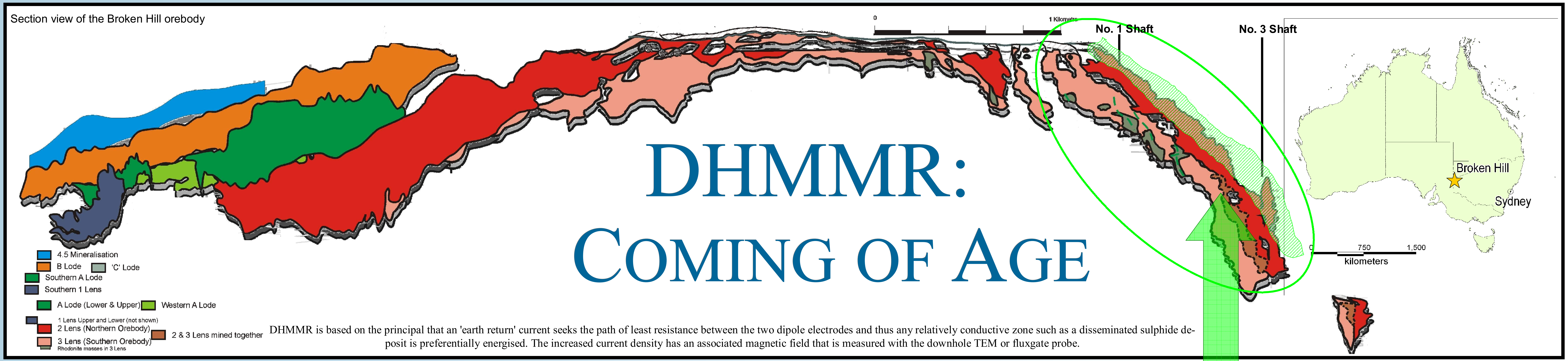
DHMMR: Coming of Age



DHMMR is based on the principal that an 'earth return' current seeks the path of least resistance between the two dipole electrodes and thus any relatively conductive zone such as a disseminated sulphide deposit is preferentially energised. The increased current density has an associated magnetic field that is measured with the downhole TEM or fluxgate probe.

ABSTRACT

The Downhole Magnetometric Resistivity (DHMMR) technique is ideally suited for detecting narrow ribbon-shaped and/or poorly conducting mineralisation. It was first suggested in the 1960s but appears to have been little used until the 1990s. It is still not widely implemented and until recently the sensor was usually a standard downhole single (axial) component time domain electromagnetic (TEM) probe measuring dB/dt. In January 2007, a DHMMR survey was conducted in Broken Hill, NSW, Australia using a 3-component B-field probe. The survey was highly successful, delineating low conductivity narrow pipe-like zinc mineralisation in the western Zinc Lodes of the North Mine. The Zinc Lodes are directly above the main development of the North Mine orebody and directly below the North Mine infrastructure, and therefore a real challenge to isolate and energise for geophysical surveys. DHEM applied on the same targets failed to respond. The success and accuracy of this survey using new equipment is expected to lead to a better appreciation of DHMMR's potential.

DHMMR is a pseudo-DC grounded dipole geophysical survey method which allows absolute direction to a conductor from a borehole to be established. The grounded dipole channels the current through more conductive units (i.e., the mineralisation), and the down-hole survey records the magnetic field generated by these galvanic currents. This are modeled in a similar way to gravity anomalies, with the current density being the prime variable alongside anomaly location and size. DHMMR has advantages over conventional EM in that it needs lower absolute conductivity, works well for narrow ribbon-like structures, has greater area of investigation around the drill hole, gives absolute direction to conductors, and is less susceptible to shielding. Until this survey, the disadvantages of lower resolution, problems with noise, lack of appropriate software, and more expensive equipment meant that DHMMR was often treated as a poor cousin to DHEM and used only as a last resort.

Introduction

With the current historically high price of zinc with few new mines on the horizon, it is not surprising that exploration for sphalerite-rich deposits is increasing worldwide. It certainly an important role in the decision of Perilya Ltd's management to investigate the 'Zinc Lodes' mineralisation directly above their North Mine main lode in Broken Hill, NSW, Australia.

The Broken Hill orebody formed about 1800 million years ago, and has proved to be the world's largest silver-lead-zinc mineral deposit. The orebody is shaped like a boomerang plunging into the earth at its ends, striking northeast-southwest, and outcropping in the centre. The northern end of the 'boomerang' is the North Mine main lode. Whilst the North Mine main lode is mostly mined out, the western Zinc Lodes have largely been ignored.

The main style of Pb-Zn mineralisation in Broken Hill (including the North Mine main lode) is invariably conductive enough to give good electromagnetic (EM) responses (Bishop et al., 1991). However, the Zinc Lodes and other lode horizons north and south of Broken Hill contain a number of sphalerite rich and galena poor zones that are much less responsive to EM.

The North mine ore-body is hosted in a distinctive mine sequence comprising elements of the Broken Hill Group (Hores Gneiss and Freyers Metasediments) and the Thackaringa Group (Rasp Ridge Gneiss) of the Willyama Supergroup. There are at least six stratiform economic mineral horizons, or Lodes, known as:

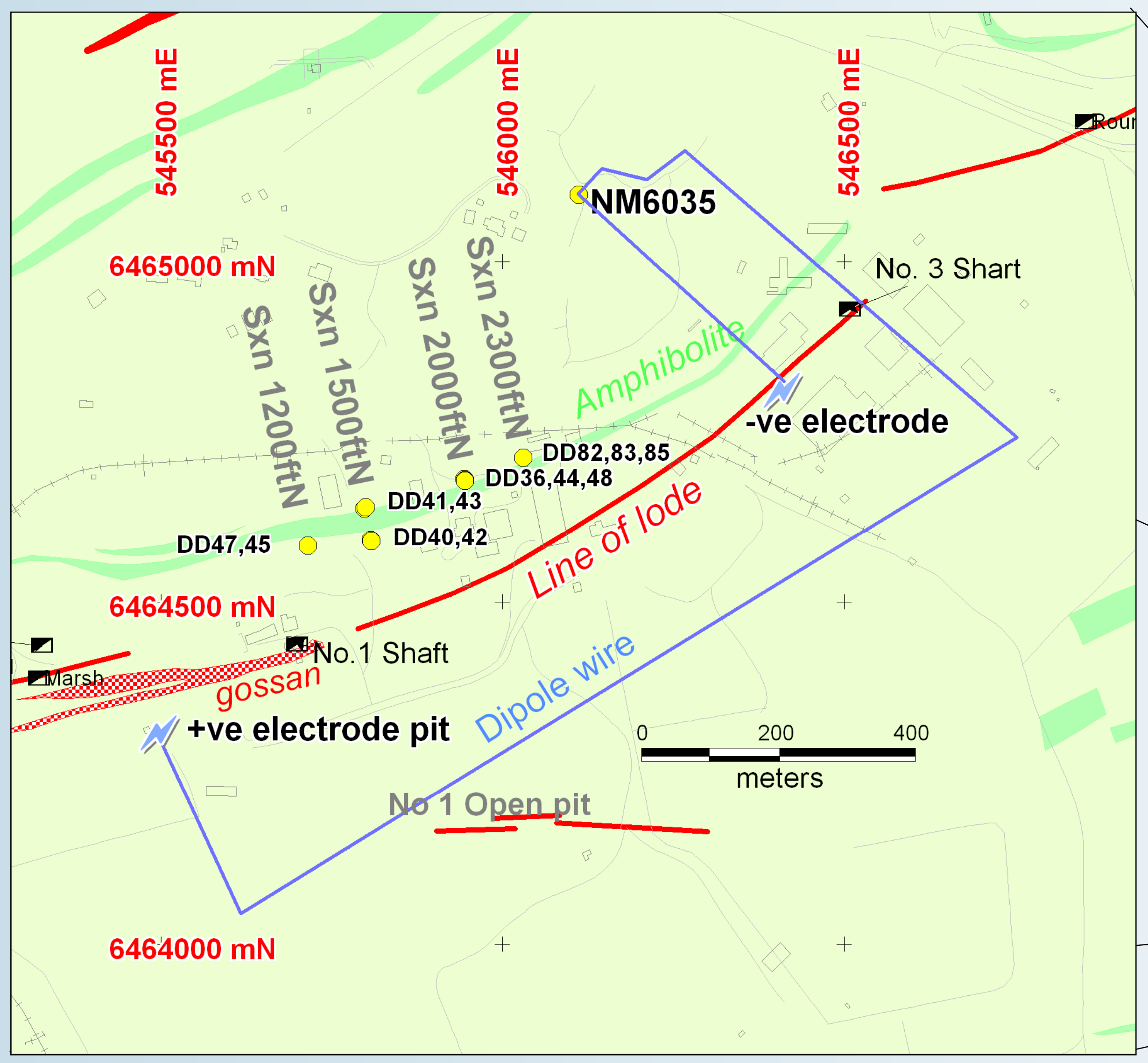
Lead Lodes :	3 Lens
	2 Lens
	1 Lens
Zinc Lodes:	A Lode
	B lode
	C Lode

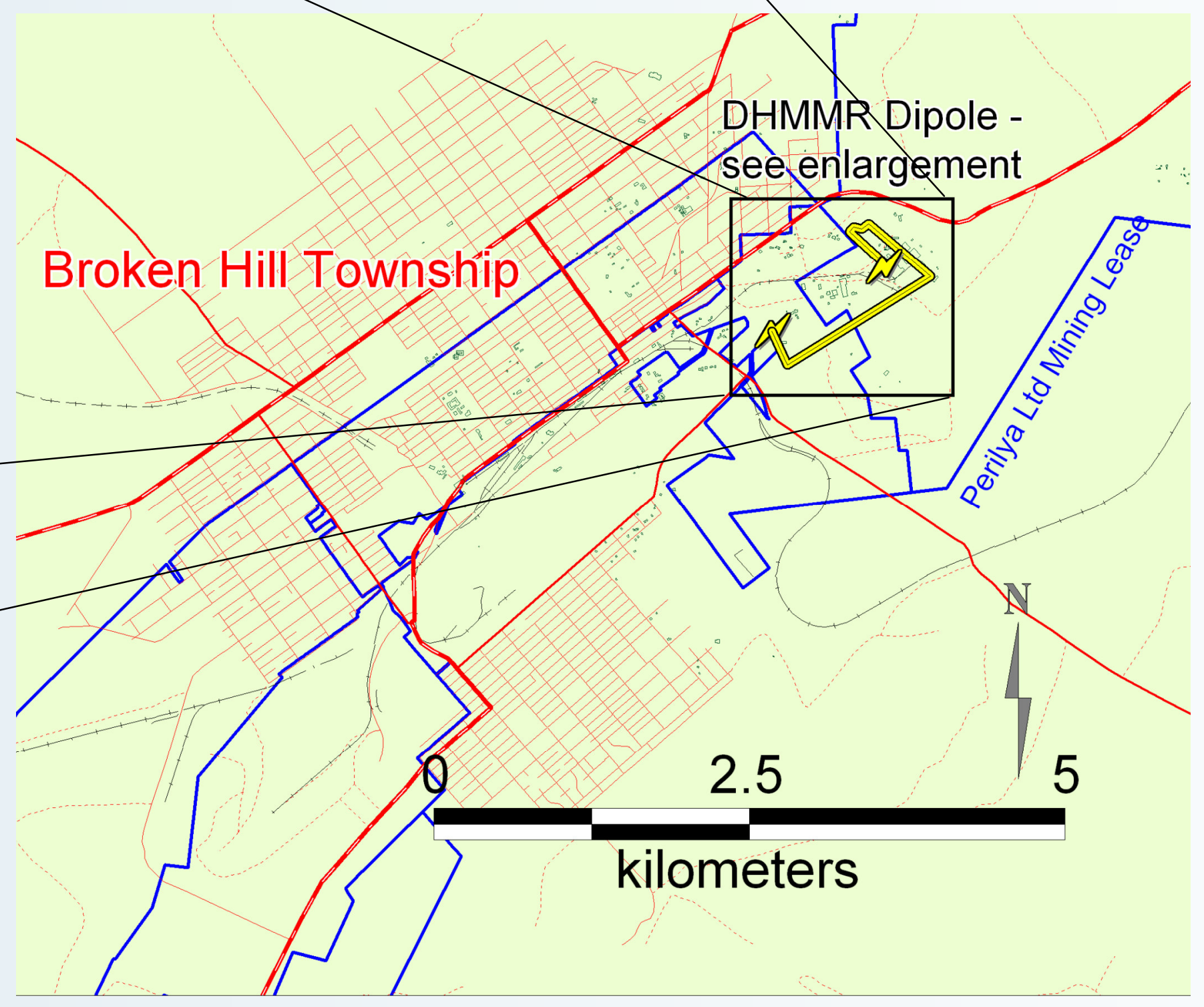
Advantages of DHMMR

1. Detect low conductivity targets—only requires a conductivity contrast rather than high absolute conductivities. A conductivity contrast of 3 is sufficient.
2. Detect extremely conductive targets where TEM establishes no currents.
3. Increased target detection range up to 150m or further.
4. Multiple holes from one survey dipole.
5. Targeting of lesser mineralisation adjacent to larger more conductive zones

Disadvantages of DHMMR

1. Poorer resolution of target dip/distance from hole
2. Lack of readily available modeling/inversion software
3. More demanding instrumentation.





Survey setup for the NorthMine DHMMR survey. Dipole length: 1000m along strike, positive electrode in the surface expression of the Zinc Lodes. The negative electrode was lowered down NM6035 to ~550m in a weak (5% Zn+Pb) Zinc Lodes mineralisation intersection. In this way, the current electrodes isolated and targeted the correct mineralisation.

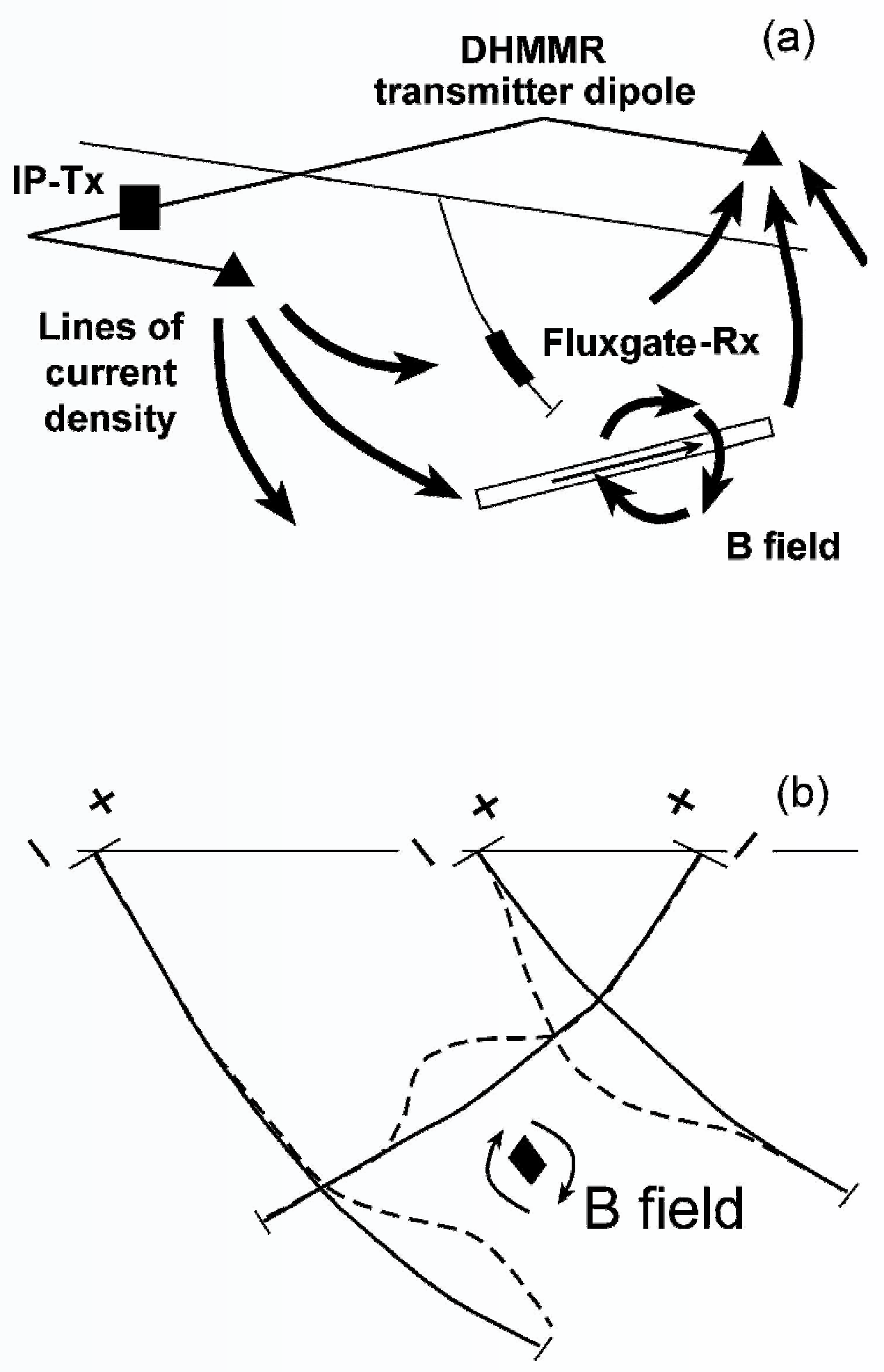
Exploration Target

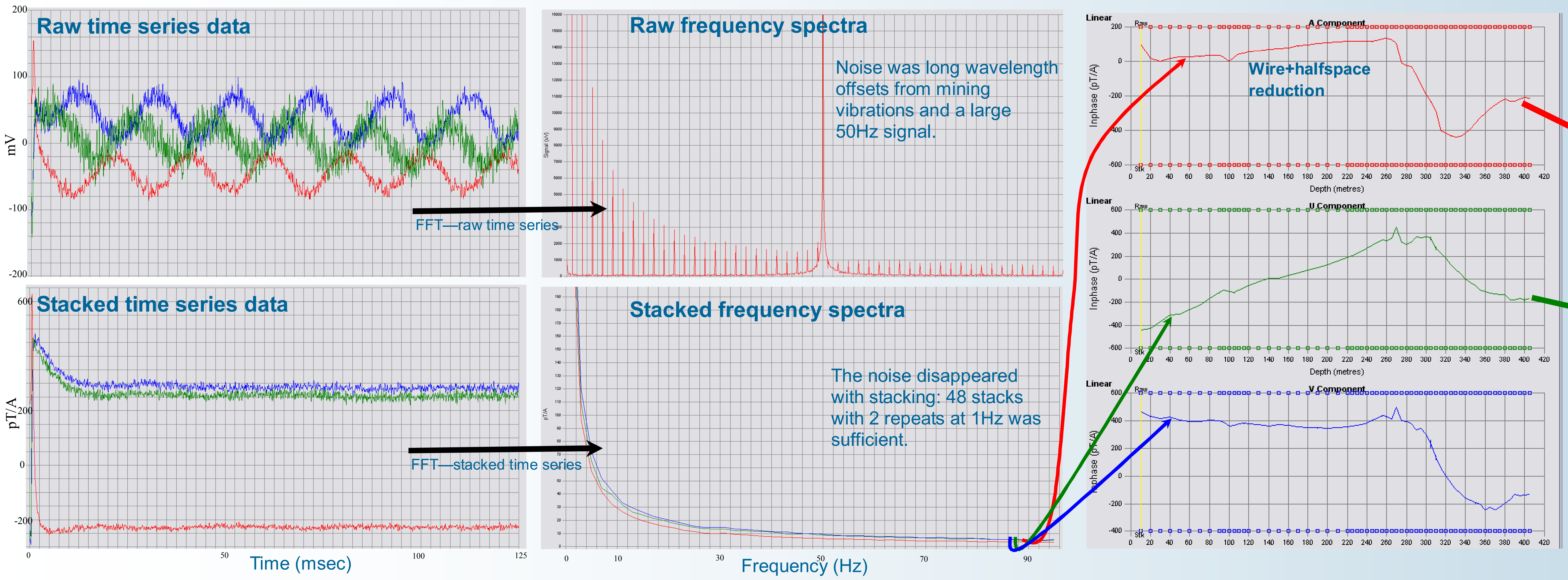
The target of the DHMMR surveys was a series of narrow discontinuous ribbons of 5-10% sphalerite called the 'Zinc Lodes'. The mineralisation is poorly conductive, steeply plunging, positioned very near massive highly conductive Pb-Zn mineralisation, and lies directly below a working mine and railway track. DHEM has been tried on the Zinc Lodes but with little success (Bishop, 1991), but DHMMR was trialed with an innovative survey design to hopefully give a better response.

The Zinc Lodes parallel the Main Lode mineralisation which consists of the 2– and 3– lens ore bodies. The mineralisation is isoclinally folded and plunges to the northeast at about 40-60°. The Zinc Lodes locally dip ~70° north-northwest, and lie about 20-50m northwest above the main lode with parallel plunge. The steep plunge makes it difficult for a surface electrode to energise the mineralisation at depth in the northeast. This problem was solved by using an old drill hole with a Zinc Lodes intersection as the plug in point for the northeastern electrode.

Method

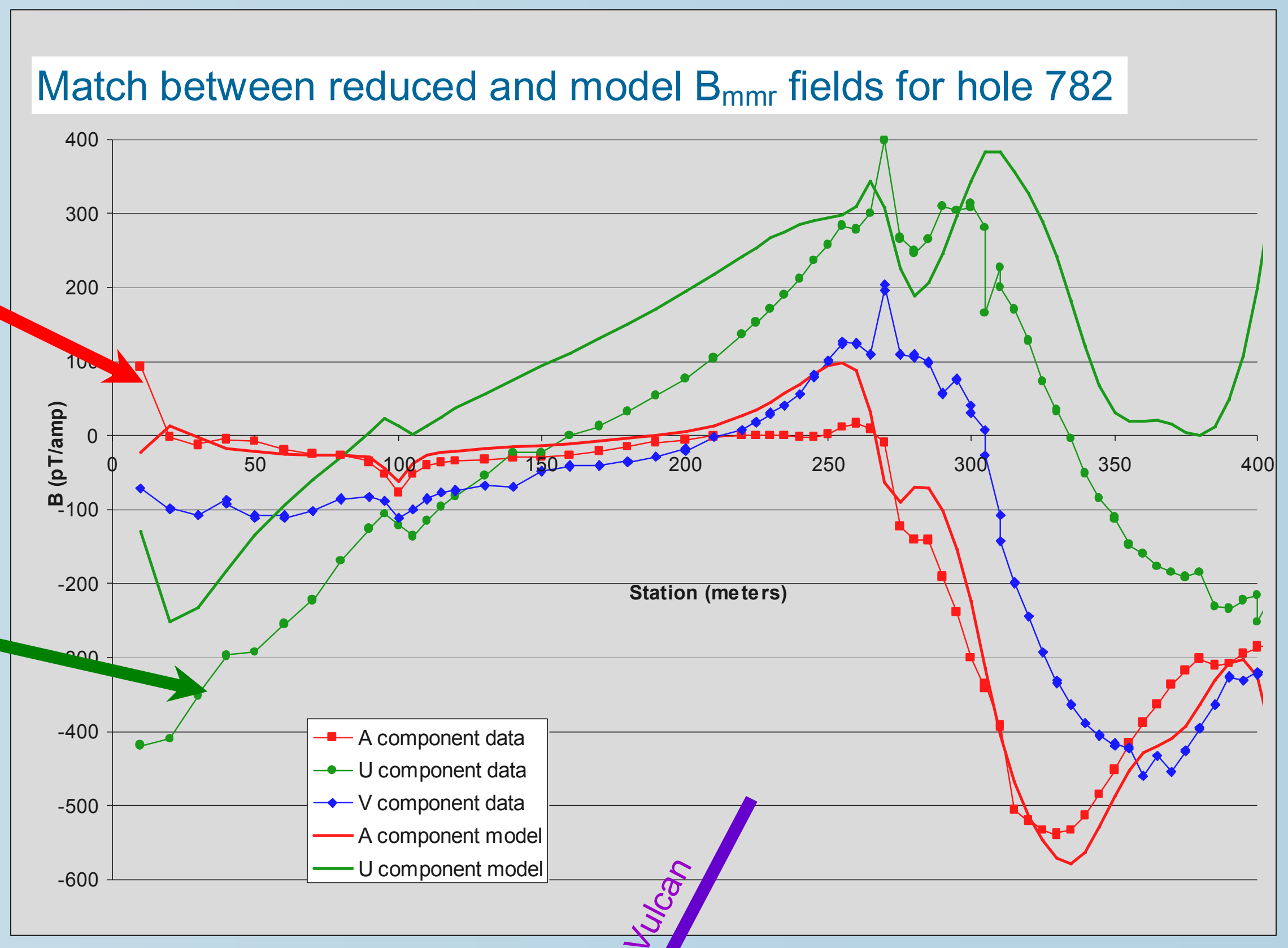
The target zone was energised with a 1Hz square wave impressed into the earth via a grounded dipole. The negative electrode was lowered down drill hole NM6035 to ~550metres in a weak (5% Zn+Pb) Zinc Lodes mineralisation intersection and the positive electrode was dug into the surface expression of the Zinc Lodes. In this way, the current electrodes isolated and targeted the correct mineralisation, which may otherwise have been too deep for a surface electrode to energize. 12 holes on four sections were surveyed. 48 stacks with 2 repeats at 1Hz was sufficient to achieve noise levels below 1 pT/A. The surveys recorded strong responses, stronger and cleaner than expected given the location.





Noise was long wavelength offsets from mining vibrations and a large 50Hz signal.

The noise disappeared with stacking: 48 stacks with 2 repeats at 1Hz was sufficient.



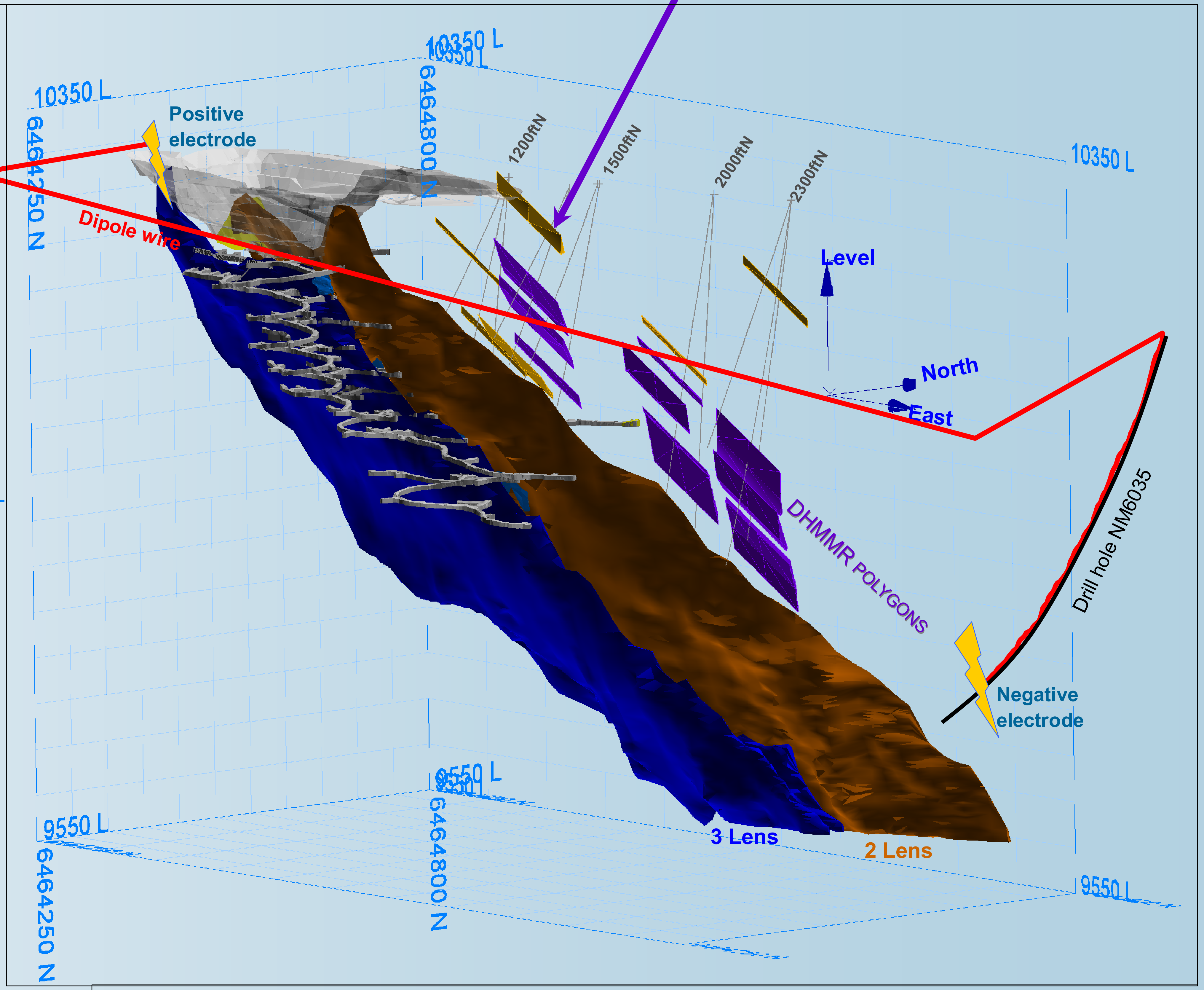
Match between reduced and model B_{mmr} fields for hole 782

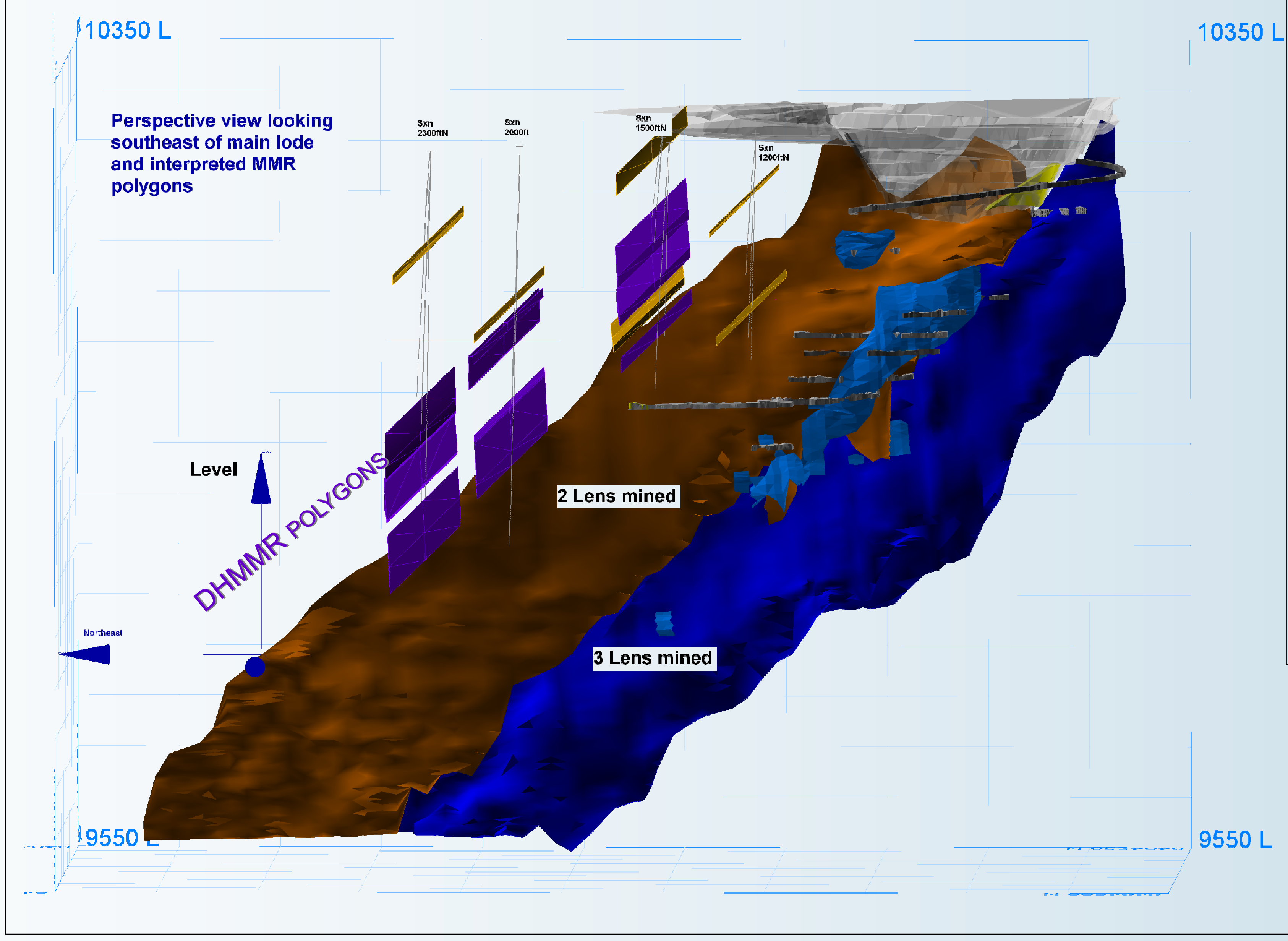
Processing

1. Raw time series data stacked and Fourier transformed to the frequency spectra.
2. 1^{st}, 3^{rd}, 5^{th}, 7^{th}, 9^{th} harmonic amplitude and phase calculated.
3. The wire magnetic field and other background fields subtracted from the data to get the MMR response. The formula used was $B_{mmr}=B_{tot}-B_{wire}-B_{halfspace}-B_{layered\_earth}$
4. DHMMR 2D-modeled on a section-by-section basis using the A+U component data. The polygons from this modeling were extended 50m up and down-plunge to create 100m strike-length polygons. These were incorporated into the mine modeling software Vulcan.

Results

1. Excellent low noise data despite proximity to underground mine workings and infrastructure.
2. The model DHMMR polygons fit very well with known geology and define several new untested targets.
3. A comparison between dB/dt and B-field probes suggest that the latter is more sensitive to off-hole anomalies, and lower noise levels.
4. A concern that the impressed current would short circuit through the highly conductive North Mine Main Lode was overcome was overcome by the careful placement of the dipole electrodes and the model bodies did plot in the correct stratigraphic position. (see right).
5. The main source of noise was long wavelength offsets from mining vibrations and a large 50Hz signal (see above).
6. The modeling indicates two types of mineralisation defined by different current densities. This variation is primarily a function of the pyrrhotite composition, manifesting as current densities of 1 mA/m^2 (po-rich) to 0.1mA/m^2(po-poor) .





Perspective view looking southeast of main lode and interpreted MMR polygons

Discussion

This survey represents the first use of a 3-component fluxgate probe in an applied DHMMR survey at Broken Hill, and one of the first examples Australia-wide. The survey was considered a success, particularly given the excellent data quality underneath the North Mine infrastructure and the accurate delineation of the low conductivity Zinc Lodes so near to the high conductivity 2– and 3– Lens mineralisation. The survey was particularly useful because the Zinc Lodes have proved to be difficult targets to drill and unresponsive to DHEM. The modeled polygons define nearly continuous ribbons west and above the main lode which correlate well the Perilya geologist’s interpretation of the expected structural position. This is encouraging, especially since the DHMMR defines several previously unrecognized anomalies.

The additional of the total magnetic intensity information allows the type of mineralisation and therefore current density to be determined. For example, a spike in the magnetic field indicates a pyrrhotite concentration, and therefore the associated DHMMR anomaly is from a smaller source. There are still some limitations in the software being that the drill holes are required to be on the same section to be realistically jointly modeled, however I expect this to develop into fully functional 3-D capable within the next few years.

Qualitatively, the B-field probe has lower noise than the TEM probes used at Broken Hill. This may be because TEM probes, in general, are well suited and calibrated for downhole time-domain EM surveys (with source frequencies generally greater than 8Hz) the output signal from the receiver coils at low frequencies (e.g., 1Hz) is greatly affected by the background noise level. The B-field probe was also superior to the TEM probes because there was less manipulation of the data required, and the survey crew could therefore plot the MMR field in real time and adjust station spacing accordingly.

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