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Understanding magnetism in the Giles Complex, Musgrave Block, SA

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Ancient mafic to ultramafic rocks, such as those found in the Giles Complex in the Musgrave Block of SA and WA, are highly prospective for magmatic nickel sulphide mineralisation. Magnetic field data are a major mapping tool over this vast area of poor exposure. However, there are a multitude of challenges in understanding the magnetic expression of magmatic nickel sulphide systems.

Rocks from the Musgrave Block (Figure 1) are mainly composed of granulite facies quartzofeldspathic metasedimentary and meta-igneous rocks, but also include a suite of layered mafic to ultramafic intrusions, known as the Giles Complex. The Giles Complex comprises peridotites, pyroxenites and gabbronorites, which collectively form one of the largest suites of this type on Earth. The geophysical characteristics of the Giles Complex are poorly known, but have received renewed interest since discovery of the Nebo-Babel Ni-Cu-PGE deposit, which sits 130 km west of the NW corner of the study area, in Western Australia.

Magnetic properties

Variability in concentration and grainsize of pyrrhotite and magnetite determine the proportions of induced and remanent magnetisations in particular layers of layered igneous intrusions. Furthermore, remanence can be highly stable, lasting millennia, through to highly unstable, acquired at low temperatures in the present field, or during drilling. Some lithologies, e.g. Kalka Intrusion cumulates, have >50% magnetite (Austin and Schmidt, 2014), associated with very high magnetic susceptibilities (e.g. >1 SI). However, remanence is very soft and held in multidomain magnetite (see demagnetisation plot, Figure 2).

Other lithologies, mafic rocks of the Mount Harcus Intrusion for example, have high intensity (up to 200 A/m) and very stable remanence in single domain magnetite (Figure 3). This stability is caused by its lamellar crystal structure, which forms when titanomagnetite exsolves into fine-grained intergrowths of magnetite and ilmenite as the rock cools through 580°C. This style of magnetisation is typical of high amplitude negative anomalies throughout the Musgrave Block.

Pyrrhotite may also be the primary remanence holder in some circumstances, in graphitic pyroxenites of the Pallatu Intrusion for example (Austin and Schmidt, 2014). Remanence in pyrrhotite is easily detected because the majority of the remanent magnetisation is removed after heating to >320°C, the Curie point of pyrrhotite (Figure 4). Remanence in pyrrhotite is variably stable and can be associated with very high Koenigsberger ratios (up to 300). However, it can be easily remagnetised during moderate metamorphism, due to its low Curie point.

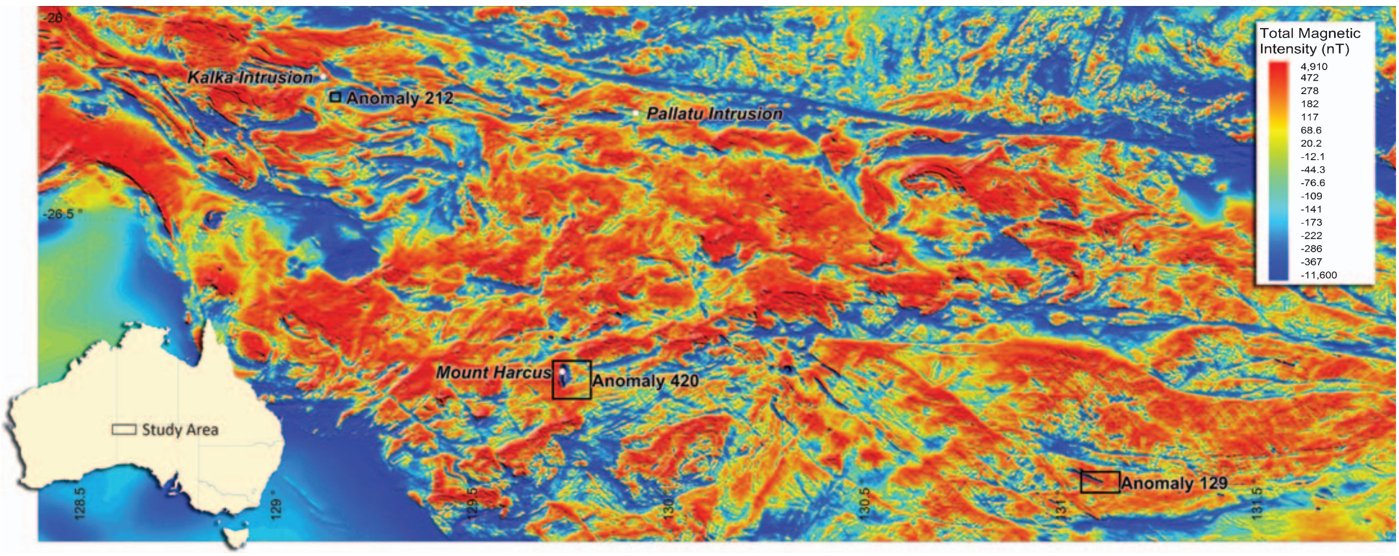

Fig. 1. *Total magnetic intensity map of the western Musgrave Block, with sampling sites marked by white dots. Black squares mark the approximate location of Figures 6–8.*

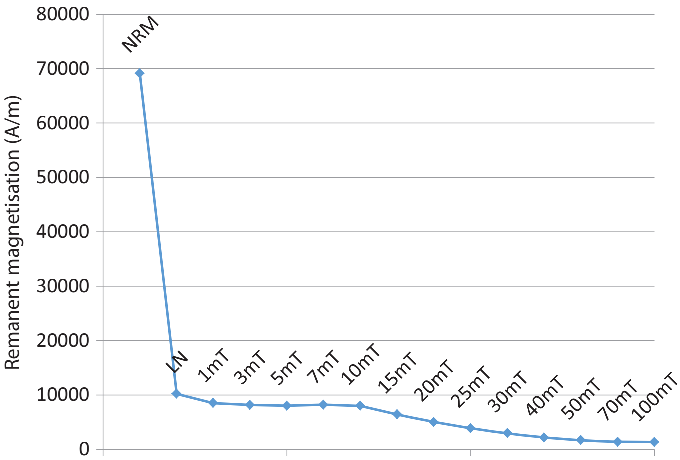

Fig. 2. *Alternating frequency demagnetisation of multidomain magnetite from the Kalka Intrusion. Note that ~80% of the magnetisation is removed by liquid nitrogen cleaning. This indicates that the majority of magnetisation is 'soft' and has a low coercivity.*

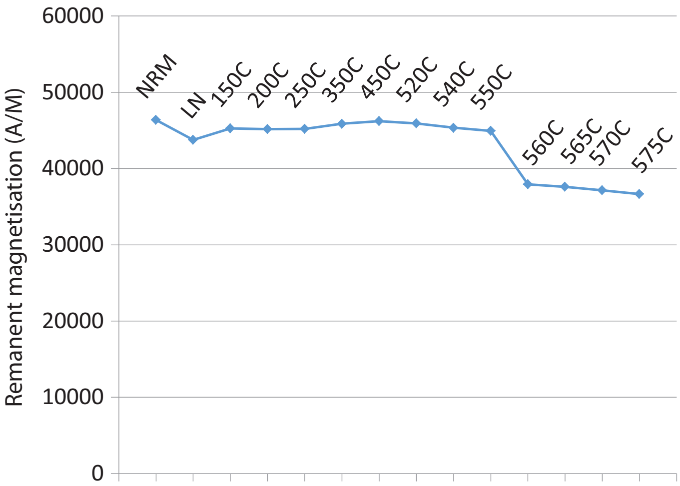

Fig. 3. *Thermal demagnetisation of single-domain magnetite from the Mount Harcus Intrusion. Note that the majority of magnetisation intensity is retained, even after the rock has been cooled past the Curie temperature. Such behaviour is typical of lamellar crystal structure in magnetite and ilmenite.*

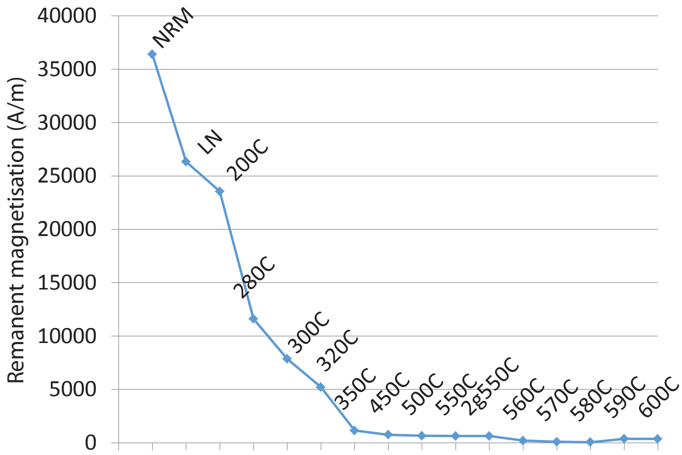

Fig. 4. *Thermal demagnetisation of pyrrhotite from the Pallatu Intrusion. Note that up to 95% remanent magnetisation is removed after heating to >320°C, the Curie point of pyrrhotite, indicating that pyrrhotite is the primary carrier of remanence.*

Architecture and modelling

Many layered intrusions have complex architecture, and their magnetic anomalies often sit within complex background fields. The magnetic anomalies of layered ultramafics reflect the bulk properties of the bodies. However, there are often sharp contrasts in rock properties of different layers in the body, and limitations of sampling make calculating bulk magnetisations difficult. One way of circumventing these issues is to determine the total magnetisation direction using only the magnetic anomaly.

The magnetisation direction of a magnetic anomaly is a crucial parameter that can often be extracted from magnetic data, and may also contain information relating to the age or mineralogy of the source. Automated methods (Hillan et al., 2013 for example) can be used to identify anomalies, based on a transformation of the magnetic field into a magnetisation map, otherwise known as an 'invariant of pseudo gravity gradient tensor' (Figure 5). The magnetisation map is used to

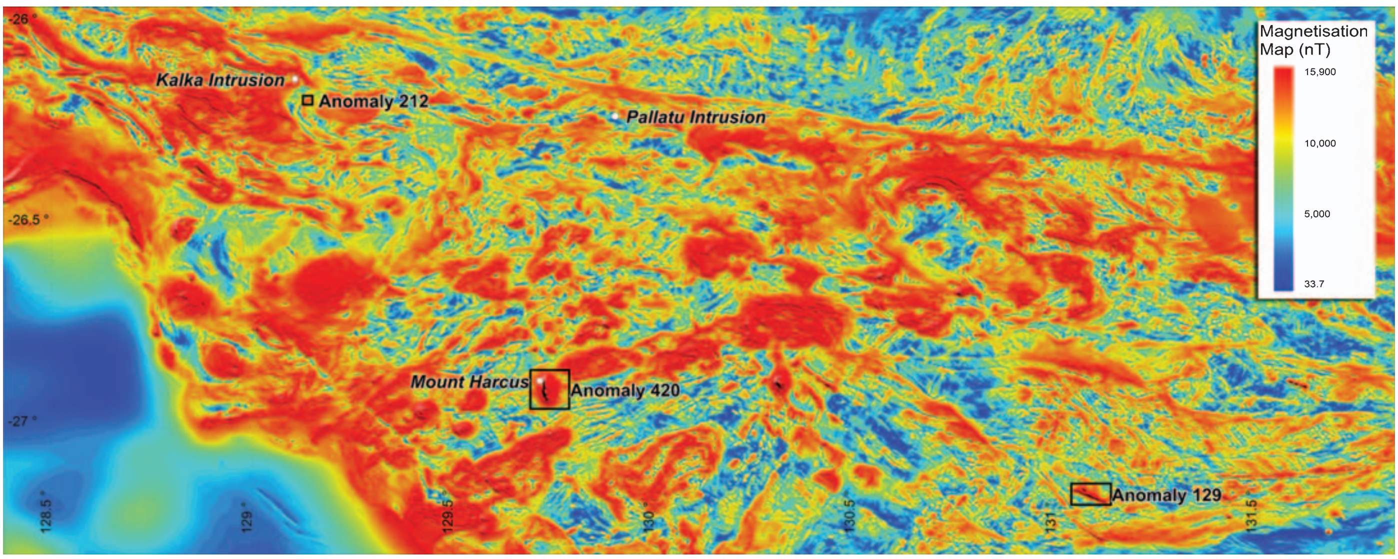

Fig. 5. *A magnetisation map of the study area, known as an 'invariant of pseudo gravity gradient tensor', which is used to map sources of magnetisation, after reducing the effects of their magnetisation direction.*

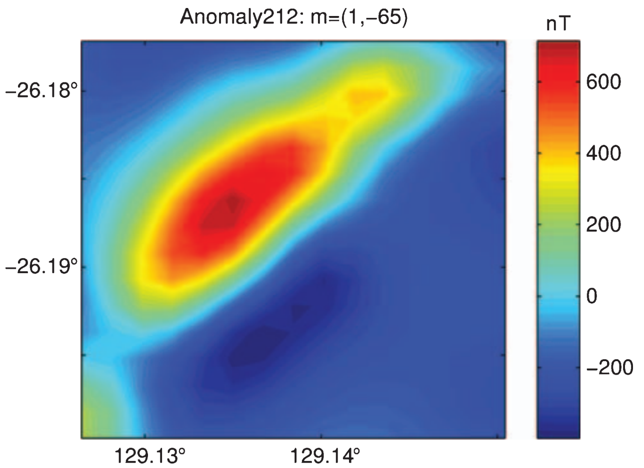

Fig. 6. *The magnetisation direction (Dec: 1°, Inc: -65°) for this anomaly, associated with the Kalka Intrusion, suggests that induced magnetisation is dominant.*

cut individual anomalies from the grid and trial magnetisation directions are applied iteratively, to determine the optimal fit to the anomaly. The recovered total magnetisation direction (remanent plus induced) plus a JPEG image of the anomaly are then exported directly into Google Earth.

Some examples are provided to illustrate how this technique can identify anomalies due to induced magnetisation, and classify anomalies by their remanent magnetisation direction. Anomaly 212 (Figure 6) is a semi-elliptic positive magnetic anomaly associated with the Kalka Intrusion. The magnetisation determined is oriented –65° (up) to the north, which is subparallel to the Earth's geomagnetic field. This suggests that the magnetisation is predominantly induced, which has been confirmed by rock property studies for similar rocks (see Figure 2).

Anomaly 129 (Figure 7) is a linear negative anomaly, which is most likely a dyke. The magnetisation determined is in a steep (74°) downward orientation, consistent with the measurements from the Gairdner dykes. However, we should note that this technique is not optimised for elongate anomalies and that there could be significant trade-off between the magnetisation direction and dip of the body in this and the following case.

The Anomaly 420 (Mount Harcus: Figure 8) is an elongate negative anomaly. The magnetisation determined is moderate (Dec: 53°) down to the west (Inc: 288°), which is reasonably consistent with palaeomagnetic data that consist of a cluster of W to NNW declinations with moderate inclinations (Schmidt and Austin, 2014).

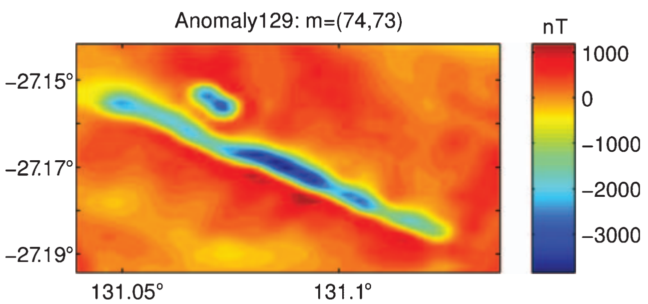

Fig. 7. *The magnetisation direction (Dec: 74°, Inc: 73°) for this magnetic anomaly is consistent with those of the Gairdner dykes. However, there could be significant trade-off between the magnetisation direction and dip of the body in this case.*

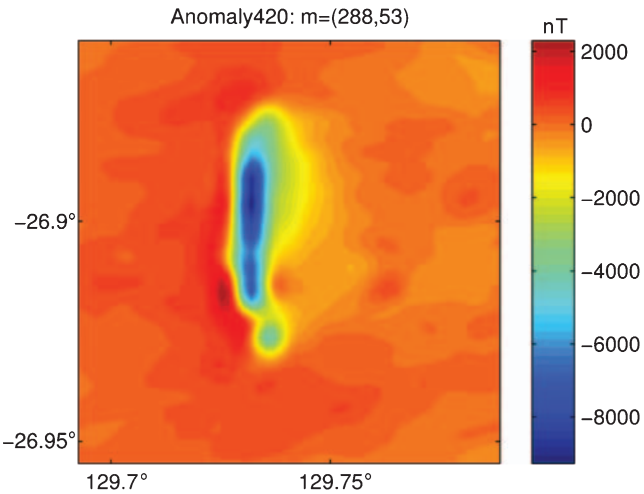

Fig. 8. *The magnetisation direction (Dec: 288°, Inc: 53°) determined for this magnetic anomaly over Mount Harcus is consistent with those measured from the body.*

Conclusions

Direct measurement of magnetic properties in rocks is problematic, particularly in geochemically complex systems such as layered ultramafic intrusive complexes. However, the knowledge gained from rock magnetic studies can be critical for determining characteristic remanent magnetisation vectors for specific rock suites. Automated techniques being developed by CSIRO have the potential to map the magnetisation directions of mafic suites remotely, and hence refine areas that may be prospective for magmatic Nickel PGE mineralisation.

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References

Austin, J. R., Schmidt, P. W. Hillan, D. and Foss, C. A., 2014. Giles, complex, magnetism. *Australian Earth Science Convention*, Newcastle, 2014.

Hillan, D., Foss, C. and Schmidt P., 2013. Recovery of resultant magnetisation vectors from magnetic anomalies. Extended Abstracts, *23rd Annual Australian Society of Exploration Geophysicists Conference and Exhibition*, Melbourne.

Schmidt, P. W. and Austin, J. R. 2014. A new palaeomagnetic study of the Warakurna Large Igneous Provence: the Giles Complex, Musgrave Ranges, Central Australia, and Earoo area, Yilgarn Craton, Western Australia. *Australian Earth Science Convention*, Newcastle, 2014.

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James Austin will be presenting a more detailed examination of remanence in layered ultramafic intrusions of the Giles Complex at the NSW branch meeting of the ASEG, 20 August at the NSW Rugby Club. Visit www.magresearch.org for further information.