Mineralogical and magnetic properties of the Golden Forty deposit: A window into the stratigraphic, structural, rheological and metasomatic evolution of the Tennant Creek mineral field

James Austin[1,2], Tobias Schlegel[1] and Sarath Patabendigedara[1]

Introduction

The Golden Forty deposit, like many other Tennant Creek deposits, is interpreted to be hosted within the 1864–1858 Ma Warramunga Formation (Smith 2000, 2001) and proximal to felsic porphyry (**Figure 1**). Golden Forty coincides with one of the larger magnetic anomalies in the Tennant Creek mineral field (TCMF). However, several narrow ironstones intersected by drilling to date do not explain the size or source of this magnetic anomaly. It therefore remains a large, poorly understood target for copper–gold–bismuth mineralisation. So far, numerous attempts to model it have not led to a geologically realistic solution. A new drone magnetic survey over the Golden Forty camp, delivering high resolution, close-to-source magnetic data, provides the best opportunity to model the source of the magnetic anomaly and interpret the controls on the magnetisation (both remanence and susceptibility).

Remanent magnetisation, which is not detectable using magnetic susceptibility meters, is suspected to be the underlying cause of the disparity. Remanence has long been recognised as an issue in Tennant Creek-style deposits (eg Clark and Tonkin 1987), and previous studies on Golden Forty have noted high remanence in ironstones. However, a thorough understanding of remanence vectors across the Golden Forty camp is necessary to truly resolve the issue at the modelling scale.

Integrated characterisation (Austin *et al* 2024, in press), which incorporates quantitative scanning electron microscope mineral mapping, returns a range of petrophysical analyses (including remanent magnetisation) and magnetic fabric measurements that can be used to constrain regional structural interpretation and magnetic modelling. Integrated characterisation uses a holistic approach to mineral system knowledge, providing quantitative constraints on the interaction of geological, structural and metasomatic processes. These processes control geophysical signatures in mineral systems but are often hard to decipher without scale-integrated multimodal geoscience data. This study provides insights into how structure and alteration interact to control both magnetisation and mineralisation at Golden Forty. It provides a thorough investigation of remanence in these rocks, but more broadly, indicates what controls the bulk magnetisation at Golden Forty. It also suggests magnetic models to explain the observed anomalies. The main outcomes provide new insights into the metallogenic evolution of the Tennant Creek mineral system that could potentially be adopted for future exploration in the TCMF.

Results

The Golden Forty camp contains numerous sources of magnetisation that vary significantly in scale and depth, and have a range of magnetic properties. They are considered to have formed as a result of several stages of alteration that precipitated magnetite in varying abundances and locally

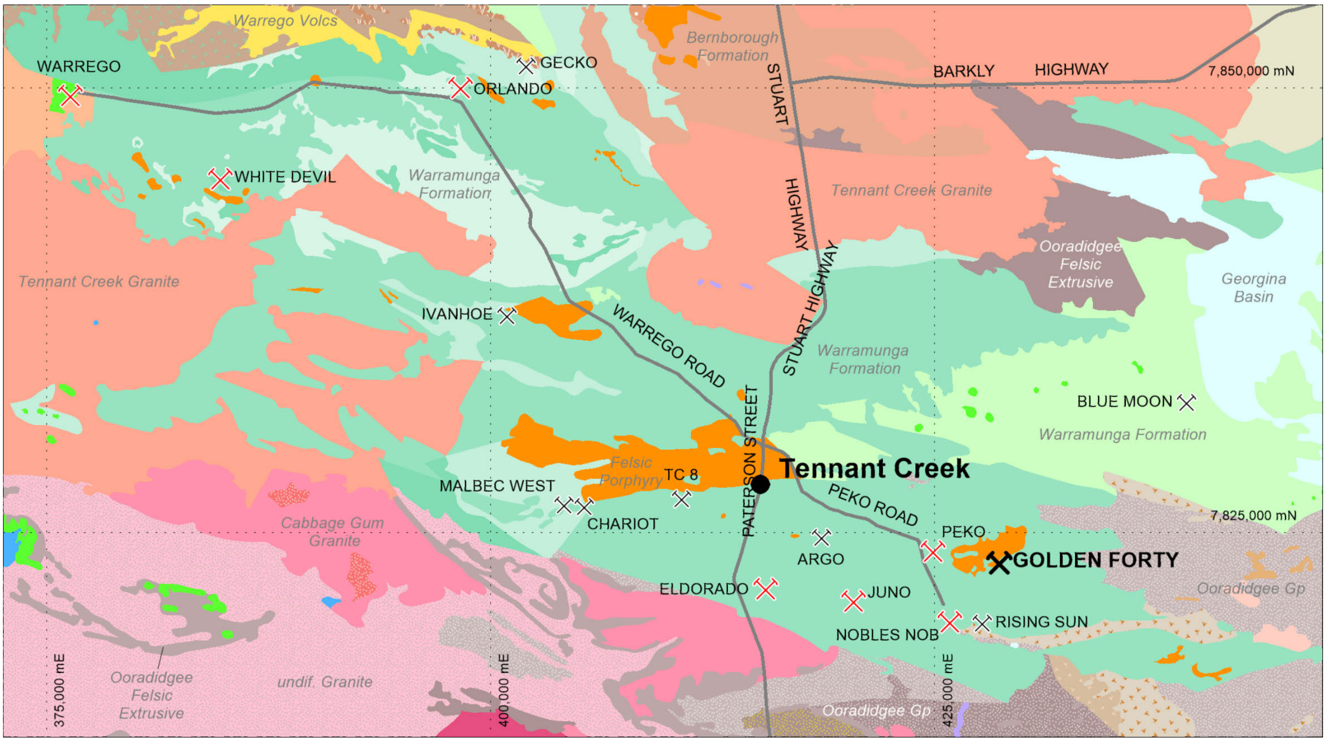

Figure 1. Geological map of the Tennant Creek mineral field (after Donnellan 2013).

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[1] CSIRO Mineral Resources, 36 Bradfield Rd, Lindfield NSW 2070, Australia

[2] Email: james.austin@csiro.au

overprinted magnetite with hematite (**Figures 2, 3**). The style of alteration and its controls evolved in parallel with two distinct orogenic cycles, the Tennant and Murchison events, both of which followed a predictable evolution of:

- sedimentation
- inversion (folding/vertical extension)
- ductile-brittle transpression
- brittle transtension (extension).

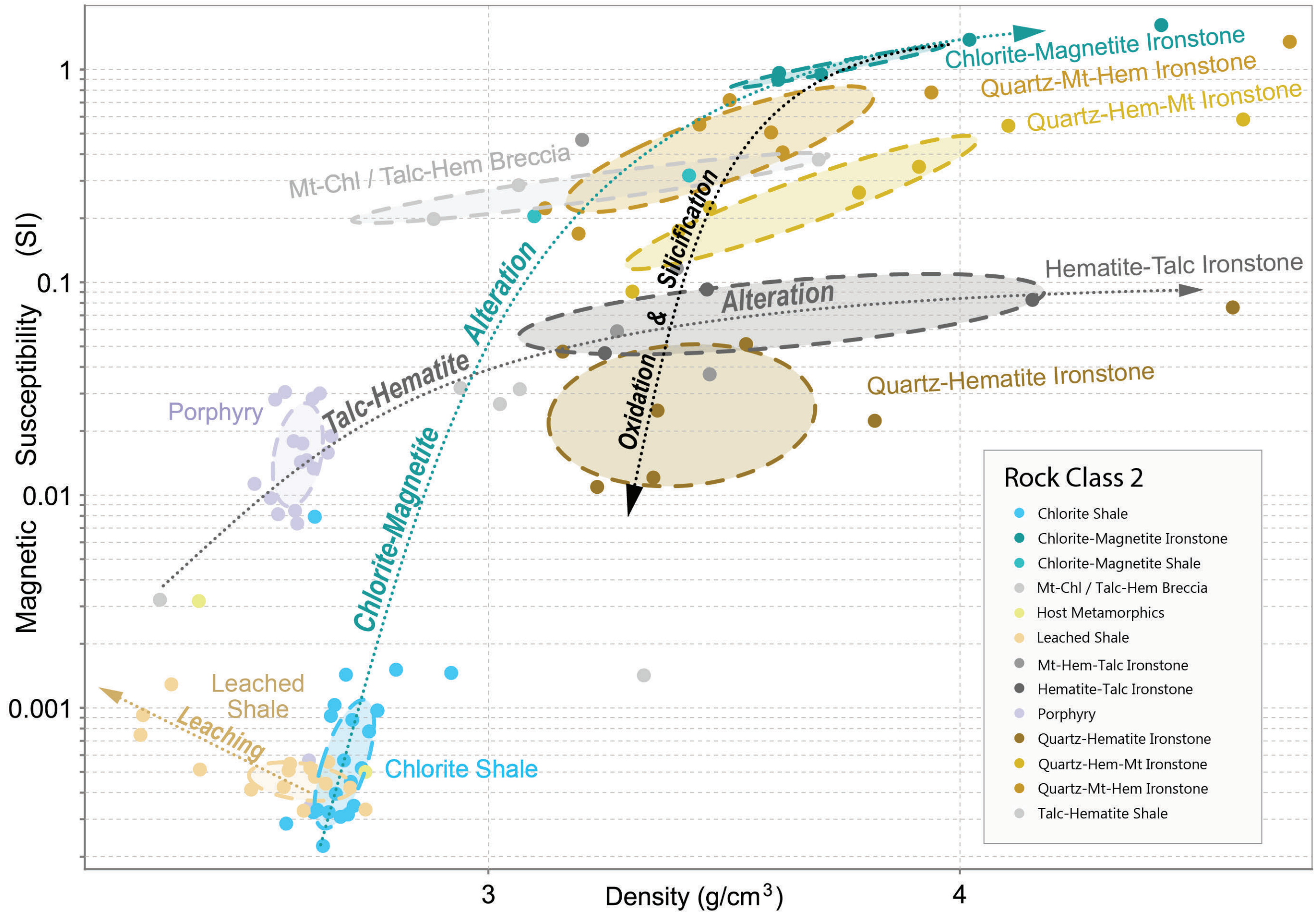

Figure 2. Plot of log-scale magnetic susceptibility vs density for the Golden Forty mineral system.

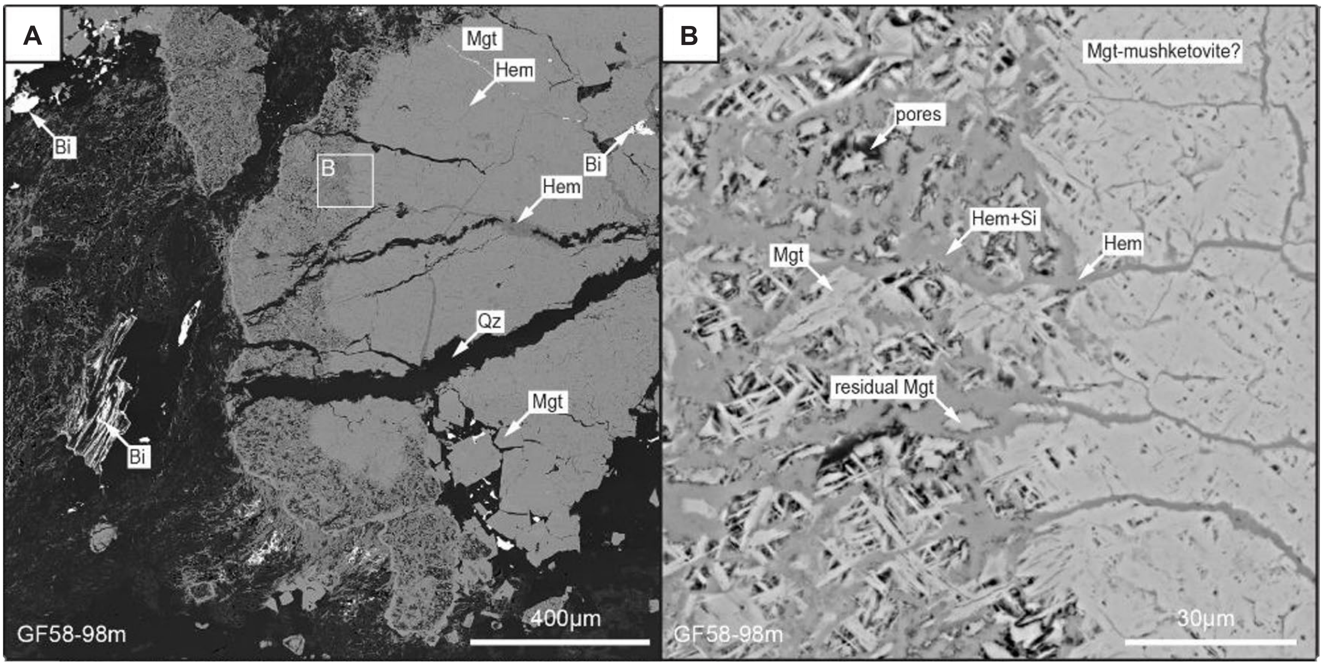

Figure 3. Backscatter images showing partial replacement of magnetite by hematite–silica and associated re-precipitation of hematite, which results in annealed as well as porous hematite. (**a**) Showing a magnetite grain with an alteration halo of partial replacement, and outline of inset B. (**b**) Inset, showing the sub-grain scale in detail. Bi = bismuth, Hem = hematite, Mgt = magnetite, Qz = quartz, Si = silica.

Early magnetite-chlorite alteration was controlled by west–northwest-trending strike-slip shear zones and focused within west–southwest-trending structures, mainly beneath a shallow southwest-dipping plane inferred to be an unconformity between the Warramunga and Ooradidgee groups. The chlorite ironstones only extend 100–200 m beneath this horizon, suggesting it acted as a permeability control, ie a 'lid' on the system. This early iron-metasomatism produced discrete west–southwest-trending zones of high magnetic intensity (eg Golden Forty East) but also produced broader stratigraphically-controlled zones of much weaker intensity that define the two camp-scale anomalies at Golden Forty North and South.

As the crust cooled, ductile brittle transtensional tectonics caused vertical displacement and strike-slip movement on a range of fault orientations, shifting and rotating the existing architecture. This resulted in earlier magnetic source bodies being cut up and rearranged, which greatly increased the complexity of the magnetisation at camp scale. Structurally-controlled talc–hematite alteration, grading upward into quartz–iron oxide alteration, formed approximately at the Warramunga/Ooradidgee unconformity around the start of the Murchison Event.

Sub-grain-scale partial replacement of magnetite by hematite reduced the grain size of magnetic carriers, transforming multidomain magnetite grains into hundreds of single domain magnetite and hematite grains (**Figure 3**). This reduction in grain size was the main factor enabling the retention of strong and highly stable remanent magnetisation in quartz–ironstone. Some quartz–ironstones at Golden Forty North retain remanence sub-parallel to the Earth's field, whereas some at Golden Forty East produced south-oriented, shallow upward to sub-horizontal, west- or east-oriented remanence directions, which appear to be paleomagnetic noise from pencil magnets. In general, significant remanence appears to be volumetrically minor and is unlikely to present a major problem for modelling. Directions from Golden Forty North also suggest remanence may have been acquired (at least in part) due to relatively recent oxidation.

Conclusions

Although the Golden Forty South anomaly is large and considered a bit of a 'geophysical mystery', there is not much evidence to suggest atypical geophysical phenomena are the cause. Modelling Golden Forty is difficult primarily because the geology and the petrophysical evolution of the system is complex. The importance of remanence, as implied by previous studies, is likely over estimated. Conversely, the importance of structural controls and the unconformity (ie the 'lid' of the system) may not have been fully recognised.

Magnetisation and mineralisation at Golden Forty South should have similar controls to Golden Forty North. It would likely sit in the same stratigraphic horizon and extend 100–200 m beneath the hypothesised unconformity. In addition, it would require early magnetite, localised at the junction of west-northwest- and west-southwest-oriented shear zones, to be overprinted by later faults that upgraded the mineralisation, forming a quartz–ironstone.

Ultimately, the coupling of specific metasomatic events with specific structural controls had focused mineralisation at favourable sites, but the metallogenic evolution of the system progresses from magnetite precipitation toward magnetite destruction/hematite precipitation. Structural controls should therefore be more predictive of mineralisation than magnetic bullseye targeting. However, consideration of magnetic zonation and radiometric properties, in conjunction with the confluence of the outlined structural controls, should prove fruitful for targeting in the TCMF.

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