Exploration Geophysics (2005) ***36****, 176–180*

Interpretation of a Sub-Audio Magnetic survey over the Lena Shear near Cue, Western Australia

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Key Words: Lena Shear, Sub-Audio Magnetic, interpretation, gold

ABSTRACT

The Lena Shear is a gold-anomalous structure that sits in an Archaean greenstone belt and extends for more than 7 km. It is partially obscured by regolith and an extensive salt lake system over its length. Identification of the shear under cover is hampered by the poor magnetic susceptibility contrasts of the host lithologies. A Sub-Audio Magnetic (SAM) survey over an exposed section of the Lena Shear recorded anomalous equivalent magnetometric resistivity (EQMMR) values proximal to the shear, but not directly associated with the geologically mapped location of the shear as expected. An interpretation of the Sub-Audio Magnetic survey highlights current channelling in structural and geological elements that were previously unknown. The relationship between the shear zone and the anomalous EQMMR response is unresolved because of the stronger response of an adjacent ultramafic unit. It is likely that deep weathering of rock units, contacts and shears has combined to produce the observed anomalies.

INTRODUCTION

The Lena Shear is located approximately 28 km south of Cue in Western Australia. It sits within Archaean greenstone stratigraphy of the Mount Magnet – Meekatharra Greenstone Belt (Watkins et al., 1987). Simplified geology for the region is shown in Figure 1. The shear can be summarised as a north-east striking, near vertically dipping package of intermixed ultramafic-mafic-sedimentary rocks (Eilu, 1996). It forms a 10–50 m wide anomalous gold and arsenic zone, heavily veined with quartz, calcite, and dolomite. The shear is sub-parallel to stratigraphy, mostly following contacts between less competent rock types. Its position becomes less identifiable where salt lake deposits cover the Archaean basement.

Gold mineralisation is known to occur in the region, the most significant being Lena, a resource that sits under regolith cover and is similar to Paddy's Flat near Meekatharra. Paddy's Flat is described as an altered ultramafic unit occupying a shear zone, and is intruded by quartz-albite porphyry dykes (Hickman and Keats, 1990). The strong association of Au mineralisation with the Lena Shear makes it a target to map under sedimentary cover. The extensive salt lake cover over the northern part of the shear presents both a challenge and an opportunity for innovative, high-definition geophysical technology such as SAM.

Initial exploration focused on the acquisition of detailed airborne magnetic data to assist in the mapping of structures, especially under the salt lake deposits. In 2001, a high-resolution airborne magnetic and radiometric survey was flown over the wider project area at a line spacing of 40 m and altitude of 30 m. Magnetic data were interpreted in an effort to define the location of the Lena Shear. With this level of detail, there was some evidence to facilitate the definition of the major shears. However, immediately proximal to the mineralisation at Lena, the shear remained ill-defined.

Following the shear northwards under regolith cover and away from known mineralisation was always going to be difficult, as the shear was known to be trending towards an area of extensive salt lake deposits. To pursue the shear under the salt lakes using a more conventional approach would require extensive drilling at high cost. Drilling along the shear and proximal to mineralisation at Lena had already tested and identified additional mineralisation, but there was a need to accurately map the shear both around Lena and under cover. Consequently, it was necessary to find another means of detecting the shear under cover ahead of drilling.

Consideration was given to the Sub-Audio Magnetic (SAM) survey technique, as this had been shown to be useful at rapidly mapping near-surface electrical conductivity changes (Cattach et al., 1993), such as might be encountered across a shear zone.

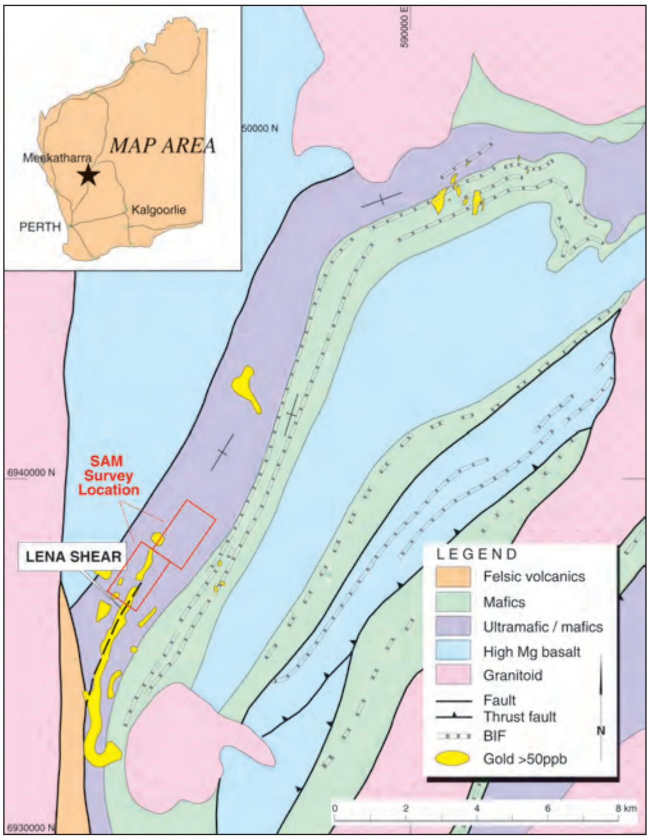

Fig. 1. Simplified geology over the Lena Shear and the location of the SAM survey grids.

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Manuscript received 23 July, 2004. Revised manuscript received 13 April, 2005.

In 2003 a SAM survey was trialled over a small portion of the Lena Shear. The area selected had good drilling information and contained known gold mineralisation. The objective was simple; if possible, observe an elevated equivalent magnetometric resistivity (EQMMR) response spatially associated with the Lena Shear. If such a response is observed, application of the same technique along the shear may permit a more accurate delineation of the shear and other features.

This study shows that strong SAM EQMMR anomalies appear to be spatially tied to the Lena Shear trend, although these anomalies do not directly correlate with the position of the Lena Shear zone. An interpretation of the EQMMR distribution of current density over a small part of the Lena Shear links this response with geological units. An anomalously high current flow in the ground is mapped immediately west of the main shear zone, and this trend appears to be related to a sequence of ultramafics and not the shear zone.

SURVEY DESIGN

This was the first trial of a SAM survey undertaken by Mines and Resources Australia and consisted of two small adjacent grids as shown in Figure 2. A more extensive coverage of the Lena Shear was considered, but the approach taken sought to minimise the risk of investing significant time and money into a survey by firstly limiting the size of the survey and by surveying in an area with reasonable geological control. Results of the survey were easily verifiable against drilling data. The two grids are slightly offset to account for the expected north-easterly trend of the Lena Shear, but remain oriented perpendicular to geological strike. The eastern ends of all survey lines were at least 500 m away from an outcropping banded-iron formation (BIF) sequence. It was important to keep the edge of the grid lines away from the BIFs as much as possible, because strong magnetic gradients caused by these BIFs were a potentially complicating factor in data acquisition and processing.

During the survey design phase, the Lena Shear zone was viewed as having potential to be the primary conducting structure, necessitating the transmission electrodes to be placed as close to the expected trend as possible (Figure 2). It was not considered an absolute requirement to dig the electrode pits over the shear, but rather to place them at least close to the shear. Current should then preferentially flow along the near-surface weathered portion of the shear or any other structure or stratigraphic contact facilitating current flow. It is important to state that prior to this survey, there was no indication of how conductive the shear zone may be. Although this may be viewed as an unnecessary risk, it was felt that the decision to trial SAM over a limited area with good geological control mitigated the inherent risk.

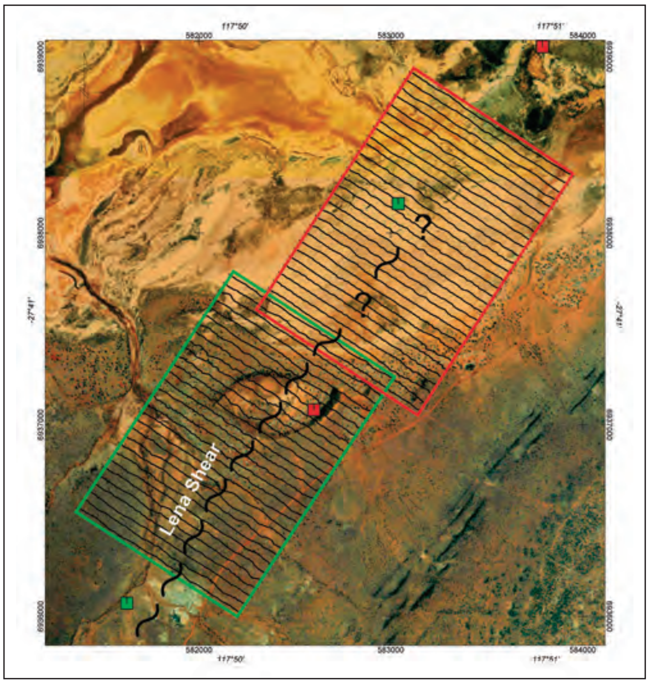

Fig. 2. Survey layout and traverse path for each SAM grid (coloured red and green), and the corresponding electrode positions. Note that the northern grid is almost wholly situated within a salt lake. Transmitting electrodes are placed close to the expected trend of the Lena Shear. The outcropping BIF sequence is visible in the south-east corner.

All survey lines were walked perpendicular to the strike of the shear zone with a line spacing of 50 m. The survey started out with a transmitter frequency of 4 Hz, but this was found to be too high when significant EM coupling was noted to be causing problems in the data. The transmitter frequency was lowered to 2 Hz, decreasing the effect of EM coupling in the data. Survey parameters are summarised in Table 1.

Roving Magnetometer Acquisition System	Magnetometer	TM4
	Sensor	Geometrics G-822AS Cs Vapour
	Sensor Elevation	2.5 m
	Sample Rate	200 samples/second
Excitation Source	Transmitter	Zonge GGT-10
	Transmitter Frequency	2 Hz
	Current	Typically 7 amperes
	Controller	Geophysical Technology SAM-XMT
	Duty Cycle	50%
Survey Specifications	Line Direction	123 degrees
	Line Spacing	50 m
	Datum	AGD84 – AMG Zone 50

Table 1. Instrument and survey parameters.

INTERPRETATION

Data collected from the SAM survey are presented as images of total magnetic intensity (TMI) and EQMMR in Figures 3 and 4 respectively. It is apparent from the TMI data that the Lena Shear has no readily discernable expression in the TMI data in this immediate region. Based on airborne and ground magnetic data, contrasts in magnetic susceptibility are poor for most rock types in the area other than the BIFs. The high magnetic gradient in the TMI is in response to these BIFs, located off the eastern end of the grids. Data is considered to be of good quality, but in the south-west there seems to be a high-frequency component in the EQMMR and TMI data. This region manifests as a less coherent grid of the EQMMR parameter compared with other parts of the survey, and it is thought that this is somehow related to the increased magnetic activity. Close inspection of the aerial photography (Figure 2) shows a colour change in the subcropping material around this region, which may be reflecting an underlying change in lithology.

At first, the dominant response in the EQMMR image was associated with the Lena Shear, as this was the anticipated result. The transmitting electrodes had been placed close to a major shear in the hope that current channelling along the shear would produce an elevated EQMMR response. However, the extensive drilling information available in this area has led to an interpretation that does not fit with this early expectation. It is also important to note that for a variety of reasons, the drilling across most of the survey, whilst extensive, is not necessarily effective. For that part of the shear where mineralisation is known to occur, there is substantial drilling available to define it. However, away from mineralisation, drilling is neither as effective nor as focussed, resulting in poor delineation of the shear and surrounding stratigraphy. Figure 5 presents a vertical cross-section that extends across the dominant EQMMR anomaly in the west to the Lena Shear in the east. Location of this section is drawn on the images of the TMI (Figure 4) and EQMMR (Figure 5). The simplified geology overlain on this section indicates that the main EQMMR response is proximal to the main shear zone, but also that a vertically dipping sequence of ultramafics in the west is even more closely positioned to the EQMMR peak. The inference is that a more probable cause of the EQMMR anomaly is the deep weathering along the ultramafic sequence, and not the shear. Similar associations are observed on parallel sections.

A complex EQMMR response is observed at the centre of the combined grids. This is interpreted as an example of an interaction between the north-east striking ultramafics and a north-south trending structure, both of which appear to be conductive. The evidence for a north-south structure at this juncture is somewhat supported in the airborne magnetic data (not shown here).

There is little published information on the interpretation of a SAM survey, which can make a first-time interpreter's job very difficult. In trying to interpret the SAM data, it is necessary to consider the geological processes that could facilitate current flow through the ground. An obvious situation is that of faulting or shearing, where alteration and deep weathering is probable along the fault plane. Increased current flow may also be realised through conductive lithologies such as carbonaceous shales or weathered ultramafics.

The interpretation presented in Figure 6 is formulated around the premise of mapping current density through the area. For that area between the electrodes, current is assumed to be flowing everywhere through the ground, but primarily in the direction of the transmitter electrodes. It is reasonable then to produce an interpretation that maps current density everywhere for an encompassed rock mass. The relationship between current flow and geology is complex and will be different for every survey, and so a simple approach is adopted in the first instance. Current density is mapped here in an empirical sense, with a subdivision of units into three main categories being strongly conductive, moderately conductive and resistive. This approach takes no account of

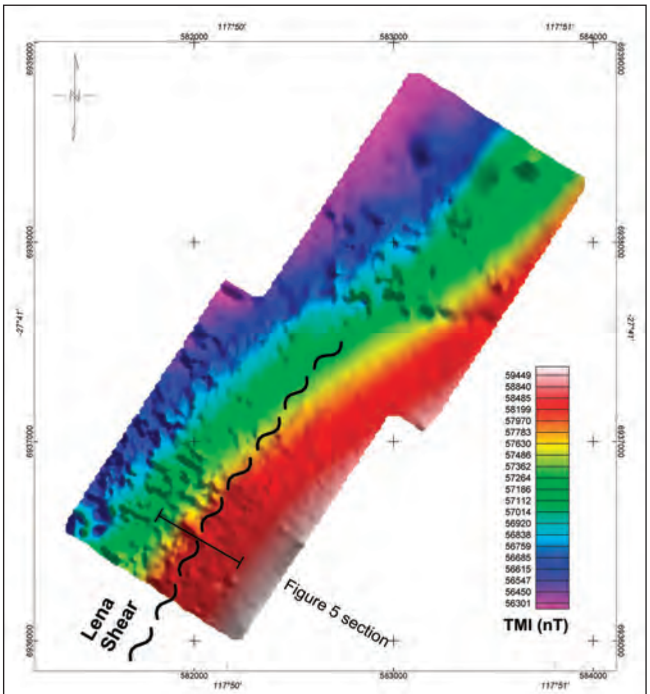

Fig. 3. Total magnetic intensity data recorded from the SAM survey. The strong magnetic gradient present in the TMI is caused by the BIFs located immediately towards the south-east.

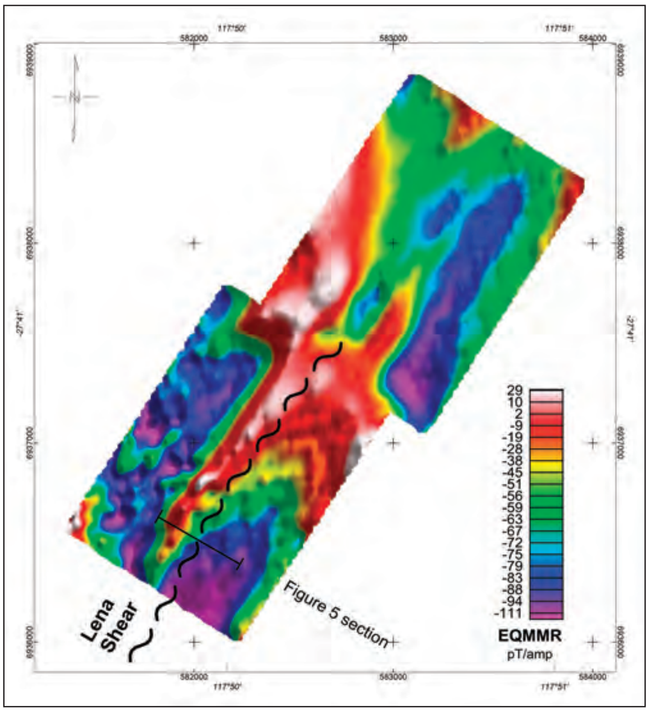

Fig. 4. EQMMR data recorded from the SAM survey.

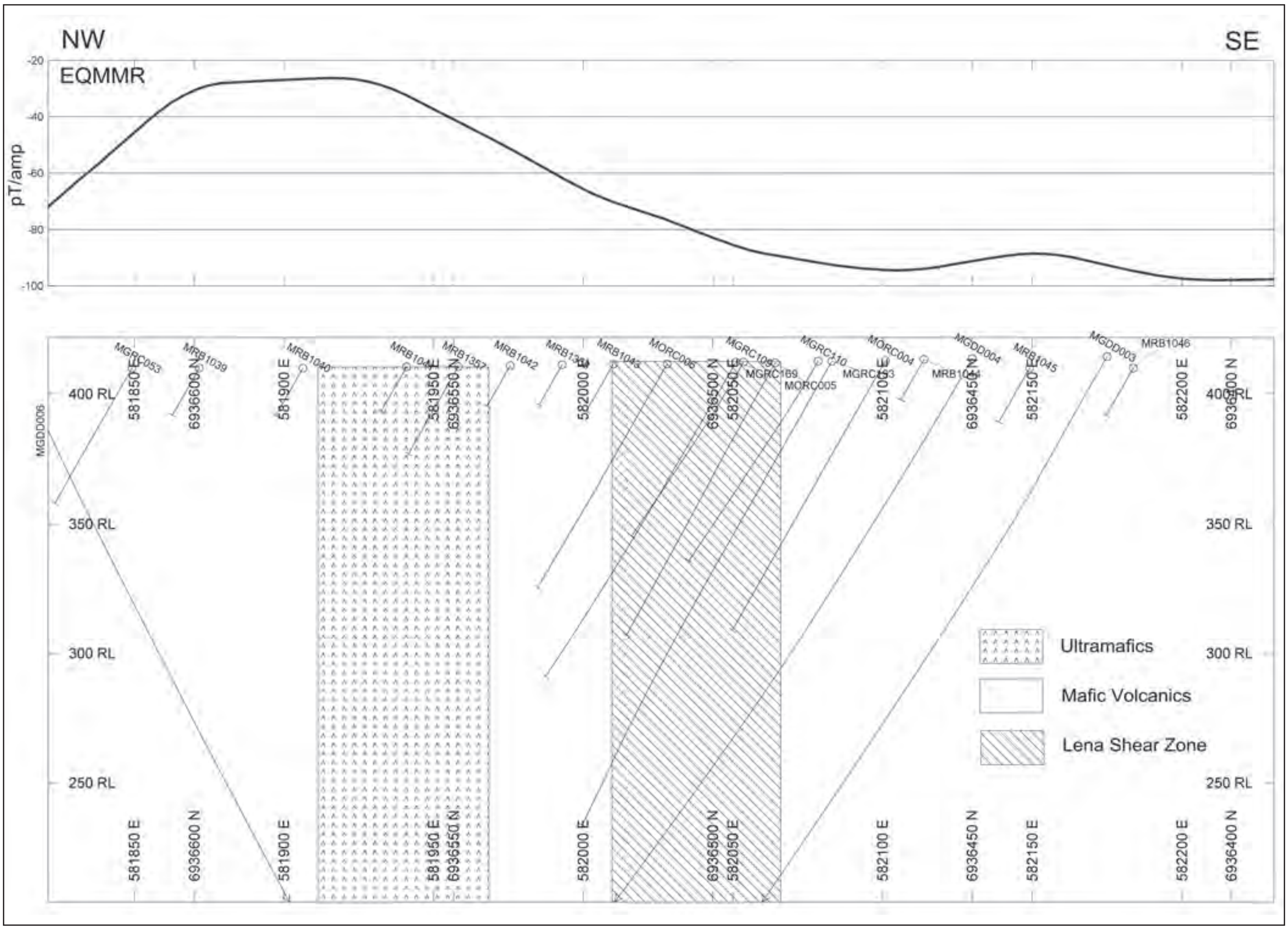

Fig. 5. Geological cross-section through the Lena Shear and the ultramafic sequence, highlighting a plausible relationship between elevated EQMMR values and the location of ultramafics.

absolute values of the EQMMR data, as this is viewed as too clinical a practice in trying to map a parameter that has no hard boundaries. Intuitively, current will flow across stratigraphic and structural boundaries, so it is important not to view the interpreted divisions as absolute. Following on from this, trying to assign a single geological unit to any given EQMMR response is considered subjective. The transition from an EQMMR anomaly responding to a weathered ultramafic, to that caused by weathering along a fault plane may be quite seamless, with no apparent change in the EQMMR character. Rather, the approach advocated here is to map the relative changes in conductivity and separately integrate this mapping with geological knowledge about the area.

Different colours of the interpretation represent varying degrees of current density in the ground. In its simplest form, the interpretation should be thought of in the following terms:

- red equates to a high current density or some geological element that facilitates current flowing between the two current electrodes, and
- blue equates to a low current density, interpreted as a geological element restricting the electrical current flowing through it.

East-west features in the interpretation may represent narrow dyke-like bodies. A majority of these responses manifest as relative lows in the EQMMR data, representing an impediment to current flow caused by their higher resistivity compared to the surrounding rocks and regolith. One enigmatic aspect observed in these responses is the apparent change in current density along strike that results in a body going from resistive to conductive, or vice versa.

North-south trending EQMMR responses are interpreted to have a stronger structural association, rather than represent geological units as described above; although this possibility should not be discounted completely. The interpretation also defines a number of faults in the northern grid that are not conductive with this electrode setup. These faults are partially substantiated in the airborne survey magnetic data. The relationship between current flow and geology is one that must be developed further as knowledge about the area increases.

CONCLUSIONS

It was expected that the Lena Shear would produce some form of conductivity contrast in the SAM EQMMR response, but this has not been resolved in the data. The SAM survey generated an EQMMR anomaly from a geological feature in close proximity to the west of the Lena Shear but this appears to be caused by deeply weathered ultramafic units running parallel to the shear. The exact influence on the anomalous EQMMR responses from the shear, ultramafics, mafics, or something else is open to interpretation, but is most likely related to current channelling in deeply weathered zones in the regolith.

This interpretation has considered salient features in the data set and presented them empirically by linking conductivity responses with interpreted geological features. More importantly, the interpreter needs to identify all features within the data set and let the end user add geological knowledge where available. This is one view of how an interpreted SAM data set can be presented.

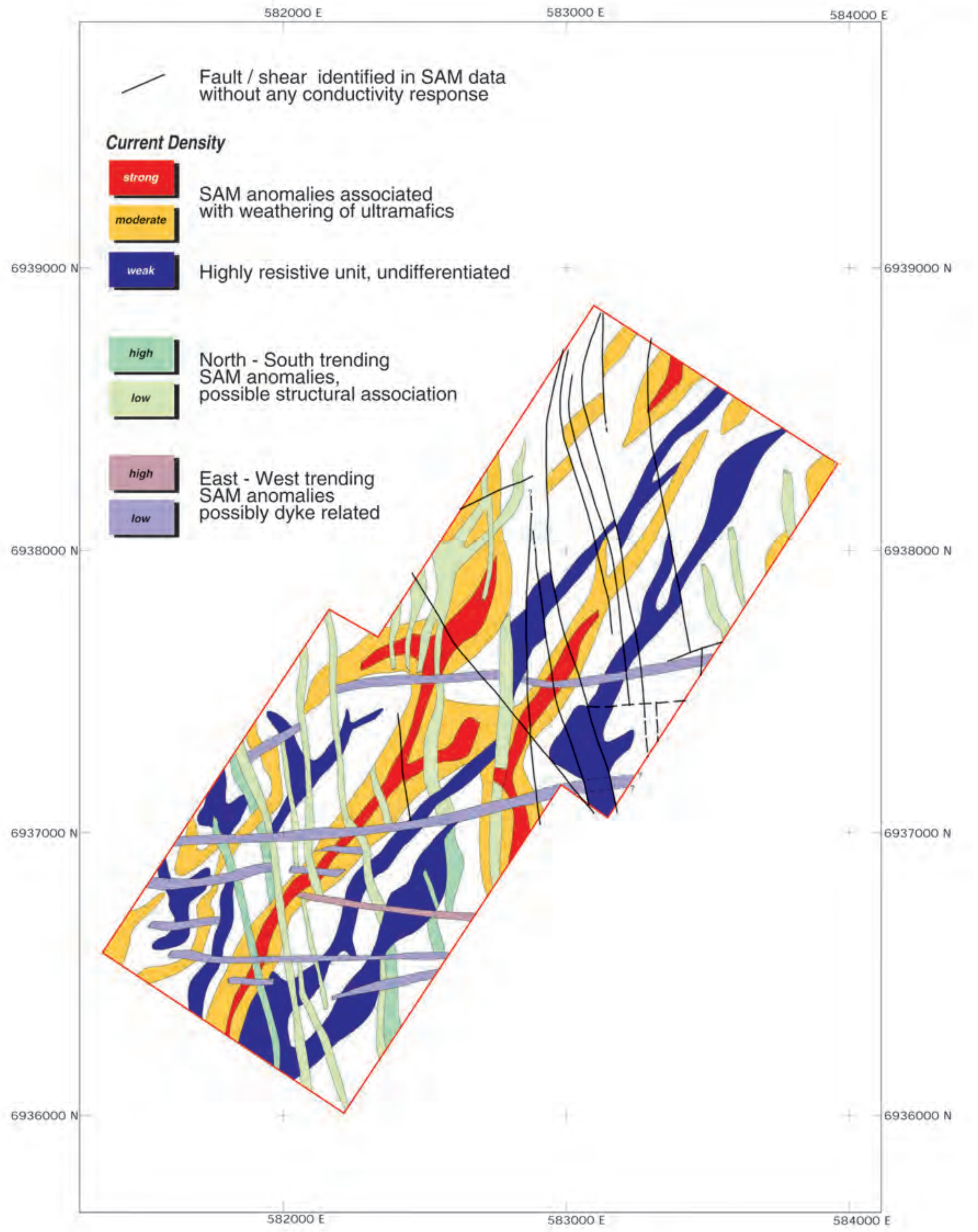

Fig. 6. An interpretation map of the SAM survey results.

As with many geophysical data sets, presentation will vary from interpreter to interpreter.

ACKNOWLEDGMENTS

The author gratefully acknowledges Mines and Resources Australia for allowing the time and resources to complete this paper. Perilya Limited and Cogema are thanked for giving permission to publish these results.

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