Rich, attractive and extremely dense: A geophysical review of Australian IOCGs

James Austin
CSIRO
CESRE –North Ryde
James.Austin@csiro.au

Clive Foss
CSIRO
CESRE –North Ryde
Clive.Foss@csiro.au

SUMMARY

Most Iron Oxide Copper-Gold deposits were initially discovered through regional magnetic and gravity targeting, but there have been few published investigations of their geophysics as a deposit class. This study investigates the magnetic and gravity anomalies associated with several IOCGs and assesses their variability as a function of their physical characteristics. 3-D magnetic and gravity inversion and forward modelling are used to generate 3-D bodies, whose physical characteristics are then modified to assess the utility of magnetic and gravity data to IOCG exploration. The hypothesis that IOCGs form as fault and/or pipe bound hydrothermal breccias is consistent with their geophysical signatures. These modelling experiments highlight that gravity data is a more robust tool for IOCG exploration than magnetics, and that high resolution gravity data is critical to the identification of IOCG deposits in the Gawler and Mount Isa provinces.

Key words: Iron-Oxide Copper-Gold, IOCG, Magnetics Gravity, Susceptibility, Density, Forward Modelling.

INTRODUCTION

Iron Oxide Copper-Gold deposits (IOCGs) are an important source of Australia's most valuable mineral exports, including: iron, gold, copper and uranium. Australia hosts two major IOCG provinces, the Mount Isa Block and Gawler Craton (Fig 1).

IOCG's geophysical signatures vary widely, particularly their magnetic and gravity signatures. For example, the Olympic Dam deposit produces a huge 17 mGal gravity anomaly, but only a 1000 nT magnetic anomaly, while at the other end of the spectrum, Ernest Henry produces a ~2 mGal gravity anomaly and 7,000 nT magnetic anomaly. Most IOCGs were initially discovered through regional magnetic and gravity targeting. However, paradoxically, there have been few published investigations of their geophysics at deposit scale, and particularly as a class of deposit (cf., Smith, 2002).

This study focuses on magnetic and gravity anomalies associated with several IOCGs and assesses their variability as a function of five main physical characteristics: 1. size; 2. percentage of Iron; 3. depth below surface; 4. magnetite vs. hematite content; 5. Koenigsberger ratio (i.e., induced: remanent magnetisation). The results are the basis for discussion of geophysical exploration criteria for IOCG's in the Gawler and Mount Isa provinces.

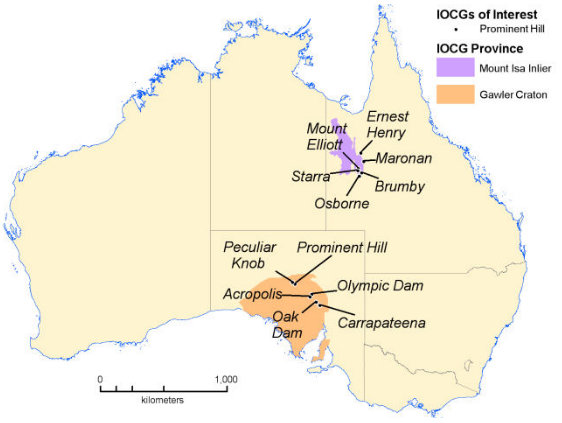

Figure 1. Location map, showing the main IOCGs discussed and the major IOCG provinces of Australia.

METHODS AND RESULTS

Gravity and magnetic data were downloaded from the GADDS website for nine anomalies that are associated with Iron Oxide Copper-Gold and some other similar mineral occurrences (referred to here as "deposits") from the Gawler Craton and the Mount Isa Inlier (Fig 1). The magnetic and gravity data were gridded and are displayed in perspective view in Fig 2. These deposits were selected because they span a variety of physical characteristics, specifically: size; percentage of iron; depth below surface; magnetite/hematite ratio; ore mineralogy and Koenigsberger ratio. Particular examples were selected in part according to availability adequate resolution gravity coverage.

Simplified bodies were constructed for four deposits via magnetic and/or gravity forward modelling and 3-D inversion using ModelVisionPro^{TM}. The modelling results are used to make some fundamental observations about the geophysical nature of IOCG deposits. Although the models are simplified, they can be used as an equivalent sources to conduct modelling experiments to assess the influence of physical characteristics (e.g., depth, Fe%, hematite: magnetite ratio) on the geophysical anomalies. Several experiments are completed for the different deposits, as outlined below, but only the first two can be shown in this abstract.

1. Olympic Dam's depth below surface is varied.
2. Ernest Henry's depth below surface and Fe% are varied.
3. Prominent Hill's Fe%, depth and magnetite/hematite ratio are varied.
4. Brumby's magnetite/hematite ratio, depth below surface and Fe % are varied.

DISCUSSION

The results, shown in Figure 2, allow us to make some fundamental observations about the geophysical nature of IOCGs in Australia.

IOCGs in the Gawler Block are often associated with large (e.g., up to 20 mGal) gravity anomalies, generally caused by large volumes of hematite breccia. They are commonly associated with non-coincident magnetic anomalies (e.g., Olympic Dam, Prominent Hill, Carrapateena). Their anomalies can be non-coincident in terms of depth to source (z), e.g., Olympic Dam, or in terms of surface coordinates (x, y), e.g., Prominent Hill (Fig 3a) and are generally thought to be caused by igneous intrusions (e.g., Esdale et al, 2003), by magnetite-rich skarns (e.g., Prominent Hill: Hart & Freeman, 2003) or by syn-post genetic mafic dykes. In some cases the magnetic and gravity anomalies are coincident (e.g., Acropolis, Oak Dam). At Acropolis the coincident magnetic anomaly is due to the presence of magnetite lenses within the ore system (Cross, 1993), which are not common in most IOCGs in the Gawler. In some extreme cases (e.g., Peculiar Knob) it is possible for hematite dominated deposits with almost no gravity anomaly to have extremely high (30,000 nT) magnetic anomalies, due to extreme upward directed remanence (Schmidt et al, 2007).

IOCGs in the Mount Isa Block tend to be associated with large magnetic anomalies (e.g., 7,000 nT at Ernest Henry), and are commonly associated with coincident gravity anomalies that can be modelled as due to the same source, e.g., Brumby (Fig 3b) and Ernest Henry (Fig 3c). The source of the gravity and magnetic anomalies is commonly magnetite breccia, which can be modelled as either sub-tabular, or pipe-like bodies, and occur as twin pipes at in some instance (e.g., Osborne, Maronan). There may be a case to suggest that the sub-tabular nature of some IOCGs could be controlled by the location of syn-depositional ironstones in the Mount Isa Block, particularly for Ag-Pb-Zn rich IOCGs (e.g., Eloise North, Monakoff).

In most cases, IOCGs from both regions tend to have either a sub-tabular architecture e.g., Olympic Dam, Prominent Hill (Fig 3a), Starra, which is consistent with hydrothermal brecciation within sub-planar fault systems; or a cylindrical architecture, e.g., Brumby Ernest Henry Oak Dam, which is consistent with formation as hydrothermal breccia pipes, potentially at fault intersections. Another feature of many IOCGs is that they tend to sit on the periphery of anomalies that appear to be caused by relatively deep (i.e., long wavelength) magnetic anomalies, (e.g., Olympic Dam, Carrapateena, Oak Dam, Ernest Henry, Maronan, Brumby, Eloise) which are often inferred to be intrusions that may have provided heat, sulphur and or metals to the mineral system. Some basic modelling of Olympic Dam (Figure 4a) suggests that a possible deep source could have a susceptibility approaching 1 SI, which could imply the presence of a magnetite-rich body, possibly an un-oxidised extension of the Olympic Dam breccia. An alternative view is that the long wavelength magnetic anomaly is due to numerous wide, but thin magnetic bodies nearer the surface (Esdale et al, 2003).

Experimental results give insights into some geophysical criteria that can be applied to IOCG exploration. The experiment in which we vary the depth of a simplified model of Olympic Dam (Figures 4 b-c) illustrates that the magnetic and particularly the gravity signature remain robust detection tools for large hematite dominated deposits, regardless of their depth below surface. However, where gravity data is widely spaced the anomalies can be easily missed, e.g., Prominent Hill is completely undetectable if using gravity data from GADDS. As deposits get smaller the magnetic and gravity signatures become significantly more attenuated with depth. E.g., if you were to make the Brumby prospect a mere 300m deeper, it would be almost invisible to both gravity and magnetics, despite having a magnetic susceptibility of 0.7 SI and density of 3.8 g/cc. In the Mount Isa Block, the highly complex regional magnetic anomalism, combined with relatively poor (or patchy) gravity coverage mean that differentiating IOCG targets from other magnetic units is very difficult, particularly under significant cover. For example, the Ernest Henry ore pipe(s) account for only a small portion of the anomaly, with much of the signal due to un-mineralised tabular bodies (Fig 5a), that are interpreted to be magnetite-bearing shear zones by Webb & Rowston (1995). If Ernest Henry was only 300m deeper (Fig 5b) it could be (geophysically) mistaken for a mafic intrusion. If the two tabular bodies were removed (Fig 5c) or its magnetite percentage was halved (Fig 5d) it could be almost invisible within the magnetically complex Eastern Succession.

CONCLUSIONS

The simplified modelling results are consistent with the current geological understanding, that IOCGs occur as fault and/or pipe bound breccias. The experiments show that gravity data is a more robust tool than magnetics for IOCG exploration, because it does not suffer exponential attenuation with increased source depth, particularly in the case of smaller prospects. Hence, high resolution gravity data (e.g., <1km spacing) is critical to the identification of IOCG targets. While magnetic coverage in Australia is very good, the patchy gravity coverage over the Gawler and Mount Isa regions is a serious impediment to both the geophysical understanding of IOCGs, and to further discoveries. Undoubtedly, much further insight could be gained on the geophysics of IOCGs via detailed, integrated studies of 3-D geology, petrophysics and geophysical modelling at the deposit scale.

REFERENCES

Cross, K.C., 1993. Acropolis and WirrdaWell prospects. In, Drexel, J.F., Preiss, W.V. and Parker, A.J., (Eds), The Geology of South Australia, Volume 1: The Precambrian. South Australia Geological Survey, Bulletin, 54, 138.

Esdale, D., Pridmore, D.F., Coggon, J., Muir, P., Williams, P., and Fritz, F., 2003, The Olympic Dam copper-uranium-gold-silver-rare earth element deposit, South Australia; a geophysical case history, *in* Dentith, M.C., ed., Geophysical signatures of South Australian mineral deposits: ASEG Special Publication 22, p. 147–168.

Hart, J., & Freeman, H., 2003, Geophysics of the Prominent Hill prospect, South Australia, *in* Dentith, M.C., ed., ASEG Special Publication 22, p. 93–100.

Schmidt, P. W., McEnroe, S. A. Clark, D. A. and Robinson, P., 2007, Magnetic properties and potential field modeling of the Peculiar Knob metamorphosed iron formation, South Australia: An analog for the source of the intense Martian magnetic anomalies?, J. Geophys. Res., 112, B03102, 1–19.

Smith,. R.J., 2002, Geophysics of Iron Oxide Copper-Gold Deposits. *In* Porter, T.M., hydrothermall Iron Oxide Copper-Gold & related Deposits: A Global Perspective, Vol 2, PGC Publishing, Adelaide, 357-367.

Webb, M. & Rowston, P., 1995, The geophysics of the Ernest Henry Cu-Au Deposit (N.W.) Qld. Exploration Geophysics 26, 51–59.

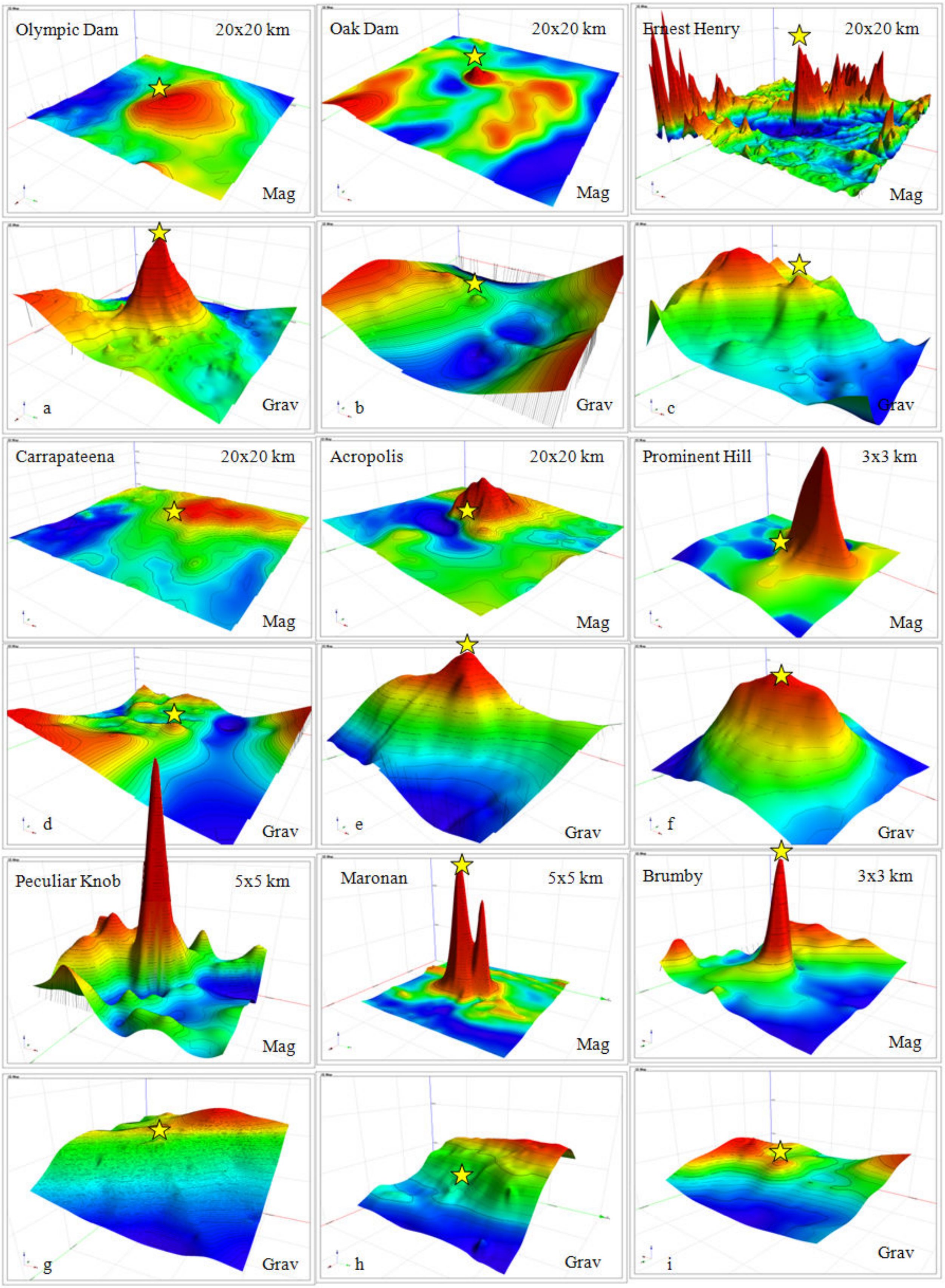

Figure 2. Perspective views of the Total Magnetic Intensity (upper) and Bouguer Gravity (lower) anomalies associated with several Australian deposits. For 20x20 km grids (a-e) the Gravity Anomaly has a vertical exaggeration of 500 relative to the TMI. The 5x5 km grids (g, h) have a vertical exaggeration of 200, and the 3 x 3 km grids (f, i) have a vertical exaggeration of 100. All data were downloaded from GADDS, except Prominent Hill which was digitised from Fig 3c and 3a of Hart and Freeman, 2003.

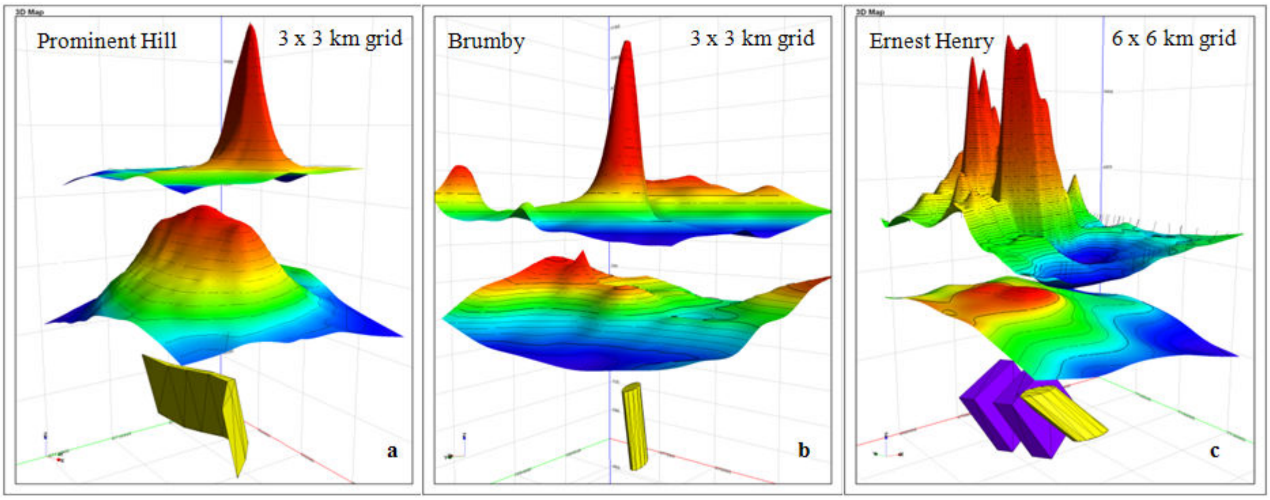

Figure 3. Forward modelling and inversion were used to generate 3-D bodies for Prominent Hill, Brumby prospect and Ernest Henry. At Prominent Hill (Fig 3a) a sub-tabular body, with density 3.2 g/cc and negligible magnetic susceptibility explains the gravity anomaly (lower), whereas non-coincident magnetic anomaly (upper) is thought to be due to a magnetite skarn. At Brumby (Fig 3b) the coincident magnetic and gravity anomalies can be modelled with a pipe of density of 3.8 g/cc and magnetic susceptibility of 0.7 SI. At Ernest Henry (Fig 3c) the coincident magnetic and gravity anomalies are modelled as an ore pipe (yellow) with a density of 3.4 g/cc and magnetic susceptibility of 1.35 SI, but most of the anomaly is due to the un-mineralised tabular bodies (purple), which represent magnetite-bearing shear zones (Rowston & Webb, 1995).

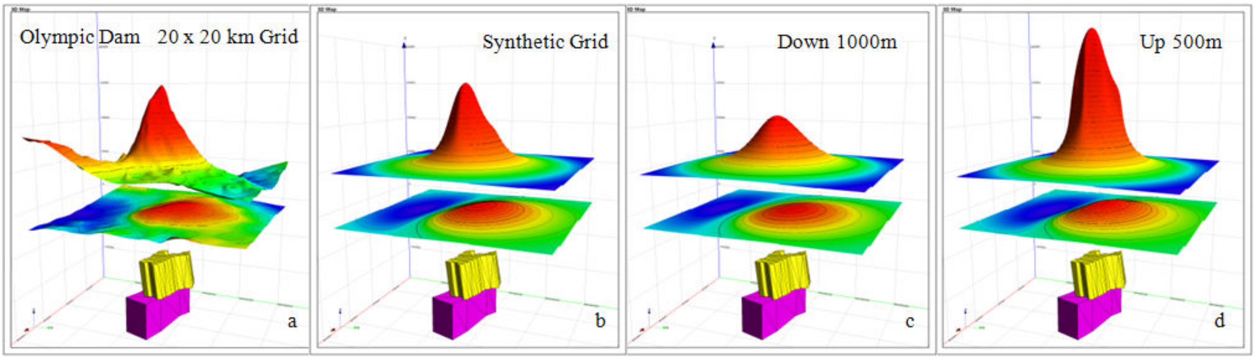

Figure 4. Forward modelling and inversion of magnetic (lower) and gravity (upper) anomalies over the Olympic Dam deposit was used to produce two simplified bodies shown in Fig 4a. The yellow body is very dense but with low magnetic susceptibility (i.e., Hematite), while the purple body is has moderate density and high susceptibility (e.g., disseminated magnetite). Synthetic grids were calculated from the bodies, as shown in Fig 4b. To illustrate the utility of gravity data for detection of IOCGs, the grids were recalculated after the bodies were moved down 1000m (Fig 4c) and up 500m (Fig 4d).

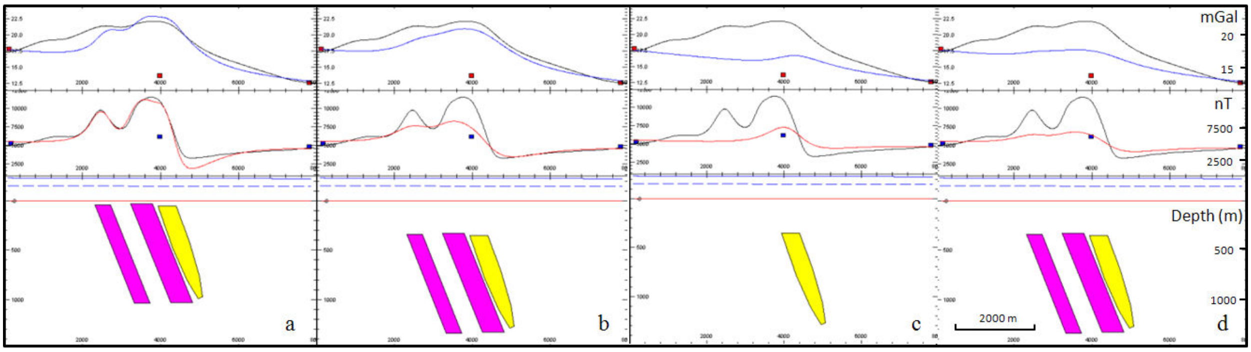

Figure 5. The Ernest Henry deposit was forward modelled in 3-D (see Figure 3c) and the gravity (upper) and magnetic (lower) profiles were taken across the anomaly on an azimuth of 330° (Fig 5a). Fig 5b shows the magnetic and gravity response if Ernest Henry were 300m deeper, and illustrates that it could (geophysically) be mistaken for a mafic intrusion at depth. Fig 5c shows the magnetic and gravity response caused by the ore pipe only, if moved down 300m and Fig 5c shows the geophysical response if Ernest Henry were at an extra 300m depth with approximately half the magnetite content.