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High-resolution mapping using SAM surveys over the Bogada Bore gold prospect, Western Australia

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ABSTRACT

The Bogada Bore prospect lies immediately to the north-east of the Jundee gold deposit, in the north-west margin of the Archaean Yandal Greenstone Belt, Western Australia. The prospect has a long exploration history and has undergone extensive but variably effective drilling. The gold mineralisation at Bogada Bore shares many common characteristics with the Jundee and Nimary deposits, and is controlled by predominantly brittle structures, with high-grade shoots occurring along the intersection of structures, or by the intersection of structures with dacitic porphyry intrusions.

Outcrop is sparse with more than 90% of the area under thin colluvial cover and regolith weathering commonly down to 50 m or more. Previous geological interpretations have been mainly generated from drilling information, with the use of geophysics limited to a single high-resolution aeromagnetic survey conducted in 1994. This survey was useful for refining the existing geological interpretation by highlighting regional structures, geological boundaries, and magnetic trends, but it failed to delineate the small-scale structures which control gold mineralisation at Bogada Bore.

Sub-Audio Magnetic (SAM) surveys were trialled over the prospect area, and have been able to delineate numerous regional and small-scale structures that are shown to correlate with gold mineralisation over several areas. These surveys have also provided the basis for a new and more detailed geological interpretation in conjunction with a gravity survey and the existing aeromagnetic and drilling data.

INTRODUCTION

The Bogada Bore gold prospect is located immediately to the north-east of the Jundee and Nimary gold deposits in the north-west margin of the Yandal Greenstone Belt, Western Australia (Figure 1). The deposits of Jundee and Nimary collectively represent the largest mineralised gold system in the Yandal Greenstone Belt, with 6.7 million contained ounces as at January 2003 (Gebre-Mariam et al., 2003), and cover approximately 15 sq km (Kohler et al., 2001).

Gold mineralisation at Bogada Bore was initially discovered by prospector Mark Creasy in 1978 and is contained within the same lithological sequence that hosts the Jundee and Nimary gold deposits. The Bogada Bore mineralisation shares many common characteristics with the Jundee and Nimary deposits, and is controlled by predominantly brittle structures, with high-grade shoots occurring along the intersection of structures, or at the intersection of structures with dacitic porphyry intrusions (Compston, 2004).

The prospect was originally explored for base metals in 1978 (Wright, 2000). Between 1985 and 1989, gold exploration was limited to prospecting and metal detecting. Systematic exploration commenced in 1989, and included geochemical soil and rock chip sampling, followed up by rotary air blast (RAB) drilling. Results from early RAB programs included four holes with 3 m intervals containing >1 g/t Au with one 3 m interval >2 g/t Au. Subsequent drilling on these intersections returned significant gold values, including 18 m at 10.5 g/t Au (Compston, 2004). Mineralised zones have now been defined in five separate areas as shown in Figure 2. Recent drilling of mineralised areas 2, 3, and 4 indicate extensive mineralisation along 1500 m of strike and extending down dip (comparable to Jundee Pits), with localised high grade shoots (Compston, 2004).

The complex nature and small-scale structures controlling mineralisation require extensive, close-spaced drilling orientated across structures. The SAM technique was trialled in an attempt to more accurately define structures controlling mineralisation, identify extent of known mineralisation, delineate resistive dacitic porphyries, and provide more accurate drill targeting.

SAM equivalent magnetometric resistivity (EQMMR) data have been shown to directly correlate with known gold mineralisation over several areas, to delineate numerous small-scale structures which appear to control or are related to gold mineralisation, and to assist in the refinement of the geological interpretation at Bogada Bore.

EXPLORATION HISTORY

The Bogada Bore area (and adjacent Jundee and Nimary Gold deposits) was initially discovered by Mark Creasy through surface sampling in 1978 (Compston, 2004). The area was explored for base metals by Chevron Exploration Corporation from 1978 to 1983, but low-level gold anomalies were also identified (Wright et al., 2000). The area was held in joint venture by Mineral Estates, of which Mark Creasy was a party, between 1983 and 1985 after Chevron relinquished its tenements. The Mineral Estates JV subsequently collapsed, and Mark Creasy was granted tenement E53/83 covering the Bogada Bore area in 1986.

The following three years of exploration included soil and rock chip geochemical sampling, geological mapping, panning,

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and nugget detection. Soil sampling over what became the Jundee "Main Zone" returned results up to 120 g/t Au, with results over the Nimary area being less successful, resulting in relinquishment of that part of the tenement in 1989 (Compston, 2004).

Systematic soil sampling over the remainder of the tenement defined a surface gold anomaly of 8 km × 3.5 km covering Jundee and Bogada Bore. Joint venture partners were sought to further explore the Jundee part of the tenure while initial RAB drilling was commenced over the Bogada Bore area, and this returned four 3 m intervals >1 g/t Au with one interval being >2 g/t Au (Compston, 2004). Sampling by Hunter Resources, who pegged the relinquished ground over Nimary, also identified a large surficial gold anomaly around this time.

Great Central Mines Ltd (GCM) entered into a joint venture agreement with Mark Creasy in late 1991 to explore the Jundee area and identified the minable resource there. Open pit mining commenced in 1995, with underground operations beginning in 1997. The Nimary deposit also came into production at a similar time by Eagle Mining Ltd, after the takeover of Hunter Resources. Newmont Mining Ltd are now the current operators of both the Jundee and Nimary Gold deposits after a series of takeovers. The combined Jundee-Nimary operation has produced 4 million ounces of gold to date.

Mark Creasy retained the Bogada Bore tenements adjacent to Jundee, and used geochemical sampling to define four areas within two zones along a strike length of 3 km, in which drilling confirmed the potential for open-pit oxide deposits. More recent, deep RC drilling of the main mineralised zones at Bogada Bore has identified extensive primary mineralisation.

REGIONAL GEOLOGY

The Bogada Bore prospect lies within the north-west portion of the Yandal Greenstone Belt (Figure 1). The Yandal Greenstone belt is approximately 250 km in length, up to 40 km wide, and has less than 10% of outcropping weathered bedrock. The belt is almost entirely covered by a deep regolith profile consisting of weathered bedrock (up to 160 m), lying under transported sedimentary horizons (Anand, 2003).

The Yandal Greenstone Belt regionally comprises a south to south-east striking succession of variably deformed, greenschist to amphibolite facies metamorphosed rocks, including ultramafic, mafic, and felsic volcanics, differentiated mafic sills, and sedimentary units (Kohler and Phillips, 2003). Outcrop mapping and drill-hole examination of the northern Yandal Belt around Jundee (Stewart, 1997; Phillips et al., 1998; Farrell and Wyche, 1999; Gebre-Mariam et al., 2003) has subdivided the greenstone sequence into three broad lithological groups (Figure 1).

From east to west these are:

1. The Jundee Mafic Sequence (Gebre-Mariam et al., 2003), also called the Middle Greenstone Sequence by Phillips et al (1998), or the Eastern Sequence by Farrell and Wyche (1999), is bounded by the Nimary Fault to the west, and granitoids to the east. It consists of dominantly ultramafic and mafic rocks (high-Mg basalts, tholeiitic basalts, and dolerite sills), and interbedded sedimentary rocks.
2. The Nimary Felsic Sequence (Gebre-Mariam et al., 2003), or the Upper Greenstone Sequence (Phillips et al., 1998), or the Central Sequence (Farrell and Wyche,1999), consisting of dacitic and andesitic volcanic and volcaniclastic rocks with subordinate basalts, shales, and ferruginous cherts. This sequence abuts the Moilers Mafic Sequence to the west and Nimary Fault to the east.
3. The Moilers Mafic Sequence (Gebre-Mariam et al., 2003), or Lower Greenstone (Phillips et al., 1998), or Western Sequence (Farrell and Wyche, 1999), contains a thin sequence of chlorite schists after tholeiitic and high-Mg basalts, with subordinate chert and BIF, located between the Moilers BIF and Nimary Felsic Volcanics.

It is important to note that economic gold mineralisation is restricted to the Jundee Mafic Sequence, which contains the Bogada Bore prospect. The Jundee deposit occurs close to a distinct variation in the regional strike, with a majority of the mineralisation occurring close to the Nimary Fault, in particular where porphyry intrusions are common and where there is significant geological complexity and competency and chemical contrasts (Gebre-Mariam et al., 2003).

LOCAL GEOLOGY

The Bogada Bore prospect lies 3 km to the north-east of the Jundee mine as shown in Figure 1. The local geology is similar to the Jundee Mine Sequence. It is dominated by NNW-trending ultramafic-mafic rocks (high-Mg basalts, tholeiitic basalts and dolerite sills) and interflow sediments, though slightly lower in the stratigraphy than Jundee, with a thickness of approximately 2200 m (Compston, 2004).

Bedrock geology is commonly obscured by widespread weathering and transported overburden up to 50 m thick, with a broad north-south trending palaeodrainage separating Bogada Bore from Jundee. Geological interpretations derived from limited outcrop mapping and drilling indicates that the Bogada Bore sequence comprises, from east to west: basalt, high-Mg basalt, ultramafic rocks, and minor interflow sediments. The sequence is intruded by dacitic porphyries, porphyritic granodiorites, lamprophyres, Archaean dolerite sills, and Proterozoic dolerite dykes. Similar to the Jundee deposits, the majority of gold mineralisation at Bogada Bore appears to be controlled by dolerite sills and dacitic porphyries (Compston, 2004).

Gold mineralisation at Bogada Bore has so far been identified over four areas within two zones along a strike length of 3000 m (Figure 2). Recent deep RC and diamond drilling of the main mineralised areas 2, 3, and 4 have indicated extensive mineralisation along strike over 1500 m in length, with localised high-grade shoots remaining open at depth (Compston, 2004).

Gold mineralisation in these zones is controlled by brittle structures, and occurs in multiple orientations with variable dips and dip directions. High-grade shoots occur in zones of geometrical complexity, such as intersecting structures, and can contain up to 20% sulphide minerals (pyrite, pyrrhotite and arsenopyrite). Delineation of the mineralised structures throughout the project area was essential for locating and targeting high-grade gold mineralisation. A number of high-resolution geophysical techniques were considered for their ability to highlight structures over the mineralised zones; SAM was found to have the best potential for mapping mineralised positions.

METHODS AND RESULTS

Aeromagnetics

A detailed high-resolution bi-directional aeromagnetic survey was undertaken in April 1994 (Figure 3). The survey was flown with flight lines 50 m apart orientated at 051° and at a 40 m terrain clearance. Tie lines were flown at the same terrain clearance with 200 m line spacing, orientated at ninety degrees to the main flight lines. The close-spaced tie lines were used because the survey

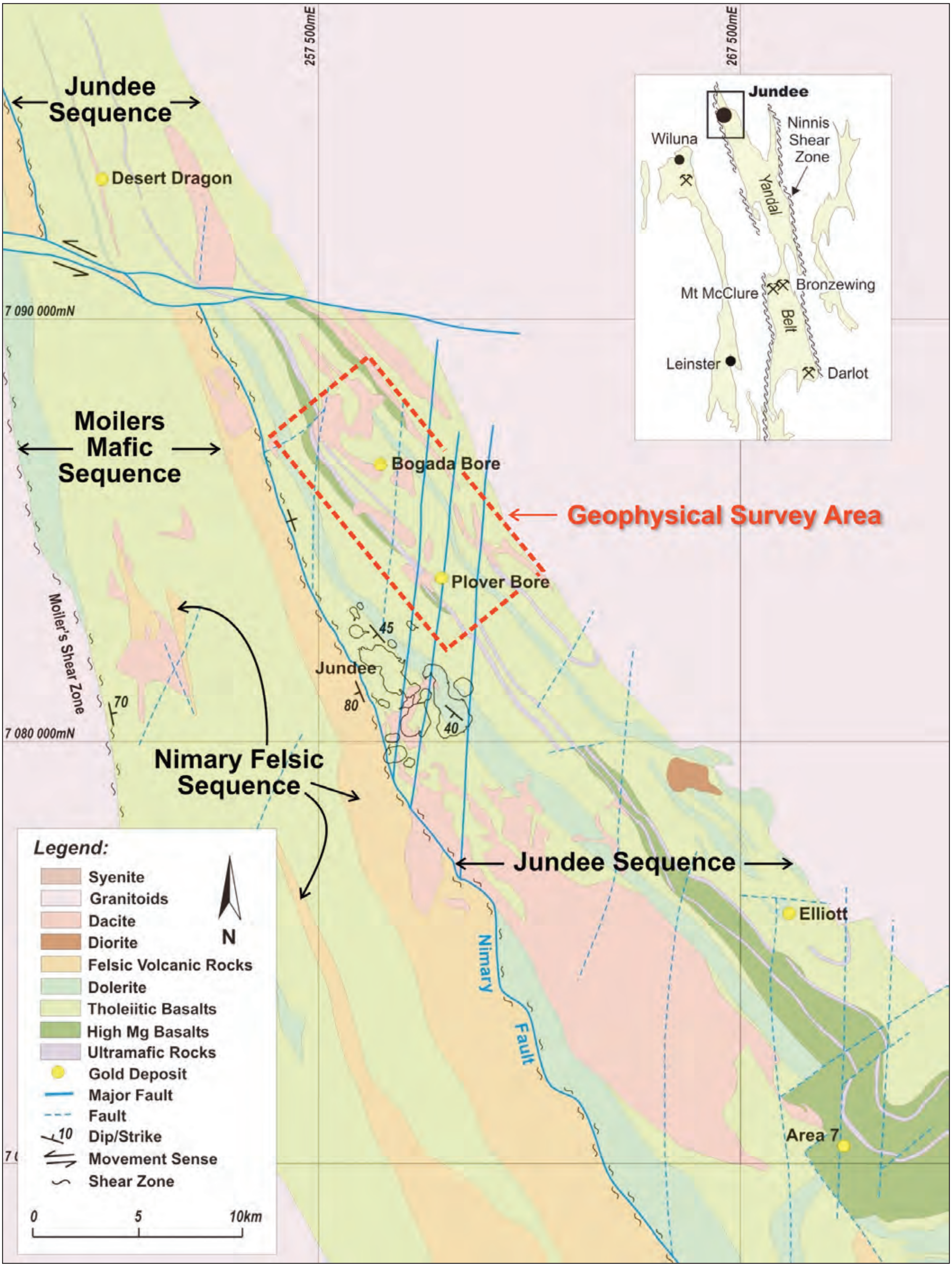

Fig. 1. Interpreted bedrock map of the Jundee and Bogada Bore area (modified from Gebre-Mariam et al, 2003). Geophysical survey area also represents the region contained in Figures 2 to 8.

Fig. 2. Outline of SAM survey blocks, gravity station locations and mineralised areas at Bogada Bore.

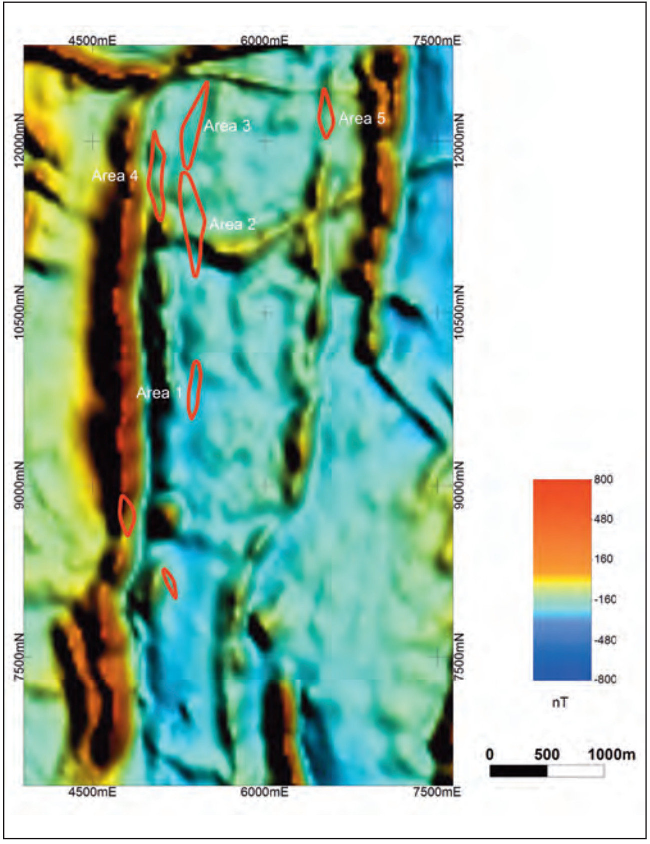

Fig. 3. Image of 50 m line spaced high-resolution aeromagnetic survey showing east sun-shaded magnetic image and outlines of gold mineralised areas.

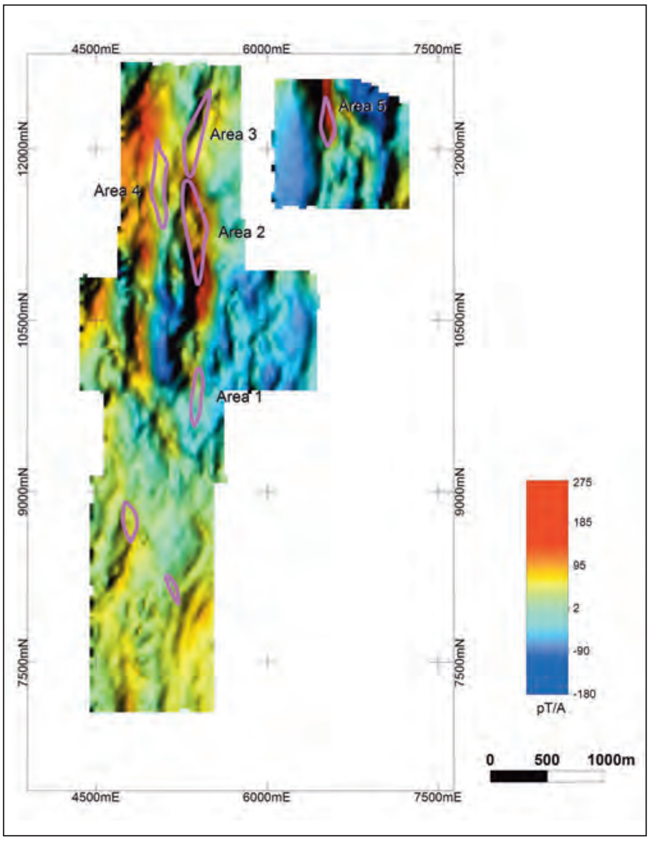

Fig. 4. East sun-shaded EQMMR image with outlines of gold mineralised areas.

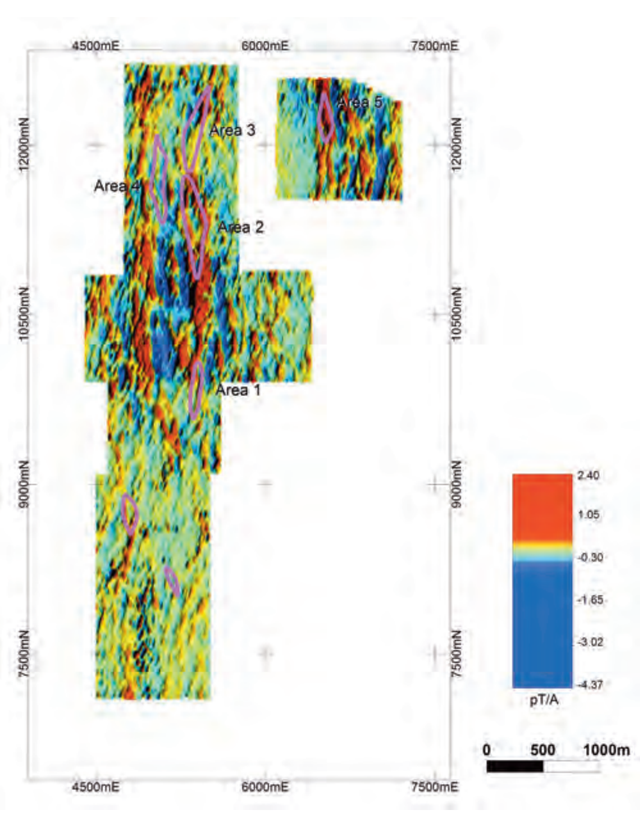

Fig. 5. East sun-shaded EQMMR first vertical derivative image with outlines of gold mineralised areas.

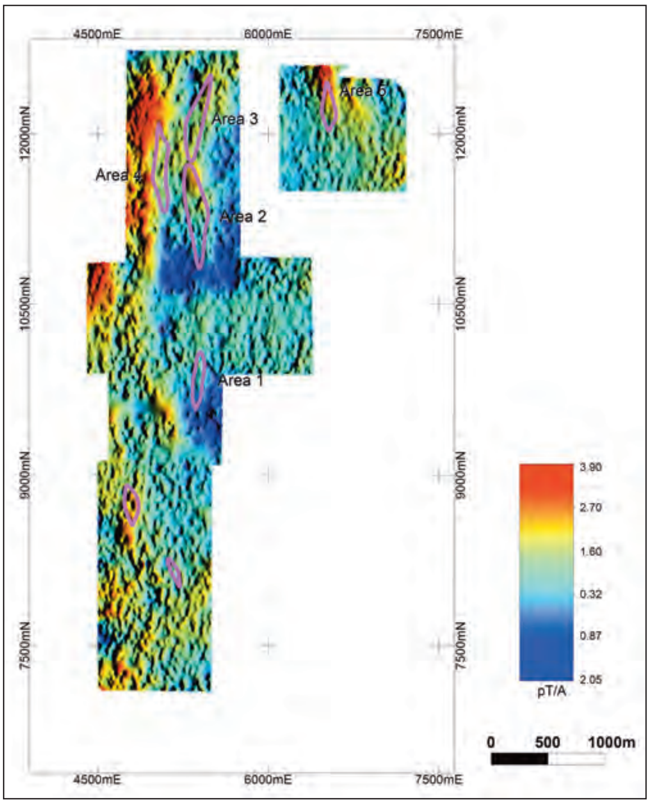

Fig. 6. North-east sun shaded TFMIP image with outlines of gold mineralised areas.

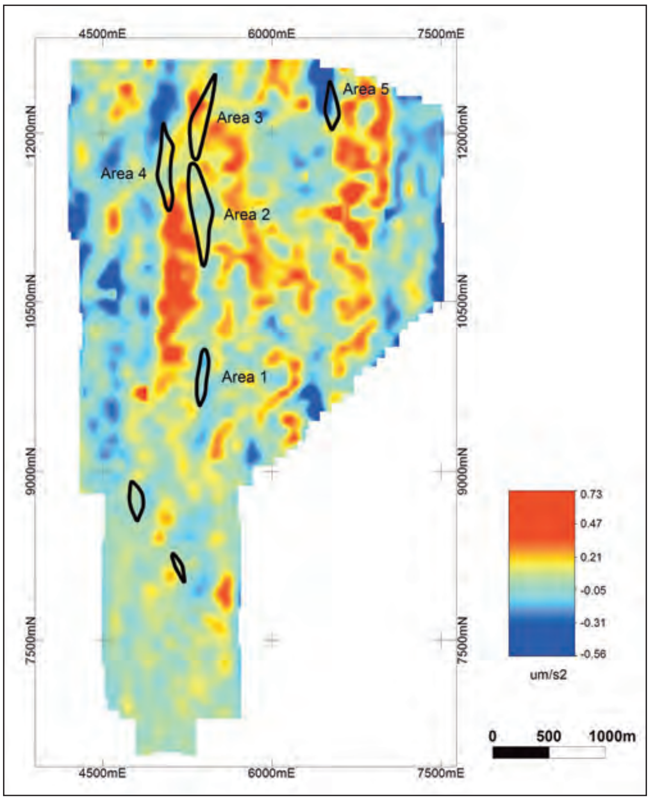

Fig. 7. First vertical derivative gravity image with outlines of gold mineralised areas.

line direction was perpendicular to the main geological strike, but ran almost parallel to the major mineralised structures which extend north from the Jundee and Nimary deposits as displayed in Figure 1. It was anticipated that the tie lines might resolve these major structures through the Bogada Bore prospect if they were gridded separately from the survey lines.

The subsequent interpretation of data in both line directions was able to map the major fault and shears extending north from Jundee and Nimary. It highlighted known magnetic ultramafic units, and indicated probable lithological boundaries for mafics and granitic units and Proterozoic dolerite dykes. The aeromagnetic survey helped provide additional lithological and structural information over the project area, but failed to highlight small-scale features known to control gold mineralisation, and did not accurately target gold mineralisation.

Sub-Audio Magnetics (SAM)

The SAM technique was trialled in late 2003, in an attempt to delineate known gold mineralisation, highlight regional and small-scale structures, refine the geological interpretation of the area, and provide targets for follow-up drilling.

The SAM technique was considered the most appropriate, because it can provide a high-resolution map of electrical current flow in the top 100 m of the earth, represented by the transformation of the measured total-field magnetometric resistivity (TFMMR) to the standardised equivalent magnetometric resistivity (EQMMR) response (Boggs, 1999). The EQMMR results can then be related to conductivity contrasts due to conductive minerals and differential weathering within shear zones, different lithologies, lithological contacts, and structures. In general, the EQMMR highs can be interpreted as sites of increased current flow in zones of higher conductivity or more intense weathering in the regolith, whereas EQMMR lows highlight more resistive areas. Offsets observed in EQMMR trends can be interpreted to result from cross-cutting faults and structures. High-resolution total magnetic intensity (TMI) is also a standard deliverable product, with total-field magnetometric induced polarisation (TFMIP) obtainable from advanced processing of the data under favourable conditions (Cattach et al., 1993).

A trial SAM block 2 km in length and 1 km wide, centred over mineralised zones 2, 3, and 4 (Figure 2) was undertaken in order to determine the effectiveness of the technique. Data were collected by G-Tek Pty Ltd using a TM-4 magnetometer and a Zonge GGT-10 transmitter with a base frequency of 4 Hz. Survey lines were spaced 40 m apart, and orientated at 047°, being perpendicular to geological strike and along an established local grid. A transmitted current of 6 amperes was possible between grounded electrodes located approximately 500 m off the northern and southern ends of the survey block, and placed approximately along the centre line of the survey block.

The results from the trial SAM block were very encouraging and included EQMMR responses correlating to known gold mineralisation trends, and defined regional and small scale structures not previously recognised. Three further SAM blocks were completed with the final coverage shown in Figure 2. The EQMMR and the EQMMR first vertical derivative response for the entire survey area along with outlines of gold mineralised trends are shown as Figures 4 and 5. Generally, the EQMMR responses are higher and more discrete in the northern portion of the survey area. This may be due to a combination of a more complex and weathered geology, and an increased conductive weathering profile compared with the southern half of the survey area. There are two main EQMMR trends striking north–south through the northern half of the survey blocks (Figure 4). The eastern trend is closely associated with known gold mineralisation at areas 2 and 3,

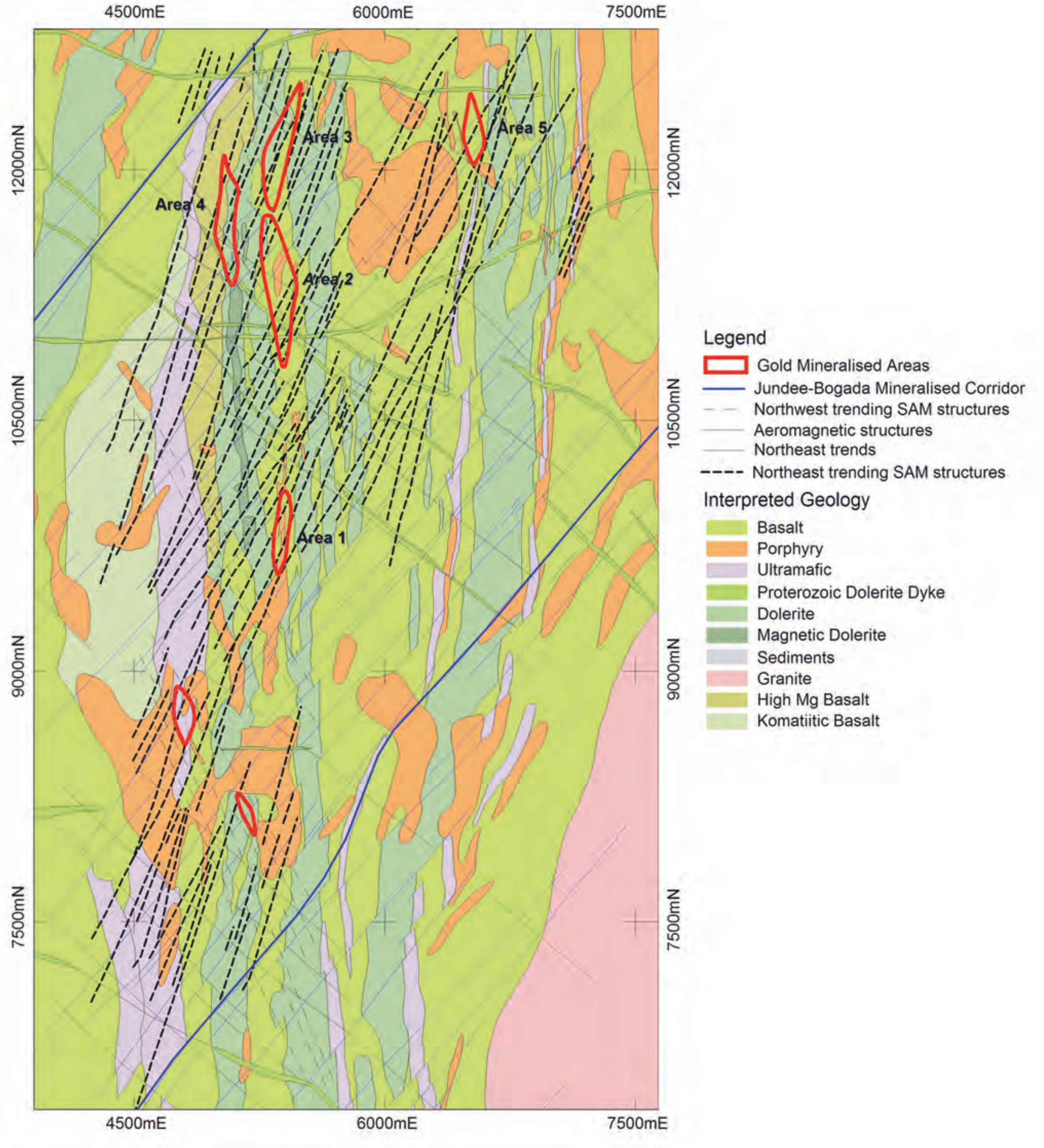

Fig. 8. Combined geophysical and geological interpretation of the Bogada Bore prospect area.

and the western trend is related to an ultramafic unit. The EQMMR high response on the easternmost grid also corresponds to known gold mineralisation at area 5.

Gold mineralised trends at areas 2 and 3 occur at EQMMR highs, but the mineralisation at areas 1 and 4 lies at the edges of EQMMR highs. This may be attributed to the host lithologies, where mineralised areas 2 and 3 are located at the contact of weathered and altered dolerites and basalts, while the mineralisation at area 4 is hosted in a complex zone between the contacts of resistive dolerites and high-Mg basalts. EQMMR responses do not directly correlate with gold mineralised trends in the south of the SAM survey area, but the mineralisation again appears to lie on the edges of EQMMR anomalies that highlight a west-trending fault (Figures 4 and 5). SAM EQMMR anomalies also highlight untested extensions to the north of area 5, and reveals a continuous anomaly linking mineralised areas 1 to 3 together (Figure 5), which was not defined in previous interpretations.

Assigning of accurate lithological units to EQMMR responses is difficult, as the relative amplitudes may change along strike due to varying dip, plunge, and regolith conditions. Furthermore, the EQMMR trends are greatly biased towards the features running sub-parallel to the transmitter electrode direction (Cantwell, 2003). However, delineation of cross-cutting structures and faults is generally less complex, as they appear to truncate and terminate EQMMR responses, and can be easily highlighted by applying different directional filters according to the structural orientation to be resolved. A simple example of this is represented by Figure 5, which shows the first vertical derivative of the EQMMR with north-east sun shading. Cross-cutting faults and fault offsets are clearly visible throughout the image as truncations in EQMMR trends, indicating the level of structural complexity in the area, and the capability of the SAM technique to resolve these features.

TFMIP was recovered from the data and an image is shown in Figure 6. The main trend of anomalous features lies along the western side of the survey block and closely follows an ultramafic unit defined from aeromagnetic and drilling data. The anomalous response probably represents preferential deep weathering along the ultramafic unit, and in some areas may be due to localised sulphidic black shales intersected in drilling. Discrete TFMIP anomalies loosely correlate with EQMMR responses and gold mineralisation at areas 2, 3, and 5 which may be indicative of increased sulphide concentrations in these areas (Figure 6). Overall, the TFMIP data is not as definitive as the EQMMR, but still shows a variety of geological and detailed structural information that complements the EQMMR and assists in interpretation.

Gravity

A high-resolution gravity survey was completed over the project area immediately after the SAM surveys. The gravity survey was designed to map dacitic porphyries, which control the spatial distribution and geometry of gold mineralisation, delineate lithologies, and map structures throughout the area. Gravity observations were acquired on 80 m lines coincident with existing drill traverses, with stations 100 m apart (Figure 2). The data was reduced to the Isogal 1984 datum and corrected to a standard Bouguer anomaly using a density of 2.67 t/m^3. A first vertical derivative image of the Bouguer gravity map (Figure 7) was produced to distinguish anomalies representing different lithologies, differential weathering, and basement topography. Dacitic porphyries appear as circular gravity lows, but many lows are also related to zones of deep weathering.

All geophysical datasets were used to update the existing interpretation of the area shown in Figure 8. This interpretation has been invaluable for identifying bedrock geology in relation to gold mineralisation, and has helped plan drilling programs that have resulted in new economic gold intersections.

CONCLUSIONS

The SAM survey at Bogada Bore has produced EQMMR responses which correlate closely with areas of known gold mineralisation, and highlight possible extensions of these zones. Although the SAM responses were not accurately attributed to definite lithological units, they do map and delineate regional and small scale structures with a high degree of confidence.

The aeromagnetic, SAM and gravity data were all used to generate a new geological and structural interpretation of the area. Each technique added different and complimentary information to the interpretation, however small scale structural detail related to gold mineralisation was primarily resolved by the high resolution SAM datasets. The final interpretation was a considerable improvement on the previous, increased the geological understanding of the area, and provided accurate targets for follow up drilling.

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