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Magnetic Measurements on Diamond Drill Core: Are We Really Measuring Magnetic Susceptibility?

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ABSTRACT

In an effort to improve the spatial resolution of geophysical-based exploration targeting, it has become common practice to collect rock magnetism data from diamond drill core. These data are often taken at face value, and little consideration is given to the complex geological controls on rock magnetism. Also, the limitations and suitability of both instrument and acquisition processes must be fully understood.

A multi-petrophysical study of core from an Archaean greenstone terrane is examined. Conventional handheld magnetic susceptibility data are compared with new natural remanent magnetisation data. Comparison of data shows that remanently dominant rocks may have total magnetisation values underreported by at least two orders of magnitude. Consequently, an exclusive use of handheld magnetic susceptibility meter data to interpret potential field data is brought into question.

INTRODUCTION

As mineral exploration moves under cover there will be a greater reliance on geophysical methods. A key component of the interpretation of geophysical data is understanding the petrophysical properties of the rocks. This information is used to link the geology and the geophysical data, and for the modelling of geophysical responses. Recognition of the importance of petrophysics has led to numerous initiatives around the world to create petrophysical databases, both in government and the private sector. The majority of data in these databases are based on measurements using portable petrophysical measurement tools. In particular, magnetic property and density data are being acquired, with many mining companies routinely making such measurements on diamond drill core. The recent creation of the Qmeter magnetisation meter now provides a means to easily measure remanent magnetism (Schmidt and Lackie, 2014). This is important as the Koenigsberger ratio of rocks is often greater than 1, i.e. rocks are remanently dominant.

Many petrophysical measurements are made without also noting their geological context. Usually lithotype is noted, but much less common is alteration. Ideally, petrophysical measurements should be acquired with geochemical and mineralogical data so that the petrophysical data may be understood within a strong mineralogical context.

Here we present physical property and reflectance spectra measurements taken from a ~1400 m section of diamond drill core at the Plutonic Gold Mine, Western Australia (Adams and Dentith, 2016). The Plutonic Gold Mine is an orogenic gold deposit, hosted within the Archaean granitoid Marymia - Plutonic Well Greenstone Belt. Mining at the Plutonic Gold Mine commenced in 1990, with production to date in excess of 5.65 Moz of gold. In addition to magnetic property measurements, we have made sonic and density measurements (Adams and Dentith, 2016). These data are important, but are not discussed here. This study compares readings from several instruments, and by doing so enables mineralogical context to be rigorously constrained and the data placed in a stronger geologic context.

METHODS

Stratigraphically complete (Duclaux et al., 2013) drill core from the Plutonic Well Greenstone Belt succession has been studied. A handheld Terraplus Kappameter KT-10 v1 magnetic susceptibility meter was used to make five measurements at approximately 2 m and 5 m intervals. Bulk susceptibility values were determined by calculating a geometric mean. Mineralogical data at each measurement point consisted of 50 averaged reflectance spectra collected using an ASD Inc. TerraSpec 4 Hi-Res spectrometer. The Spectral Geologist™ (TSG) spectra unmixing mineral identification software was used during post-processing. Physical samples were taken at 5 m intervals, with further measurements made at the University of Western Australia Petrophysical Laboratory.

Natural remanent magnetisation (NRM) measurements were made using a MagneticEarth Qmeter magnetisation meter. This instrument applies the methods of Breiner (1973) to measure both induced and remanent magnetism. One hundred three samples were randomly selected across a variety of lithologies. Remanent and induced magnetisation intensities were calculated where samples presented a reliably measurable magnetic moment (Schmidt and Lackie, 2014; MagneticEarth, 2015).

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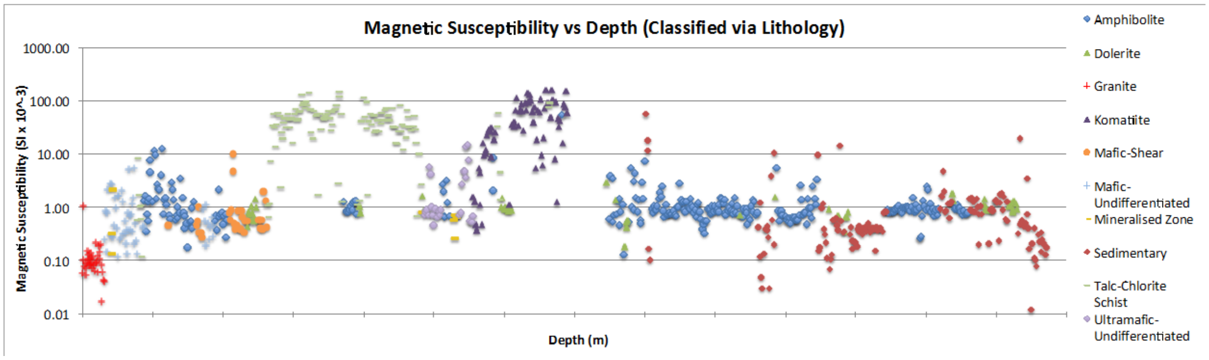

Figure 1: Magnetic susceptibility (log-scale) vs. relative depth, classified via the geologist's lithological log. Due to a requirement of commercial confidentiality, drill-hole ID and actual depths have been omitted. The horizontal scale is therefore a relative depth. Tick marked intervals are 100 m.

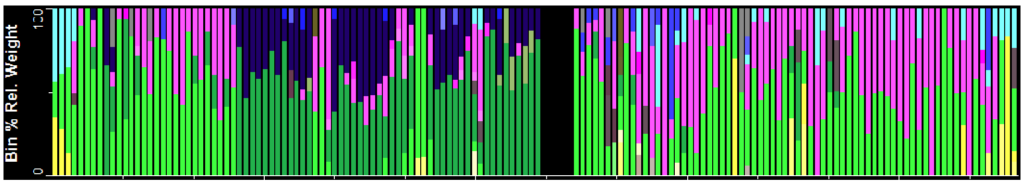

Figure 2: Spectral frequency overview of TerraSpec 4 Hi-Res data vs. relative depth. Data are normalised to minerals reported within the visible and near-infrared (VNIR) and short-wave infrared (SWIR) bandwidths. A legend of classified minerals is shown to the right.

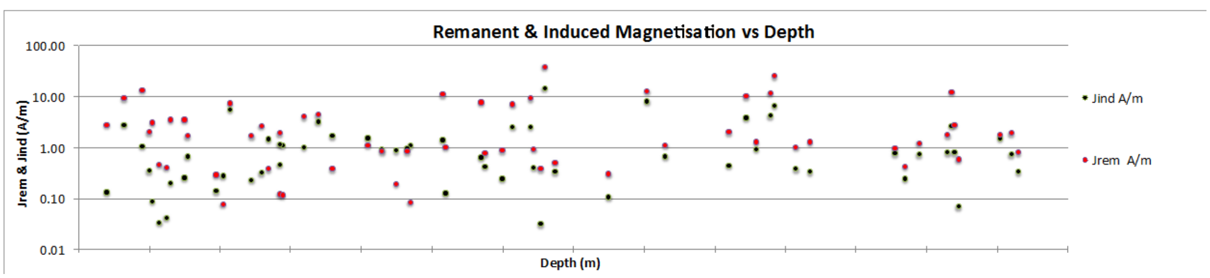

Figure 3: Remanent (Jrem) and induced (Jind) magnetisation intensities vs. relative depth.

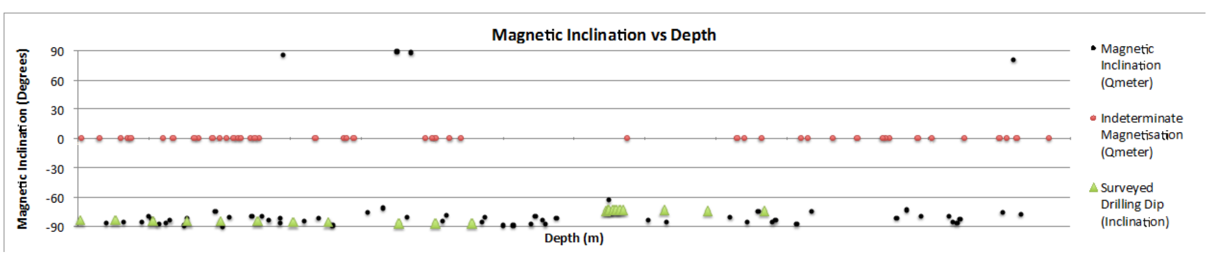

Figure 4: Magnetic inclination vs. relative depth. Null values (red) show samples with unreliable magnetic moments due to a lack of magnetic mineral content.

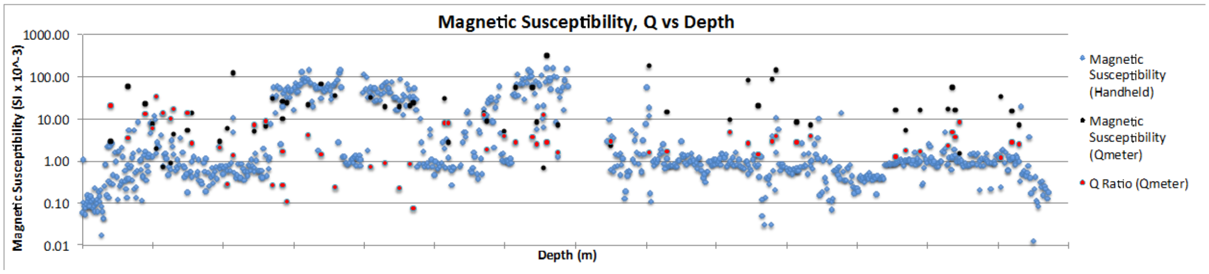

Figure 5: Magnetic susceptibility (log-scale) vs. relative depth. Qmeter derived magnetic susceptibility data and Q data are overlain.

Data on drill core orientation are not available and magnetic vectors cannot be easily determined. Fortunately, down hole direction has been recorded, so it is possible to determine magnetic inclination. This is achieved by ensuring that the Qmeter is correctly aligned with the Earth's magnetic meridian, making an assumption that induced magnetisation is in the direction of Earth's field, and carefully rotating the sample in order to obtain four multi-axial measurements (MagneticEarth, 2015). Only the inclination of the dominant magnetism can be reliably determined (MagneticEarth, 2015).

Provided that the applied field (F) in which samples are measured is known, induced magnetisation (J_{ind}) data can be used to calculate magnetic susceptibility (k), which is assumed to be isotropic (Equation 1). Care must be taken to convert the applied field, conventionally expressed in nT, to A/m. In addition, a magnetic permeability factor (μ) should be applied (Clark, 2014).

$$J_{ind} = k*\mu(F) \qquad \text{(Equation 1)}$$

Two laboratory-determined test standards (MagneticEarth, 2015) permitted checks of satisfactory reproducibility of magnetic susceptibility and remanent magnetisation intensity. Instrument accuracy was determined to be better than 9% and 3%, respectively.

RESULTS

Mafic and ultramafic rocks dominate the Plutonic Well Greenstone Belt succession. Data show that high magnetic susceptibility values are useful as an indicator of ultramafic rocks, these being about one order magnitude higher than most mafic rocks (Figure 1). The spectral data in Figure 2 provide rigorous mineralogical context. Talc-carbonate alteration is variably present in all ultramafic rocks; magnesium-rich chlorite ± amphibole is dominant; and serpentine minerals are observed in stratigraphically lower ultramafic rocks and have been lithologically logged as komatiites. Mafic rocks are observed to be abundant in iron-rich chlorite and amphibole. Mafic rocks with high magnetic susceptibility values are observed to have a greater abundance of magnesium-rich chlorite or a lower abundance of amphibole.

Fifty-eight samples were sufficiently magnetised to allow remanent and induced magnetisation intensities to be determined (Figure 3). The inclination of the dominant magnetic intensity is observed to be consistent across the drill core (Figure 4). Four measurements report a sudden reversal in sign. This is attributed to incorrectly measuring the down hole direction of the samples. Magnetic inclination data are parallel to drilling survey dip data. Preliminary investigations of drill core from nearby holes, with dissimilar orientation relative to the local geology, are also parallel to survey data.

Figure 5 shows Qmeter susceptibility and Q data overlain on a plot of handheld susceptibility data with depth. Here, lithological (Figure 1) and mineralogical controls (Figure 2) may be used as discriminators. Handheld magnetic susceptibility values of amphibolite rocks with high Q are observed to be lower than the equivalent Qmeter data. This is also true of ultramafic rocks where a reduction in talc-carbonate minerals, or increase in serpentine minerals is observed. Most talc-carbonate ultramafic rocks are observed to have a weak Q and have magnetic susceptibility data in agreement with Qmeter data.

Figure 6 shows Qmeter susceptibility data compared with handheld magnetic susceptibility meter data. Three distinct populations are observed within this plot: Group 1 correlate and show that induced magnetisation is dominant, and/or is isotropic to remanence; Group 2 handheld magnetic susceptibility values correlate poorly and appear greater than Qmeter data, and is ascribed to rocks having a dominant remanence (Figure 7) and associated anisotropy; and Group 3 which is highly remanent, have handheld magnetic susceptibility meter values less than Qmeter data. Visible pyrrhotite, shearing or ferruginised weathering is evident in the latter population.

DISCUSSION

Under certain circumstances there is a clear discrepancy between magnetic susceptibility values derived from the handheld instrument and the Qmeter. This is associated with magnetic remanence and related anisotropy. An understanding of grain size and the collection of all magnetic vector data, i.e. declination and inclination, are required to evaluate anisotropy. Remanent magnetism dominant mafic-amphibolite rocks are shown to have at least two orders of magnitude variation of magnetic susceptibility between instrument data. Very high Q rocks, i.e. Q>~10, are associated with visible pyrrhotite, mafic shear zones, and ferruginised weathering. Subtle overestimation of magnetic susceptibility by the handheld instrument may be due to magnetic viscosity caused by frequency dependent susceptibility (Clark and Emerson, 1991). This may also occur in talc-carbonate altered rocks, where chemical processes can redistribute fining magnetite grains prior to the complete consumption of magnetite. The use of a dual-low-frequency sensor would mitigate super-paramagnetic (SPM) effects of very fine grains (Clark and Emerson, 1991). Drilling induced remanence is hypothesised to be the cause of the inclination of the dominant magnetism. Paleomagnetic-cleaning and the use of more sensitive apparatus are required to quantify geologically induced remanent magnetisms. Alternatively, oriented hand specimens from pit faces or outcrop could be investigated.

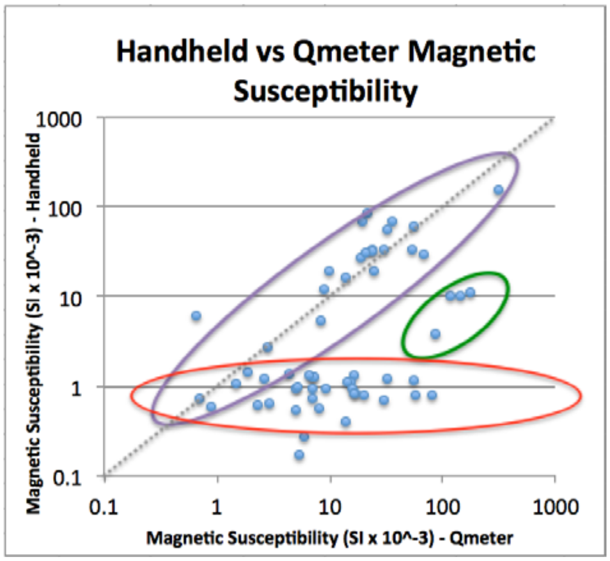

Figure 6: Comparison of instrument magnetic susceptibility values (log-scale). Ellipses show: correlating population (Group 1 - purple); effects of remanence and related anisotropy (Group 2 - red); and weathered and ferruginised samples, visible Po content, or proximal to shear zone (Group 3 - green). A dashed line shows hypothetical equal values.

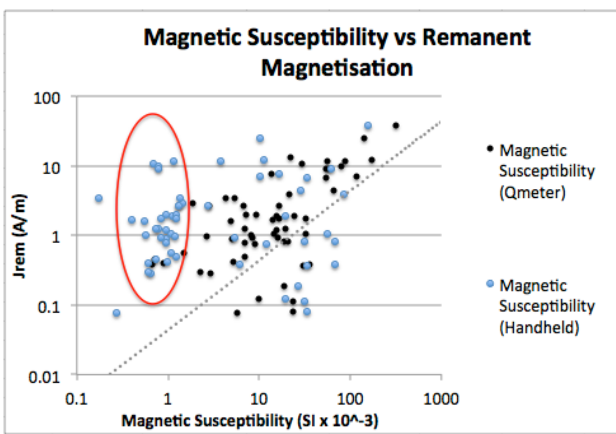

Figure 7: Remanent magnetisation intensity vs. magnetic susceptibility data (both log-scale). A slope of unity, as shown by a dashed line, divides the plot between Q>1 (above the line), and Q<1 (below the line). Red ellipse is coincident with that in Figure 6.

CONCLUSIONS

A magnetic remanence study allows the comparison of measurements from different instruments on drill core. Data show that handheld susceptibility meter values can be significantly in error. These erroneous circumstances are attributed to magnetic remanence and coincidental anisotropy.

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