Mapping IOCG-related alteration using 3D gravity and magnetic inversion: an example from the Tennant Creek – Mount Isa region, northern Australia

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SUMMARY

To support the Exploring for the Future (EFTF) initiative, identification of possible hydrothermal alteration systems associated with iron oxide copper-gold (IOCG) deposits has been carried out in the Tennant Creek–Mount Isa region of northern Australia.

To identify the possible presence of IOCG-related alteration, gravity and magnetic intensity data were inverted to produce 3D models of density and magnetic susceptibility, respectively. The inversion models provide an indication of the volume and distribution of these physical properties within the subsurface. The models were used to define volumes with relatively high densities and high magnetic susceptibilities as proxies for magnetite-rich alteration, and volumes with high density and low magnetic susceptibility as proxies for hematite-rich alteration.

Contact zones between these two sets of volumes are considered to be the most favourable areas for potential IOCG mineralisation. However, the inversion modelling inevitably will have mapped a number of false-positives, which will require more detailed inversion modelling and/or other data sets to discriminate these from true IOCG-related alteration.

Key words: 3D inversion, gravity, magnetics, hydrothermal alteration, IOCG deposits

INTRODUCTION

The Exploring for the Future (EFTF) initiative aims to reduce the technical risk of mineral exploration by providing pre-competitive data and information to support investment and mineral exploration in northern Australia.

This study supports the EFTF initiative by identifying the possible presence of hydrothermal alteration systems associated with iron oxide copper-gold (IOCG) deposits throughout the Tennant Creek–Mount Isa region of northern Australia (Figure 1). It is within such zones that copper, gold, uranium and rare-earth element mineralisation may be present. The results of this study, therefore, will be of interest to the mineral exploration industry in targeting new areas with potential for IOCG deposits.

According to Williams et al. (2005) host rocks in the vicinity of IOCG deposits will display hydrothermal alteration along a spectrum in which the dominant iron oxide is either magnetite or hematite, which are both relatively dense minerals but differ greatly in magnetic susceptibility.

The inversion of gravity and magnetic intensity data is a useful tool for providing an indication of the subsurface distribution of density and magnetic susceptibility, respectively. Deviations of these physical properties from those of an average host rock are used to indicate potential volumes of highly magnetic and dense minerals (termed 'magnetite alteration' herein) and volumes of less magnetic and dense minerals (termed 'hematite alteration' herein).

Gravity and magnetic inversion has been applied in a similar way in other studies, such as those in the Olympic copper-gold province in South Australia, where inversion models have mapped IOCG-related magnetite and hematite-rich alteration in the region of the Olympic Dam copper-uranium-gold deposit (Williams et al., 2004; Williams and Dipple, 2007). Other inversion modelling in this area has revealed the presence of possible magnetite-rich alteration extending several kilometres beneath the Olympic Dam IOCG deposit (Hayward and Skirrow, 2010). Similar methods were applied by Chopping (2008) and Chopping and van der Wielen (2009) in the Cobar region (New South Wales).

INPUT DATA

The following data were downloaded from the Geophysical Archive Data Delivery System for use in inversion modelling: (1) Elevation data from the 9-second digital elevation model of Australia version 3, (2) terrain-corrected spherical cap Bouguer anomaly data from the September 2017 edition of the National Gravity Database (NGD), and (3) magnetic intensity data from the Magnetic Map of Australia 6th edition 2015 with a variable reduction to the pole filter applied.

The EIGEN-6C4 Bouguer-corrected gravity grid derived from satellite measurements (Förste et al., 2014) was merged with the NGD to provide offshore data. All data were resampled by minimum curvature to ensure that only one data point existed per column of cells in the inversion model. A detailed explanation of the methods of data preparation for inversion can be found in Goodwin and Skirrow (2019).

MODEL DIMENSIONS AND CONSTRAINTS

The core volume of the inversion (830 km east x 670 km north x 70 km depth) defines the volume of interest for this study and covers the Tennant Creek–Mount Isa region (Figure 1). The data and padding volumes extend beyond this, by 70 km each laterally, to account for edge effects (Figure 1).

The horizontal cell size within the core and data volumes was set to 2 km x 2 km in order to (a) limit the total number of cells in the model (~12.7 million) so that the inversions can be run within a reasonable time, (b) optimise the inversions in relation to the spacing of gravity and magnetic data, and (c) identify IOCG-related hydrothermal alteration zones which may attain dimensions of up to 5-10 km length and width in provinces hosting the largest IOCG deposits (e.g. Williams et al., 2005).

Regional geological information was included as a reference model that described the topography, bathymetry, Phanerozoic sedimentary rocks, and Proterozoic basement rocks for both models. Additionally, a depth-to-Moho surface was used as a lower boundary constraint for the gravity inversions, and depth to top of magnetisation and Curie depth surfaces were used as upper and lower constraints, respectively, in the magnetic intensity inversions (Goodwin and Skirrow, 2019).

3D INVERSION

The University of British Columbia - Geophysical Inversion Facility (UBC-GIF) 3D gravity and magnetic inversion codes (GRAV3D v5.0 and MAG3D v5.0; Li and Oldenburg, 1996, 1998) were used to produce coincident 3D models of density and magnetic susceptibility. The code has been parallelised to work simultaneously across multiple computer processors on the National Computational Infrastructure's (NCI) Raijin supercomputer, hosted by the Australian National University, Canberra.

A detailed explanation of the inversion modelling method and evaluation can be found in Goodwin and Skirrow (2019).

MAGNETITE AND HEMATITE ALTERATION PROXIES

The presence of magnetite and hematite alteration was estimated using the concept of the alteration cone (Williams et al., 2004; Williams and Dipple 2007; Chopping 2008; Chopping and van der Wielen, 2009; Williams and Chopping 2009). The alteration cone highlights trends towards different alteration minerals from a population of unaltered host rock material. This approach uses the 3D density and magnetic susceptibility models produced by inversion to qualitatively estimate the distribution of magnetite and hematite alteration from a cross-plot of density versus magnetic susceptibility (Figure 2).

In general, magnetite alteration will produce cells in the density model which are significantly denser, and cells in the magnetic susceptibility model which are more magnetic, when compared with an unaltered host rock, while hematite alteration will produce cells that are predominantly denser, but with similar or slightly higher magnetic susceptibility, when compared to the properties of an unaltered host rock (Figure 2).

The portion of the final inversion models included in the assessment of magnetite and hematite proxies was the core region extending down to 10 km depth. Although this is far greater than the economic depth for mineral exploration, values down to 10 km were included to account for the ambiguity in the inversion models, whereby the depth of bodies is difficult to determine due to the non-uniqueness of the solutions inherent in the inversion modelling. The extents of these subsurface bodies have been projected onto a 2D surface in Figure 3.

APPLICATION TO MAPPING IOCG ALTERATION

The lateral dimensions of IOCG deposits typically extend up to ~1 km, with the exception of the super-giant Olympic Dam deposit which measures ~3 km x ~5 km (Ehrig et al., 2012). Therefore, the horizontal cell size in the inversion models reported here (2 km) is too large to resolve all but the largest IOCG deposits. Hydrothermal alteration systems containing IOCG deposits, however, are much larger and can extend over many cubic kilometres (Williams et al., 2005).

These systems can be characterised by three zones including; (1) an upper hematite- and/or magnetite-rich zone, ~1-3 km in horizontal diameter, associated with copper and iron sulphides (e.g. chalcopyrite, bornite and pyrite) together with sericite, chlorite and carbonate alteration, (2) a mid-depth zone rich in magnetite with biotite or potassium feldspar ± minor pyrite, typically of a few hundred metres to ~1-3 km in lateral dimensions, and (3) a lower zone with sodic-calcic alteration rich in albite, actinolite ± clinopyroxene, with minor magnetite, potentially extending laterally up to 5-10 km in major IOGC provinces (Williams et al., 2005).

The physical properties of each of these three levels of IOCG hydrothermal alteration will be quite distinct and, therefore, theoretically could be distinguished from one another in gravity and magnetic inversions if sufficiently fine spatial resolution was achievable in the models.

The cell size used here may be sufficient to identify the generally more extensive magnetite-biotite/potassium-feldspar zones and the regional calc-silicate-rich albitic alteration zones. The latter may be mapped within the 'hematite alteration' proxy, which could also contain true hematitic alteration.

In the Cloncurry district, to the east of Mount Isa, one of the key styles of copper-gold mineralisation is closely associated with magnetite and potassium feldspar alteration (e.g. Ernest Henry deposit) whereas another style occurs with pyrrhotite and magnetite (e.g. Eloise deposit; Williams et al., 2005). Both the Ernest Henry and Eloise deposits are closely associated with regions mapped in the present study as magnetite alteration (Figure 3).

Chemical and thermodynamic modelling shows that the contact zones between magnetite- and hematite-rich alteration are highly favourable for the formation of higher grade copper-gold mineralisation (Bastrakov et al., 2007). Such redox gradients also appear to be important in the high grade gold-copper-bismuth deposits of the Tennant Creek district, where both magnetite- and hematite-rich deposits are present in association with chlorite ± sericite alteration (Wedekind et al., 1989; Skirrow, 2000). Therefore, the most attractive copper-gold exploration targets identified in Figure 3 are those relatively small bodies (e.g. <15 km width) where exceptionally dense and magnetic material (magnetite ± pyrrhotite) is laterally or vertically in contact with exceptionally dense bodies of low magnetic susceptibility (e.g. hematite ± pyrite ± copper sulphides).

LIMITATIONS AND UNCERTAINTY

Given that the distribution of geological units within such a large study area is not well defined, the areas predicted to contain magnetite and hematite alteration have the potential to overlap with the distribution of unaltered geological units. This will result in the predicted volumes of magnetite and hematite alteration being overestimated. For example, mafic/ultramafic rocks that are dense (>2.80 g/cm^3) and have high magnetic susceptibility (>0.01 SI) may be represented within the population for magnetite alteration. Similarly, some (meta)sedimentary rocks (such as calc-silicate-rich rocks) and mafic igneous rocks (e.g. gabbro, dolerite, basalt) can have magnetic susceptibilities <10^{-3} SI and densities >2.80 g/cm^3 (Clark and Emerson 1991; Emerson 1990). This would place those geological units within the same range of values that are suggested to represent hematite alteration (Figure 2).

CONCLUSIONS

Two models describing the 3D distribution of density and magnetic susceptibility in the subsurface were produced through the inversion of gravity and magnetic intensity data, respectively. The inversion models were used to define volumes with relatively high densities and high magnetic susceptibilities as proxies for magnetite-rich alteration, and volumes with high density but low magnetic susceptibility as proxies for hematite-rich alteration. These volumes have the potential to map hydrothermal systems which, in turn, could host IOCG deposits. Contact zones between these two sets of volumes are considered to be the most favourable areas for potential IOCG mineralisation. However, the inversion modelling inevitably will have mapped a number of false-positives, which will require more detailed inversion modelling and/or other data sets to discriminate these from true IOCG-related alteration.

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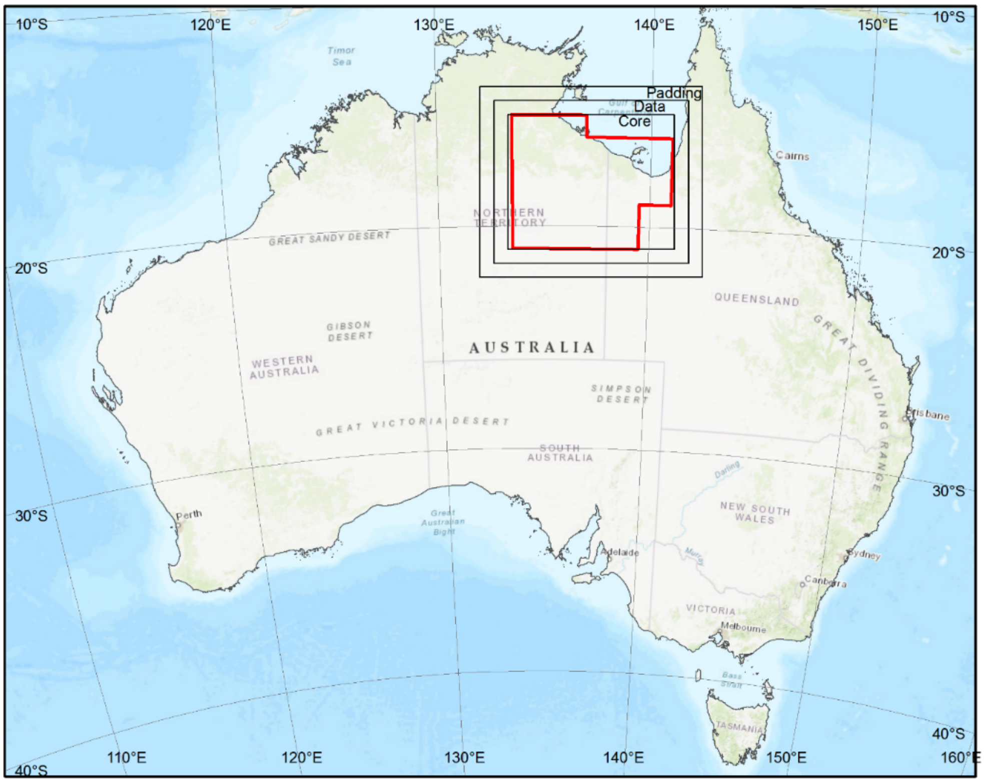

Figure 1. Location of the EFTF Tennant Creek – Mt Isa region (red outline) and inversion model bounds (black outlines) in northern Australia. Basemap layer credits: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

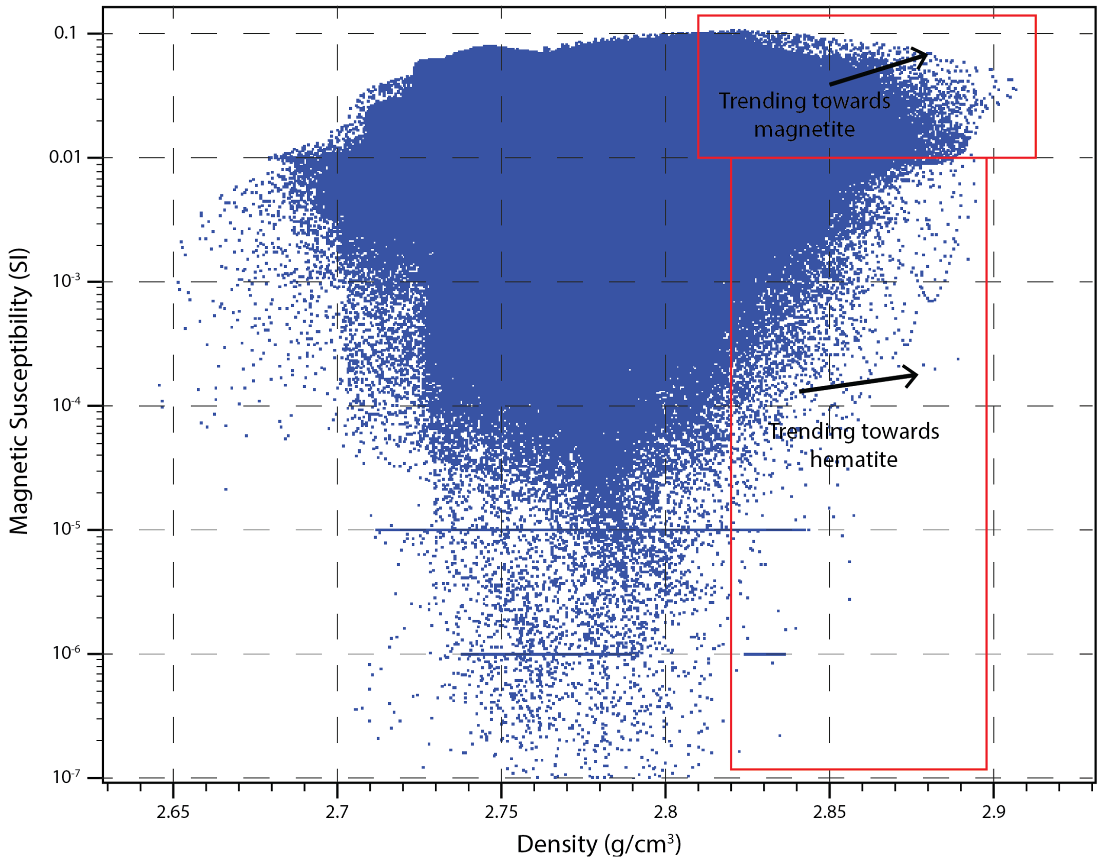

Figure 2. Cross-plot of density versus magnetic susceptibility from the gravity and magnetic inversion model results. Shown with red boxes are the ranges of values used to define magnetite and hematite alteration proxies.

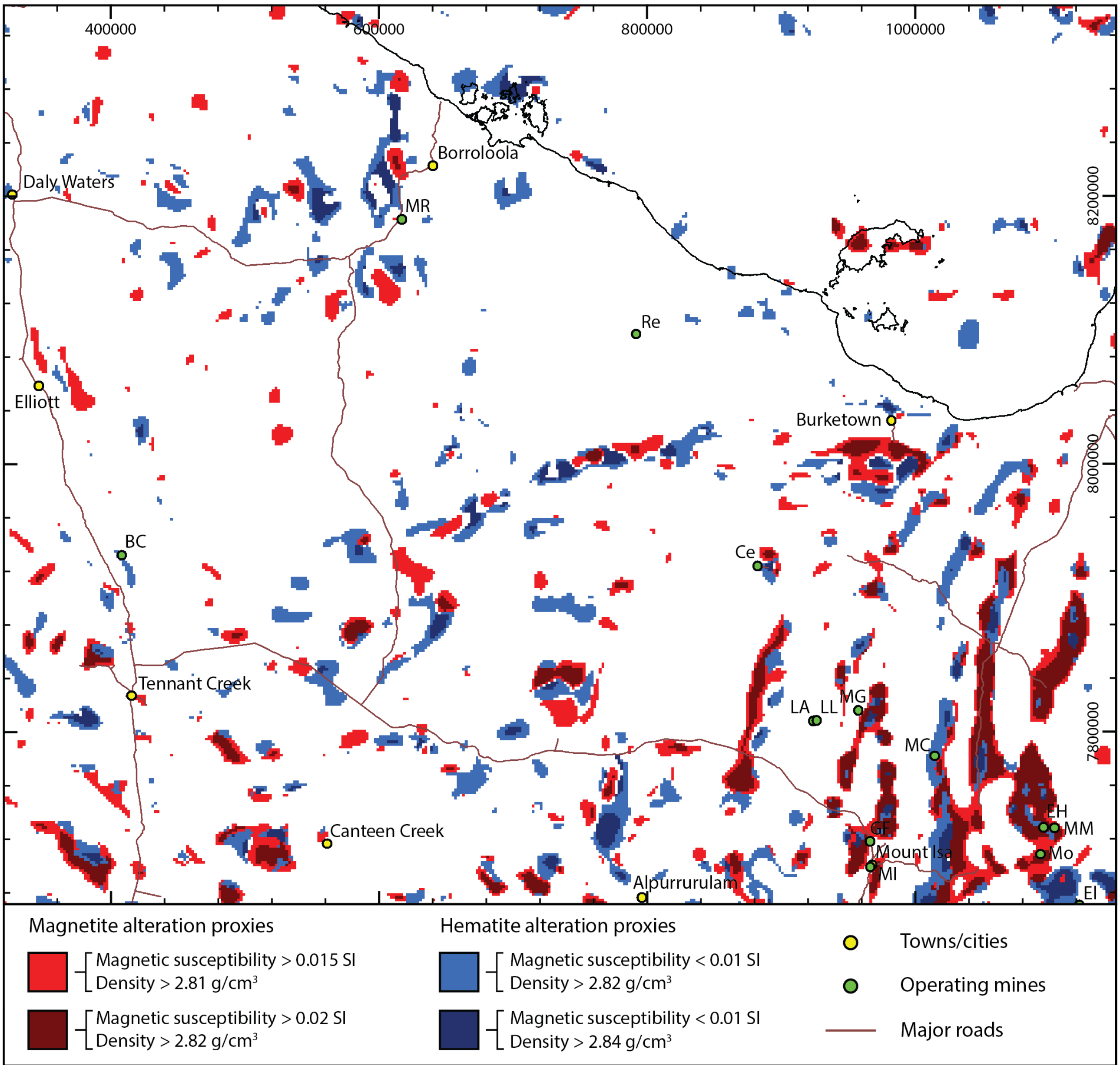

Figure 3. Map view representation of the qualitative assessment of magnetite and hematite alteration. Operating mine abbreviations: BC = Bootu Creek, Ce = Century, El = Eloise, EH = Ernest Henry, GF = George Fisher, LA = Lady Annie, LL = Lady Loretta, MR = McArthur River, Mo = Monakoff, MC = Mount Cuthbert, MG = Mount Gordon, MI = Mount Isa, MM = Mount Margaret, Re = Redbank.