drill hole EM systems used in minerals exploration. Ground follow-up results confirm the SPM responses.

Techniques that have been found to be effective to firstly avoid, and secondly to identify SPM anomalies in survey data are presented. These techniques are based around minimising the primary energising magnetic field at the source of the SPM, and by distancing the sensor so that it is separated from the source. The main technique for recognising SPM effects directly in data remains the fairly predictable power law decay rate. Secondary techniques such as association of anomalies with alluvial sediments, topographical features (e.g. drainage, hills), and palaeochannel patterns also provide indications of SPM. Associations of anomalies with low transmitter loop height in airborne systems is also indicative of SPM, however systems that can better discriminate SPM need to be developed.

Key words: superparamagnetism, magnetic viscosity, electromagnetic, TDEM

INTRODUCTION

SPM effects in time domain EM data were noted and described in Australia in the late 1970's. The effects are mainly due to very small particles of iron oxides. The effects in TDEM data are typically observed as a slow signal decay with a t^{-1} decay rate in the "late time" data when the response from the earth ("half space") has died away or is a small fraction of the measured signal (Buselli, 1982). Most mineral exploration EM surveys target highly conductive sulphides that also have a slow signal decay. These decays are most easily recognised when the half space response is small and are commonly observed in the same time periods as SPM effects. Thus SPM effects cannot be separated in time from those of deep conductors but may sometimes be identified by signal decay characteristics.

SPM levels in soils and rock vary from being laterally uniform and laterally extensive to discrete anomalies that may have similar dimensions to the anomalies caused by economic sulphide mineralisation at depth. SPM anomalies may be mistakenly modelled as deep conductive base metal targets if the dimensions of the SPM anomalies are similar to those expected from conductive targets and noise levels are too high to reliably recognise the decay characteristics.

The most common technique for handing SPM effects to date has been avoidance. When initially recognised in coincident loop data on the 1970's, a simple technique of offsetting the receiving sensor by 5-10m from the transmitter loop was sufficient to bring SPM effects below system noise levels. During the 1980's, small multi-turn coil receivers located were located in the centre of larger transmitter loops (the "in-loop" configuration) to reduce the SPM response below system noise levels. As the signal to noise ratio in systems increased through the 1990's SPM effects in ground EM survey data became a more common problem, and in areas where SPM effects were significant the receiver coil was moved outside the transmitter loop to distance it further from the large SPM effect near the transmitter wires.

SPM effects were recognised in airborne EM surveys around 2005 following the development of new helicopter systems with much improved signal/noise ratios. Since 2005 the numbers of AEM systems with characteristics that enable detection of SPM has increased, and the signal/noise ratio of these systems has further increased by several orders of magnitude increasing the SPM probelm.

QUANTITATIVE MEASUREMENTS OF SPM

In the last few years there has been developments in the TDEM measurement of SPM with the commercial availability of the MVM1 (Magnetic Viscosity Meter) in 2007. This is a small portable instrument that makes SPM measurements in the field quick and easy. Prior to this, small home-made coils connected to conventional acquisition systems (Smartem / Sirotem / Terratem, metal detectors etc..) were the best way to measure SPM with a TDEM system. This new equipment has enabled measurements of core samples to be easily made on site.

Core measurements have shown that most SPM sources come from surficial soils (Figure 14 `Late time AEM channel image showing a correlation of anomaly with soil SPM measurements. Conductive nickel sulphide mineralisation was later found to be located at a depth of 80m below this anomaly.`
), however some paleochannel SPM anomalies have sources that are much deeper (Figure 2).

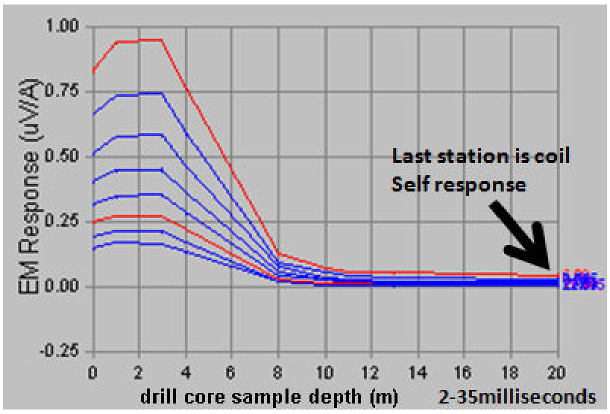

Figure 1 Profile of core measurements of a drilled SPM anomaly showing the source of the SPM response is at the surface.

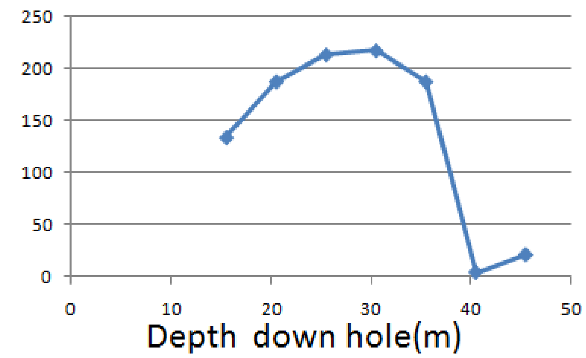

Figure 2 Profile of core measurements of a drilled SPM anomaly with the MVM meter (30 microsecond delay) showing the source of the SPM response is at a depth of about 40m. This corresponds to palaeochannel sediments.

AVOIDING SPM IN GROUND EM SURVEYS

The principle technique to avoid SPM in ground surveys is to offset the receiver from the transmitter loop.

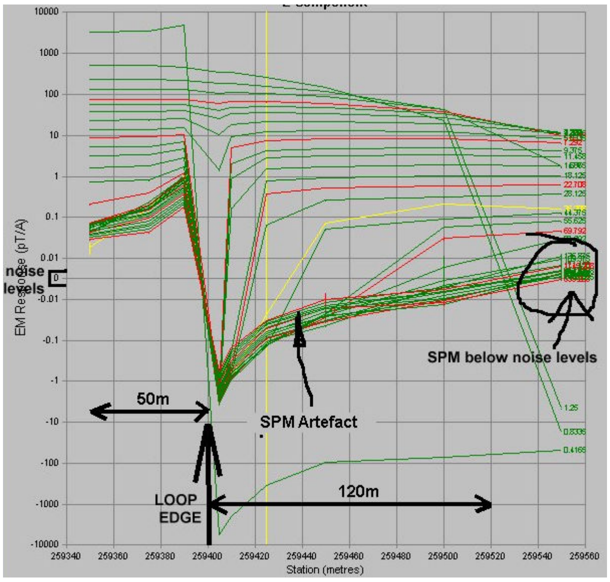

Figure 3 shows the profile of a coil receiver across a small (100m x 100m) transmitter loop that was acquired at the start of a survey. With this information it is possible to specify that the coil much be located at least 120m away from the loop edge to avoid a signal from the SPM soil.

Figure 4 shows the response from a FLTEM survey over ground with high SPM that extends about 150m away from the loop edge. The high levels of SPM here hides the signal from a small nickel sulphide conductor that was clearly detected in a MLTEM survey when the receiver was offset 150m from the transmitter loop edge.

SPM can also be a problem in DHEM surveys where the target is quite shallow (Mutton and Mortimer, 2007). Figure 5 is a profile of a shallow SPM source that has effects detectable down to a depth of about 170m.

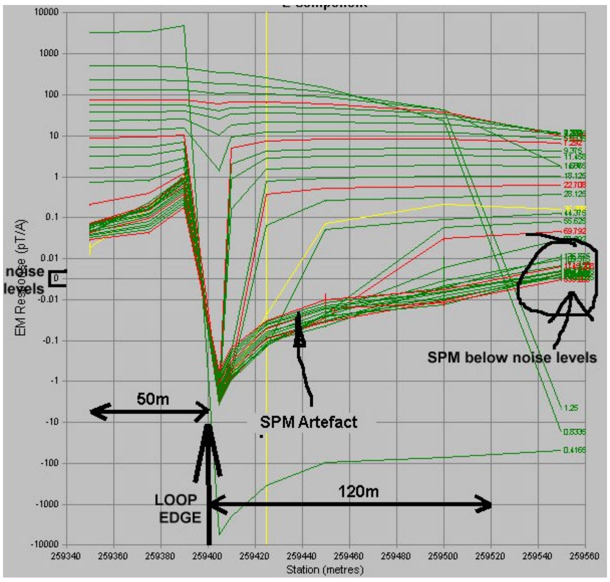

Figure 3 Profile across MLTEM loop showing SPM response near transmitter wire extending over 120m from the loop edge.

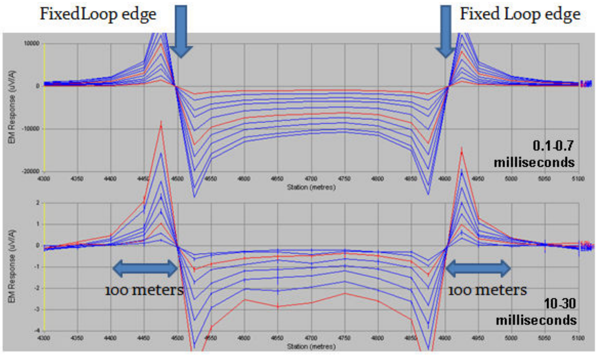

Figure 4 Profile across FLTEM loop with large SPM response.

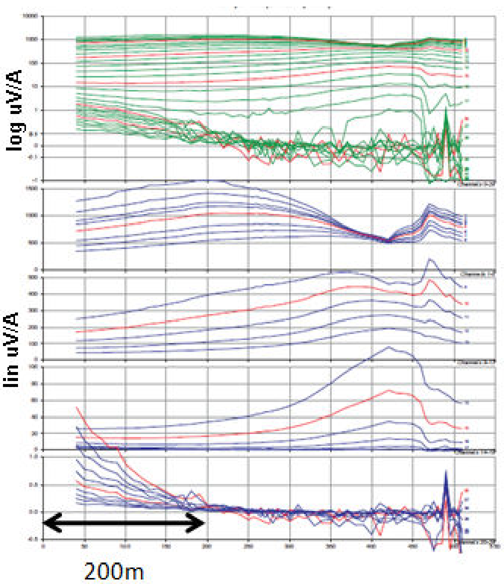

Figure 5 DHEM profile with SPM effects present in data down to a depth of about 170m.

AVOIDING SPM IN AEM SURVEYS

The SPM response of an in-loop system drops off rapidly when the system is raised off the ground. Figure 6 shows the response of a coincident loop system with a 20cm diameter receiver and transmitter loop as the system is raised off the ground.

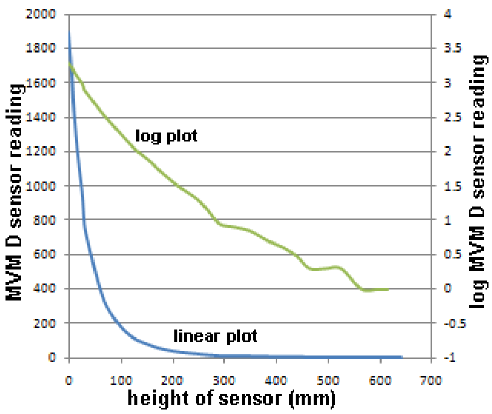

Figure 6 Profile of a small (20cm diameter) coincident loop response as it is raised above the ground over highly SPM ground. The ground is extremely resistive but readings were taken only at a 30uS delay so there may be some half space response.

Early trials of varying the flying height over SPM anomalies indicated that with the current systems, a flying height of around 60m will all but eliminate most SPM effects (Mutton & Mortimer, 2007). This is confirmed when ground measurements of SPM, taken with a small magnetic viscosity meter (MVM1) are compared with SPM anomalies in AEM data. Figure 7 shows the rapid drop off in the AEM anomaly magnitude with height over ground with height, but uniform levels of SPM.

IDENTIFYING SPM IN EM SURVEY DATA

In all TDEM datasets SPM anomalies will decay with a t^{-1} response when the measuring sensor is a coil. When measured with a B field sensor, the response is $t^{-0.5}$ (

Figure 8

Figure 8 Example of SPM decays as measured by a coil and B field sensor showing power law decays.

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Decay characteristics are the easiest way to identify SPM, however when the base frequency is high, decays are usually not sufficiently long enough to distinguish between exponential decays and power law decays. This is commonly the case with AEM systems that operate at 20-25Hz. In this case decay characteristics are so difficult to accurately identify that they are commonly considered to be unreliable as a means for discrimination.

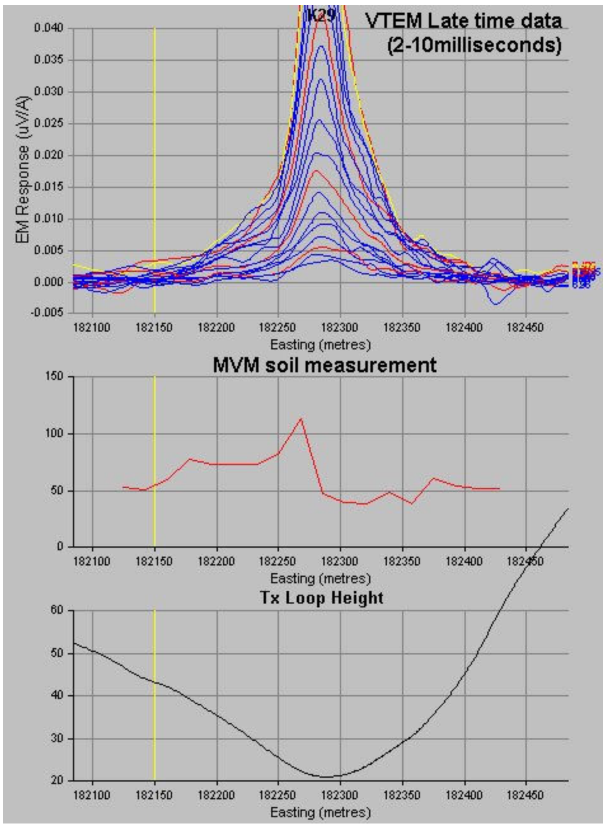

Figure 7 Comparison of ground SPM measurements with flying height and SPM anomaly showing SPM effects are very small to absent at loop heights of more than 50m.

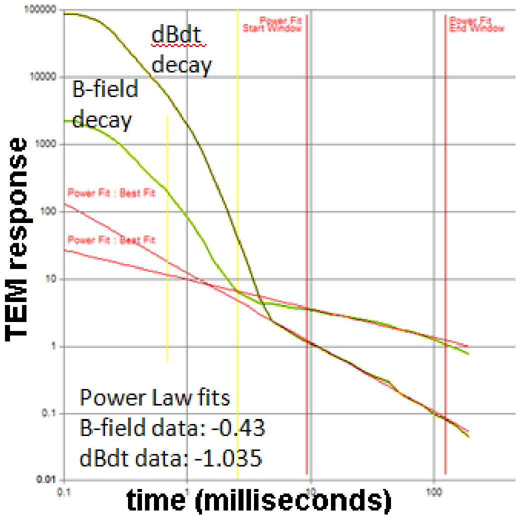

Figure 8 Example of SPM decays as measured by a coil and B field sensor showing power law decays.

A useful technique to screen anomalies is to check for a correlation of flying height with late time anomaly (Figure 9). While not conclusive it has been found to be a reasonably good technique to rapidly prioritise anomalies for ground follow-up. Figure 10 shows a radar altimeter image showing a very close correlation of low flying height with late time anomalies. These responses were later confirmed with ground measurements to have high levels of SPM soils.

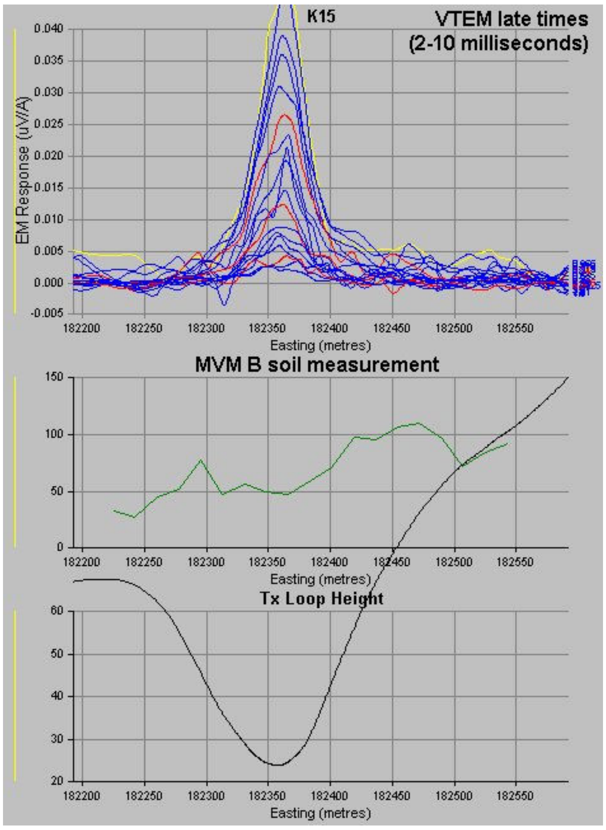

Figure 9 Correlation of late time anomaly with low flying height is strongly indicative of SPM effects. SPM in soils can be confirmed by ground measurement with a MVM.

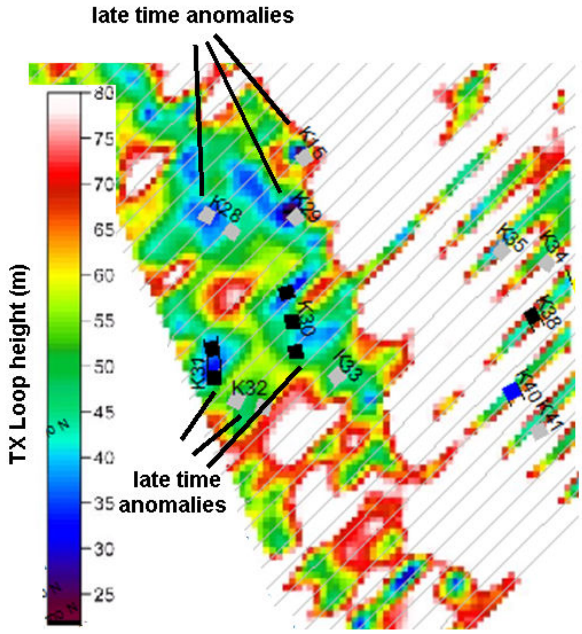

Figure 10 Radar altimeter image showing regular radar altimeter lows coincident with late time anomalies. This is strongly indicative of SPM. Line spacing is 150m

If slow late time decays have a correlation with drainage channels, then it is also strongly indicative that the source is shallow and could be due to SPM. Figure 11 shows a correlation of 2005 VTEM data with streams showing that the anomaly disappears across the streams. This was later confirmed with ground measurements that showed low SPM values in stream samples where the iron oxides causing the SPM had been washed away.

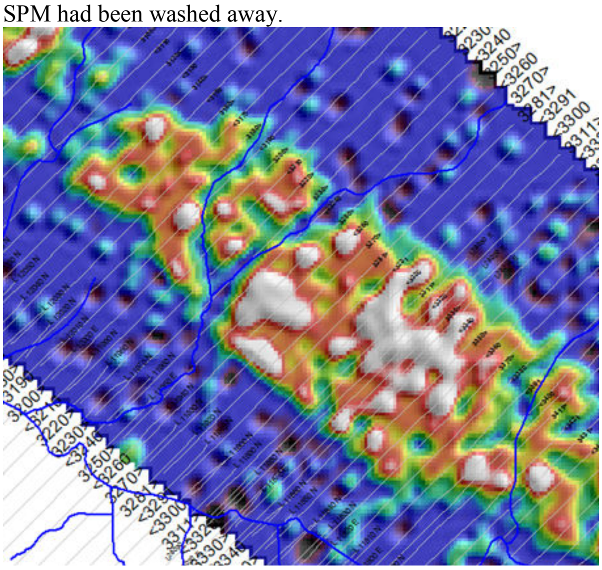

Figure 11 Late time (4 millisecond) 2005 VTEM channel image showing a correlation of EM anomalies with stream channels. This indicates the anomaly is due to a very shallow source. Line spacing is 150m.

GROUND CHECKING SPM ANOMALIES

A cheap option to prioritise anomalies following an airborne EM survey is to conduct SPM measurements of the soil prior to expensive ground EM follow-up. As most SPM sources are due to soils, samples may be taken across anomalies and tested for SPM with a MVM meter. Anomalies can then be classified as likely to be due to:

1. high levels of SPM and a varying flying height
2. an SPM anomaly (Figure 12)
3. a combination of 1 and 2 (Figure 13)
4. ambiguous: high priority for ground EM follow-up.

It should be noted that it is possible to have a genuine conductor correlate with a low flying height or a SPM soil anomaly. Figure 14 shows an airborne EM profile showing a late time anomaly that correlates to a soil SPM anomaly. This anomaly was later found to be coincident with massive sulphide mineralisation.

CONCLUSIONS

SPM effects are an increasingly common issue in TDEM survey for exploration geophysicists. It can be difficult to identify in commonly used systems and may not only create ore body response look-alike anomalies but may also obscure the response from deep, highly conductive base metal targets.

Furthermore, it is likely to become a bigger issue in the future as signal/noise ratios continue to increase and exploration geophysicists try to detect deeper, smaller ore bodies. Innovative work is required to develop systems and techniques to identify SPM in TDEM datasets.

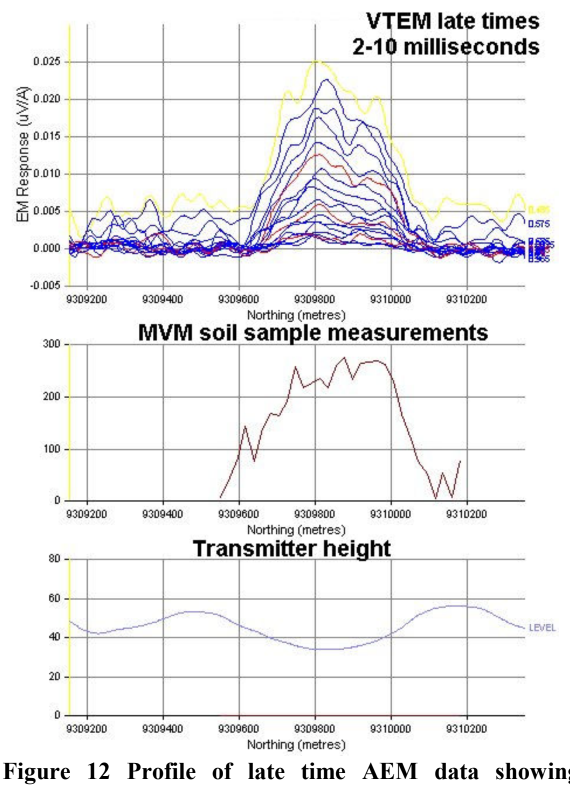

Figure 12 Profile of late time AEM data showing a correlation with SPM measurements in soil samples.

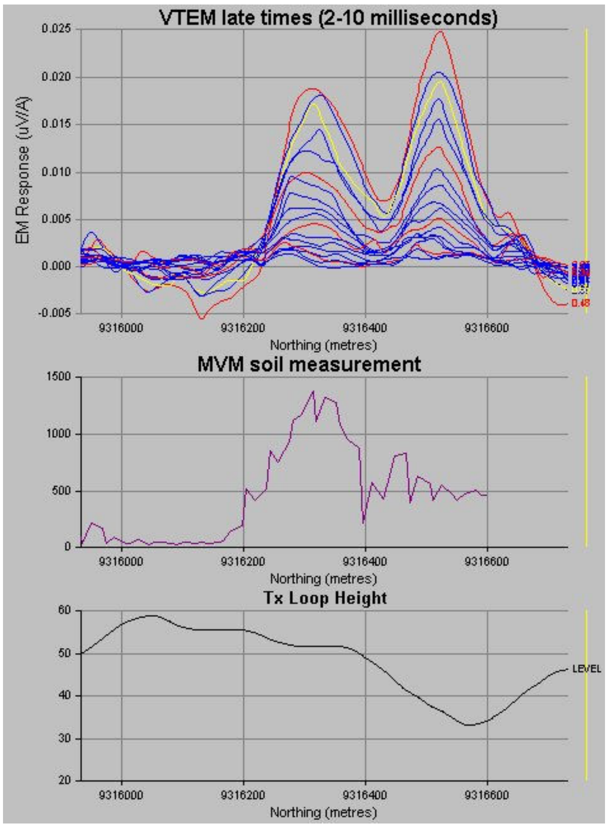

Figure 13 Profile of late time AEM data showing a correlation with SPM measurements in soil samples and a variation in flying height.

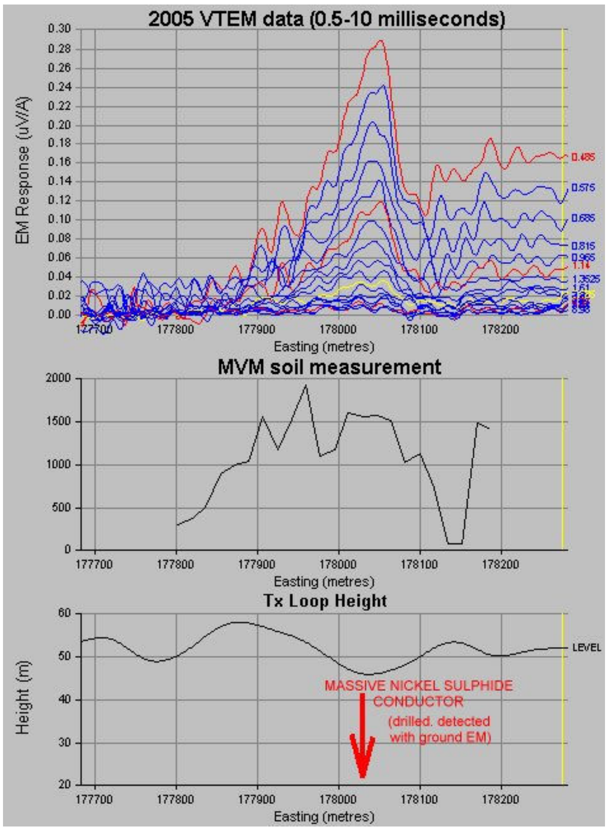

Figure 14 Late time AEM channel image showing a correlation of anomaly with soil SPM measurements.

Conductive nickel sulphide mineralisation was later found to be located at a depth of 80m below this anomaly.

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