A review of the Jaguar Cu-Zn-Ag VMS discovery and subsequent geophysical trials

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INTRODUCTION

Jaguar is an Archaean volcanogenic massive sulphide (VMS) deposit is located approximately 250km NNW of Kalgoorlie, and about 4 km south of the historic Teutonic Bore Cu-Zn-Ag mine (Figure 1). The current mining reserve is 1.6mt @ 3.1% Cu, 11.7% Zn, 0.72% Pb and 120g/t Ag. Jabiru Metals Limited began mining the deposit in May 2007 via a 1.8 km long decline that reaches the top of the orebody, which is 300m below the surface. The underground operation has a planned life of five years.

The Canadian company Inmet Mining Pty Ltd entered a joint venture with Jabiru's predecessor, Pilbara Mines Ltd, to explore for VMS deposits in 2001 and discovered the Jaguar deposit in February 2002. Their exploration programme included a large FLEM survey that covered most of their tenure. The discovery drillhole, TBD-202, was the second of two holes drilled into an 1800m long FLEM conductor. The initial holes were planned 600m apart as Inmet Mining were chasing large targets. Following the technical success provided by the FLEM survey a range of electrical geophysical techniques were trialled over the Jaguar deposit. The results of these surveys are reviewed here.

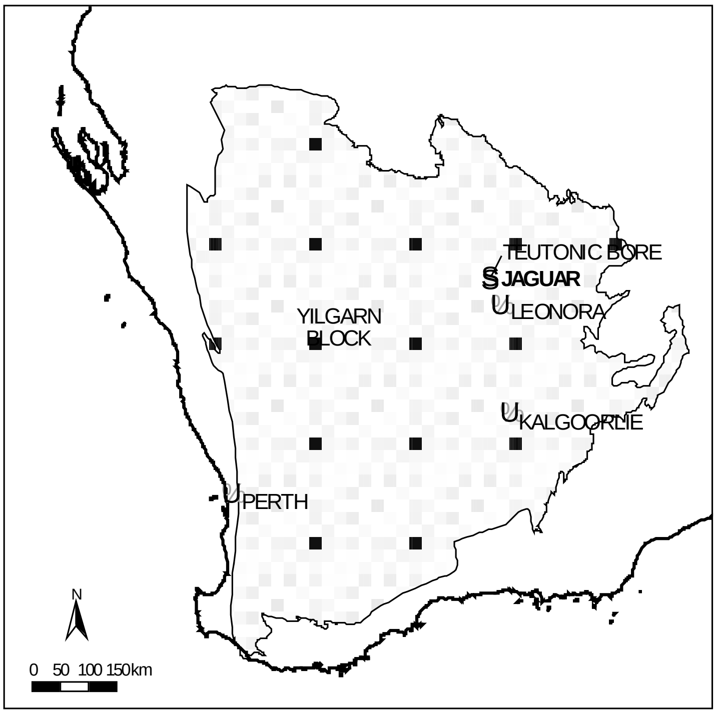

Figure 1: Location map showing the south-west part of Western Australia.

REGIONAL GEOLOGY

The Jaguar VMS deposit is located in the northern portion of the Norseman-Wiluna greenstone belt in the Yilgarn Craton of Western Australia. The geology is dominated by Archaean mafic to felsic volcanic rocks with some sedimentary and intrusive rocks, which have all undergone tight folding and tilting to become sub-vertical. The Archean units are overlain by a Tertiary alluvial cover and weathering of the Archaean bedrock is intense resulting in oxidation levels that are commonly up to 120m deep (Morrison, 2003).

LOCAL GEOLOGY

Outcrop decreases from Teutonic Bore in the north down to virtually none above Jaguar. The Jaguar deposit is covered by more than 20m of transported colluvial material over a deeply weathered laterite profile. The geology around Jaguar has been determined by projecting drill hole lithologies to surface.

The Jaguar deposit consists of a single massive sulphide lens 300-350m in diammeter, which dips 75 degrees to the west, plus a zone of stringer sulphide in the stratigraphic footwall on the eastern side of the massive sulphide. The average thickness of the massive sulphide is 4.4m. A post-mineralisation fault occurs along the dip of the orebody and has an offset of 80m. The top of the deposit is about 280m below the surface (Ellis, 2004).

The ore texture is typically finely-banded to massive sulphide. The mineralogy includes pyrite, pyrrhotite, sphalerite and chalcopyrite. These are commonly intergrown with minor amounts of galena, stannite and arseno-pyrite (Ellis, 2003). The pyrrhotite appears to be dominant over pyrite, unlike the Teutonic Bore deposit.

The massive sulphides are hosted by the "Jaguar package" which sits within the upper tholeitic volcanic sequence of the greenstone belt. The Jaguar package is a mixed unit containing sedimentary and volcanic rocks. The sediments within the Jaguar package include graphitic shale, siltstone, greywacke plus some minor amounts of pebble conglomerate and chert. These sediment units are bounded by massive and pillowed basaltic flows and are cut by related volcanic feeder dykes (Ellis, 2004).

The host stratigraphy has been intruded by post-mineralisation mafic sills (mainly dolerite and gabbro), one of which is more than 150m in thickness underlies the Jaguar deposit and is termed the Footwall Gabbro.

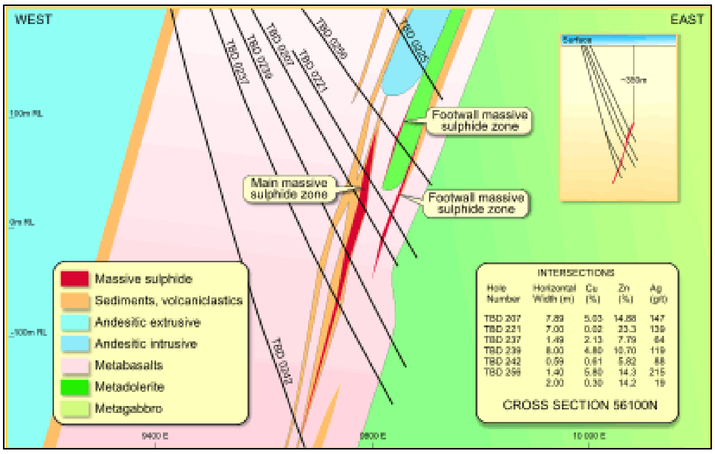

Figure 2: Cross-section of the Jaguar Cu-Zn-Ag VMS deposit. Image sourced from Jabiru Metals Ltd website.

GEOPHYSICAL METHODS AND RESULTS

Fixed-loop Electromagnetics (FLEM)

FLEM surveys were completed over the Jaguar region by Outer-Rim Exploration Services (ORE) between 2001 and 2004 and covering 34km of strike length over prospective ground (Figure 4). ORE employed the Crone PEM system developed in Canada. EM loops were 900m wide by 1000m long with survey lines separated by 300m, and 50m station spacing.

The Crone PEM receiver used a 50ms time base which is equivalent to a frequency of 5Hz. This gave 36 time windows for each reading with a final window time of approximately 45ms. The transmitter current was commonly in the range 12-15Amps. The Z and X components were measured using a Crone PEM receiver.

Due to the 300m line spacing of the Inmet FLEM survey two lines were completed over the south and north extents of the orebody, which were 55900N and 56200N respectively. No lines were surveyed directly over the centre of the deposit.

The Z and X component EM profile results are shown for a single survey line (line 55900N) in Figure 3. The Jaguar deposit is characterised by a Z-component crossover in mid to late times, and an X-component positive response.

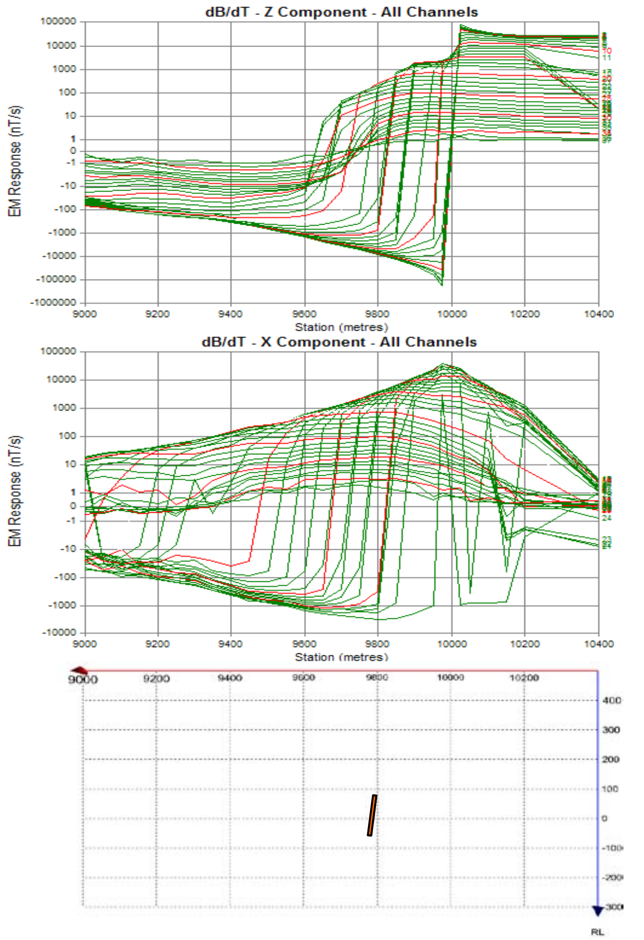

Figure 3: The FLEM results for survey line 55900N (local grid). The Jaguar orebody is located at 9800E at a depth of approximately 280m below the surface. At this local grid northing the orebody has smaller depth extent of about 160m.

This FLEM anomaly can be observed in the profile data over a strike length of approximately 1.8km, however the response is stronger and more defined on survey lines 55900N and 56200N over southern and northern extents the Jaguar orebody. The conductive shale units overlying the massive sulphide of the jaguar orebody have a greater strike length and contribute to the long strike FLEM anomaly observed, but the Jaguar mineralisation can be distinguished from the shale because it gives a greater amplitude EM response.

The Inmet FLEM channel data were gridded for several lines in the Jaguar mine corridor. The X component response is shown in Figure 4. The Jaguar deposit is within the 5 uV/A contour line. Although there is a long strike length FLEM anomaly, Jaguar lies in the highest amplitude portion of the FLEM anomaly.

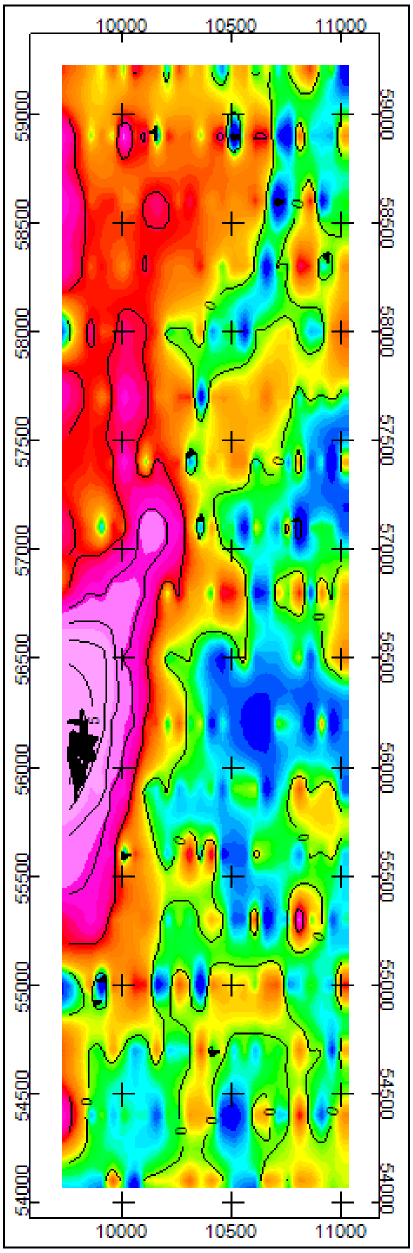

Figure 4: X Component FLEM response over the Jaguar deposit. This image corresponds to channel 35. The Jaguar deposit is shown by the black polygon which has been projected vertically to surface. Jaguar sits on the edge of the 5uV/A contour line, in the highest amplitude portion of a long strike length FLEM anomaly.

Downhole Electromagnetics (DHEM)

DHEM surveys were integral to the delineation of the Jaguar orebody. Many holes were drilled into the Jaguar orebody during the few years following discovery and DHEM was performed on most of these holes to provide a vector towards massive sulphides. In particular, the Crone STEP Response or Impulse response, which is described by Ravenshurst (2001), was effective in discriminating the conductive shales and sediments from the Jaguar VMS mineralisation.

The DHEM results for the discovery hole TBD-202 are reviewed for this hole because they highlight the importance of careful DHEM interpretation and the use of either B-Field or STEP response measurements. TBD-202 was drilled into the southern extremity of the Jaguar massive sulphide lens.

Modelling of the DHEM off-time data shown in Figure 5 demonstrates that the resulting model plate is in the opposite direction to the Jaguar orebody. The STEP Response data for this hole indicates that the direction to the most conductive EM source was actually in the opposite direction.

The STEP Response responds to massive sulphide conductors that act like 'super conductors' and have long EM decay times that may not be detected by conventional off-time DHEM systems. It is interpreted that the anomaly observed at approximately 500m downhole in the off-time DHEM data is due to conductive shales and sediments overlying and along strike of the Jaguar deposit, whilst the STEP Response is due to the Jaguar VMS mineralisation which generates a response in the on-time.

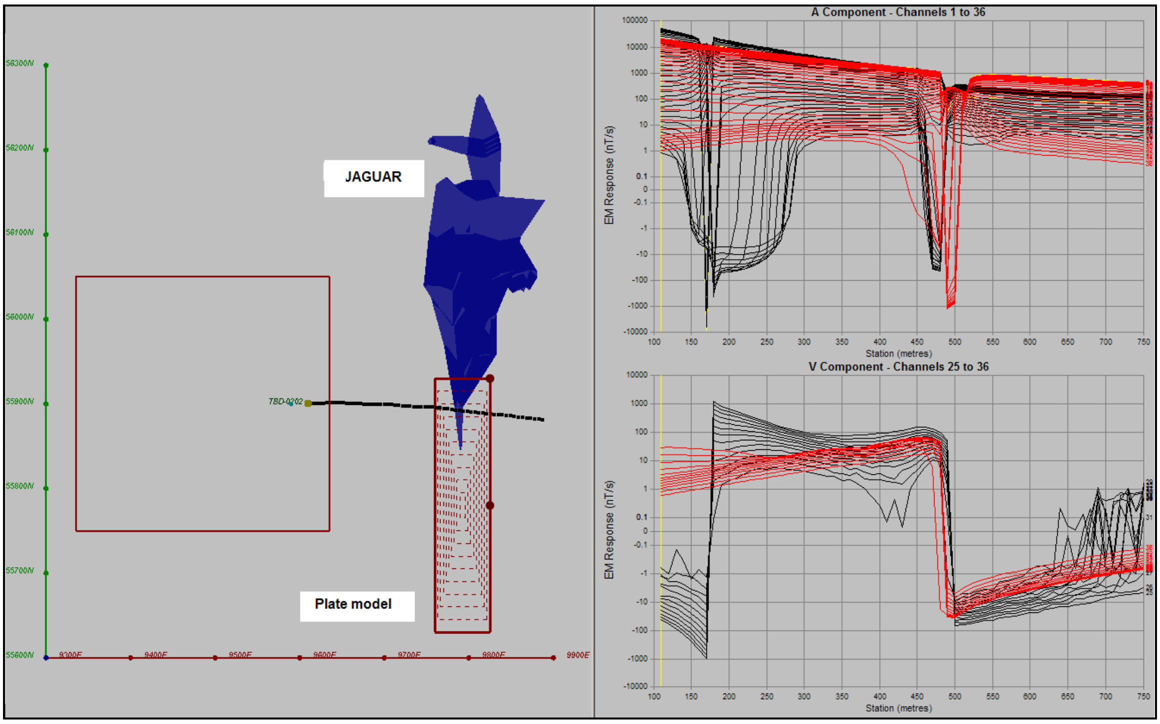

Figure 5: DHEM modelling results for TBD-202 off-time data. The best-fit model for the V component suggests a target to the south (local grid) of TBD-202, which contradicts the known mineralisation.

Moving-loop Electromagnetics (MLEM)

MLEM surveys were subsequently trialled over the Jaguar deposit using a SQUID (Superconducting Quantum Interference Device) sensor plus a low noise level dB/dT coil developed by The Department of Exploration Geophysics at Curtin University. The data were collected by Outer-Rim Exploration in the period February – March 2005.

The SQUID sensor is a B-field sensor that measures three components (X, Y and Z) which were measured during the survey. The SQUID used in this instance was the CSIRO developed "high temperature" SQUID which uses liquid nitrogen to cool the sensor. The dB/dT coil sensor is a single component receiver and was used to collect the Z component only. Both the SQUID and dB/dT coil sensors were used in the inloop and slingram positions. The survey consisted of 200 m by 200 m transmitter loops with 2 turns, and was moved along the survey line with 50 m station moves. The slingram position was 100m to the west of the loop edge. The SMARTEM MKV receiver developed by EMIT Technology with a base frequency of 0.2083 Hz were used to generate a long recording time at each station. This setup recorded 43 time channels reading out to a final channel time of approximately 1 second. The average transmitter current was 30 Amps.

Two test lines were conducted over the Jaguar orebody; line 1 on 55950N and line 2 on 56100N. Only the results for line 1, 55950N are presented in this abstract.

The inloop SQUID B-Field results in Figure 6 show a distinct double peak anomaly as 'bunching up' from mid to late channel times centered at approximately 319700E (GDA94-MGA51 co-ordinates) can be attributed to the EM response of the Jaguar orebody. There is a coincident broad X component response which is characterised by a peak in amplitudes from mid to late channel times, whilst the Y component response is weak but trend from positive to negative values suggesting the main part of the conductor is to the north. There is also a separate but superimposed Z component response to the west which occurs at later times due to the conductive shale units that occur higher up in the hanging wall.

The inloop SQUID B-Field results are compared to the coil dB/dT data in Figure 7. The dB/dT data collected by the 'Curtin Coil' shows an anomaly centred over the Jaguar deposit, but as expected does not appear to be as strong as that produced from the SQUID data. The dB/dT response is visible in the data between channels 18 and 23 as a double peaked response indicating a steep dip to the west. The "Curtin Coil" has produced very low noise levels of below 0.1 μV/A in this line which compared well to the SQUID data.

The slingram SQUID B-Field and coil dB/dT results displayed in Figure 8. The Curtin Coil again provided very low noise levels and the slingram response appears more definitive than the dB/dT double peak anomaly at late times in the inloop Z component data due to the enhanced coupling of the offset transmitter loop. The slingram SQUID response however is better resolved and has an asymmetry to the profile response suggesting a steep west dip to the conductor. This appears to be the most robust surface EM response over the Jaguar orebody position.

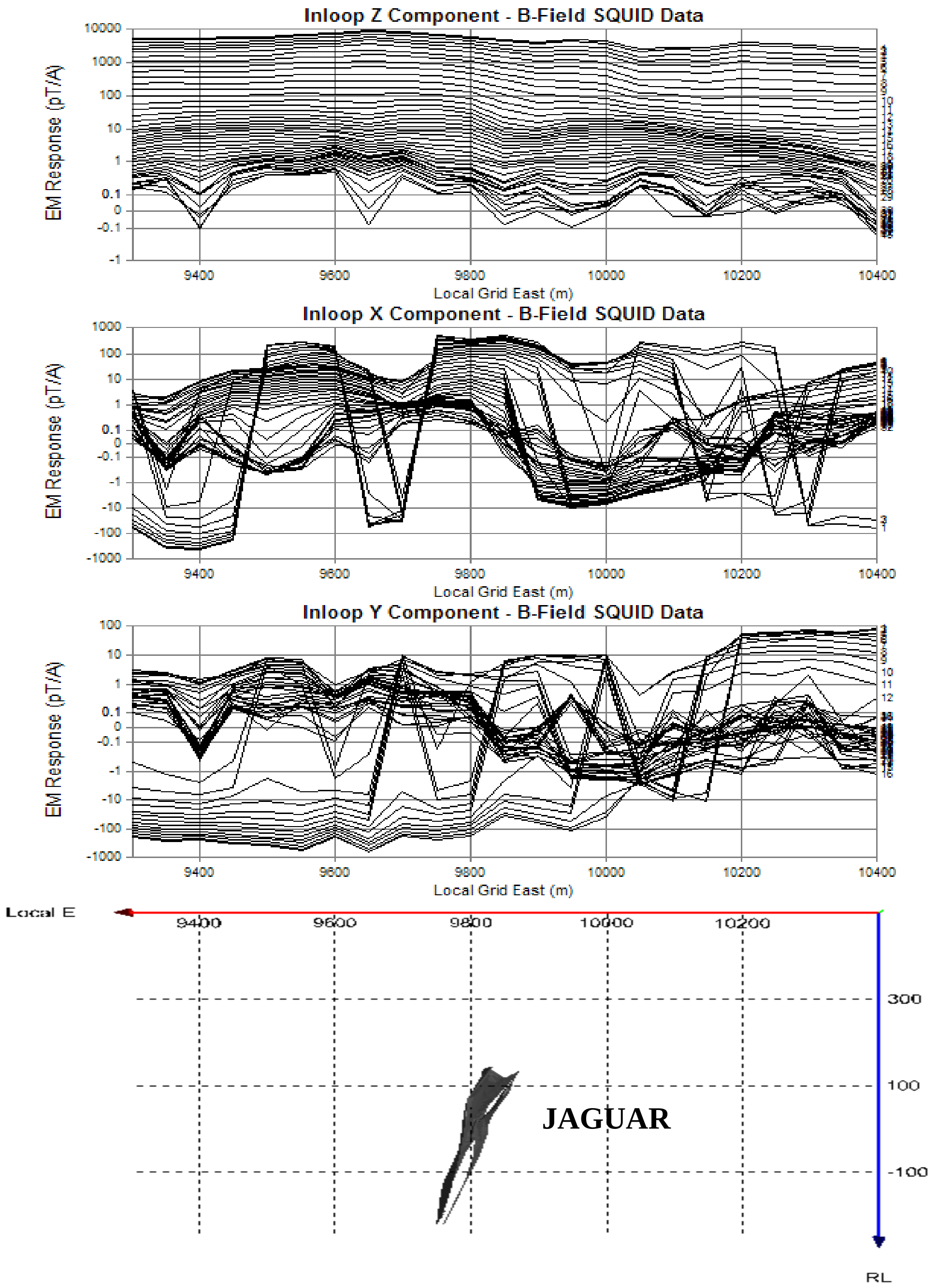

Figure 6: The MLEM in-loop B-Field X, Y and Z component results for line 55950N. X-axis co-ordinates are shown in GDA9- MGA51 coordinates.

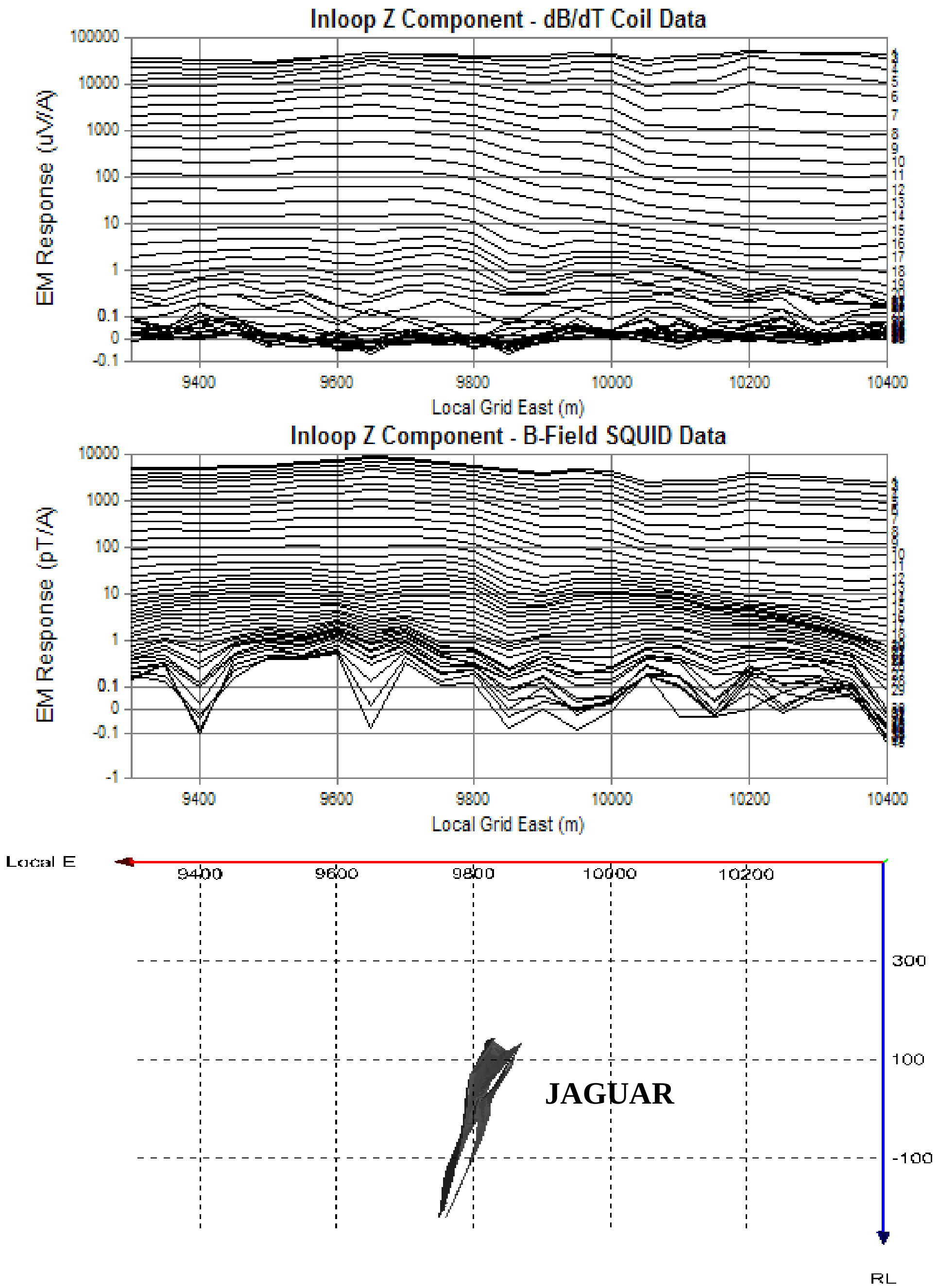

Figure 7: Comparison of in-loop dB/dT and B-Field Z Component results for line 55950N. X-axis co-ordinates are shown in GDA9- MGA51 coordinates.

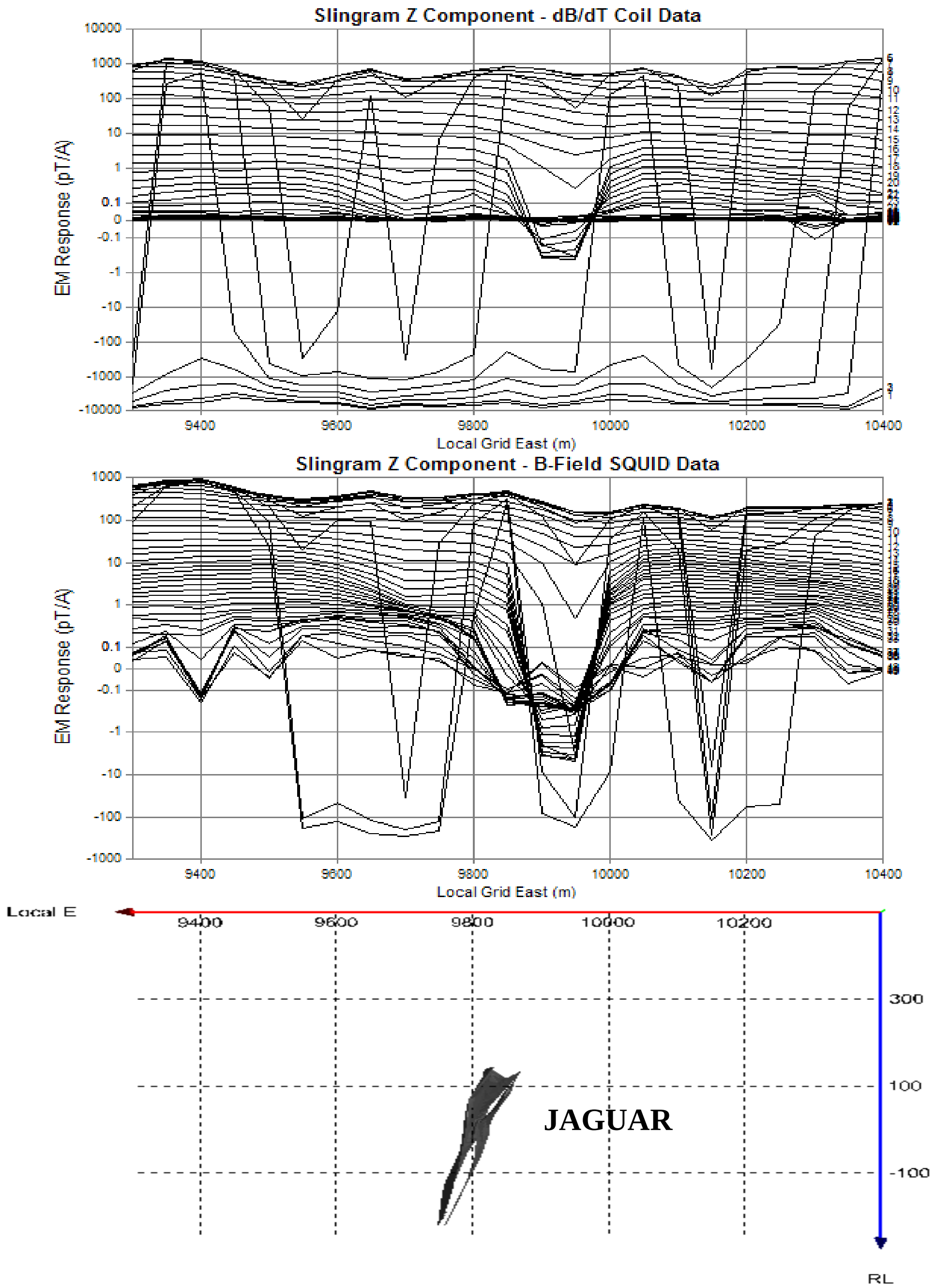

Figure 8: Comparison of slingram dB/dT and B-Field Z component results for line 55950N. X-axis co-ordinates are shown in GDA94-MGA51 co-ordinates. The easting position corresponds to the centre position between the centre or the loop and the slingram position.

OTHER GEOPHYSICAL METHODS

In addition to the geophysical methods described above, AEM (GEOTEM system) and DDIP surveys were also trialled over Jaguar. The results are not presented in this abstract but are summarised as follows; GEOTEM and DDIP surveys were not as successful in directly detecting the Jaguar orebody. Only broad anomalies were observed in the results when using these methods and the results are likely to be due to responses from both Jaguar mineralisation and shale units above the Jaguar orebody.

CONCLUSIONS

The discovery of the Jaguar VMS deposit was made by a drillhole into the strongest EM amplitude portion of a 1.8 km long FLEM anomaly. The shale units that lie directly alongside the Jaguar orebody must have contributed to the overall EM response, but did not mask the massive sulphide response. The Jaguar discovery was the result of a well-funded exploration programme that involved several deeper drillholes into the large FLEM anomaly associated with Jaguar.

Subsequent DHEM and MLEM surveys greatly assisted resource definition drilling, and whilst the EM influence of the shale units remains an issue these methods have the depth penetration and spatial resolution to resolve the Jaguar VMS mineralisation. DHEM was the key to helping define the limit of mineralisation, and subsequently drill out the deposit.

AEM and DDIP surveys were trialled over the Jaguar but neither system trialled appears to have the depth penetration and spatial resolution required to directly detect the Jaguar orebody.

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