# Controls on Cu-Au mineralisation and Fe oxide metasomatism in the Eastern Fold Belt, N.W. Queensland, Australia

Thesis submitted by
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## *ABSTRACT*

The Eastern Fold Belt (EFB) in north-west Queensland, Australia, is an extensively metasomatised terrain that contains a variety of Fe oxide (Cu-Au) and related deposits (IOCG). Most of these deposits formed after the peak of *ca.* 1600-1575 Ma regional metamorphism and exhibit a broad range of mineralogical and chemical associations. The origin of fluids associated with mineralisation is particularly controversial, whereby magmatic, non-magmatic and magmatic-evaporitic fluid-derived models have all been proposed. Several deposits in the district also exhibit different relations to ironstone (Fe oxide-rich rock) occurrences. These relations vary from early to pre-mineralisation Fe oxides (Starra and Osborne), syn-mineralisation Fe oxides (Ernest Henry) and examples where significant amounts of Fe oxide are distal to the site of mineralisation (Eloise).

Fe oxide-rich rocks can form from a number of different processes (orthomagmatic, replacement, infill, sedimentary), and can be distinguished by textural observations and geochemical analysis. Sulphide mineralisation and Fe oxide-rich rocks within the Mount Fort Constantine (MFC) exploration lease (the main study area) are of particular interest due to their proximity to the Ernest Henry (Cu-Au) deposit. At the FC4NW and FC12 prospects in the MFC lease, sulphide mineralisation post-dates the formation of Fe oxide-rich rocks and is associated with amphibole-rich Na-Ca alteration. Fe oxide-rich rocks in the FC12 prospect were formed by orthomagmatic processes directly related to the formation of their tholeiitic gabbroic host. In contrast, Fe oxide-rich rocks in outcrop and at the FC4NW prospect were formed by hydrothermal processes. Fe oxide-rich rocks at the FC4NW prospect exhibit a close spatial and temporal association with an earlier clinopyroxene-rich Na-Ca alteration phase that predates sulphide mineralisation. The poor correlation between Fe oxide-rich occurrences and sulphide mineralisation at MFC differs from Ernest Henry, where Fe oxide and Cu-Au mineralisation are synchronous and post-date Na-Ca alteration.

Na-Ca alteration at FC12 is associated with the enrichment of Fe, Mg, REE, Cu and S. In contrast, Fe is typically depleted and Mg, REE, Cu and S are variable in regional Na-Ca alteration throughout the Cloncurry District. Na was also found to be variable at FC12. These geochemical patterns suggest that the fluids at FC12 were cooler and more evolved than for regional Na-Ca alteration, and had previously undergone significant

fluid-rock interaction prior to mineral precipitation. This is reflected in the low temperature mineral assemblage (chlorite, calcite, magnetite, hematite, pyrite, chalcopyrite) associated with these veins.

Na-Ca alteration at FC4NW formed by a hypersaline (25 to 50 wt% $NaCl_{equiv}$) and $CO_2$-bearing fluid at temperatures of around 260 to 442°C. These fluids cooled and became less saline with time, reflecting the transition from clinopyroxene-rich to amphibole-rich Na-Ca alteration. The chemistry of these fluids is similar to regional Na-Ca assemblages, containing elevated Mn, Zn, Cu, Fe, K, Cl, Ca, Ba and Pb. In contrast, they are distinctly different to fluids associated with Cu-Au mineralisation at Ernest Henry, Starra, and Lightning Creek in the EFB. In particular, Mn, Zn, Ba and Cu concentrations are significantly lower in Na-Ca assemblages from FC4NW. The lack of significant Cu-Au mineralisation at FC4NW may be attributed to the low Cu content in the fluid.

The mineral chemistry of magnetite, hematite, pyrite and chalcopyrite can be used to discriminate between Cu-Au mineralised systems and systems which are weakly mineralised to barren. Magnetite associated with Cu-Au mineralisation contains a greater variety of elements including Mo, W, Th and U, which are typically low to below detection in other systems. In addition, Cu-Au mineralised systems are associated with higher Sc and Mn (magnetite), As and Co (pyrite), Bi, Sn, In and Ag (chalcopyrite) and As, Sb, Ga, and W (hematite). In contrast, Ti, V, Ga and Cr (magnetite) and Se and Ni (pyrite) are lower in Cu-Au mineralised systems. Fluid chemistry is interpreted to be the dominant control on the trace element content of magnetite, hematite, pyrite and chalcopyrite, however, other physicochemical factors including $f_{O2}$ and temperature may also affect the relative concentration of elements including V, Cu and Se. These chemical signatures have the potential to be used as vectors towards geochemical haloes peripheral to Fe oxide (Cu-Au) mineralisation.

The presence of granitic and pegmatitic dykes at FC12 and FC4NW suggests the presence of a nearby igneous intrusion. In contrast, no igneous intrusive phases are present at Ernest Henry. The felsic igneous rocks at FC4NW exhibit a close spatial and temporal relationship to clinopyroxene-rich Na-Ca alteration suggesting a genetic link. The presence of sulphide associated with the latter amphibole-rich Na-Ca phase at

FC4NW, together with the low temperature mineral assemblage associated with Na-Ca alteration at FC12, suggests that mineralisation may have occurred due to a drop in temperature over time, irrespective of the specific mechanism responsible for the precipitation of sulphide.

The paragenesis and fluid inclusion chemistry at MFC suggest that sulphide mineralisation is an earlier / unrelated event compared to the phase of Cu-Au mineralisation at Ernest Henry. Instead, sulphide mineralisation at MFC more closely resembles the early, weakly mineralised Na-Ca alteration phase and related hanging wall Fe oxide-rich rocks at Ernest Henry. The main ore genesis stage at Ernest Henry is noted by a more complex fluid chemistry, in addition to the presence of Au (absent at MFC) and K-Fe alteration, which suggest that at least one fluid associated with Cu-Au mineralisation at Ernest Henry was absent at MFC. However, the whole rock geochemistry of low temperature Na-Ca alteration at FC12 as well as the mineral chemistry of Fe oxides and Fe sulphides suggest that sulphide mineralisation at MFC and Ernest Henry may be more implicitly linked. In particular, magnetite associated with sulphide-bearing Na-Ca alteration at FC4NW and FC12 contain high Ni and anomalous W, Mo, Th and U, the latter of which are minor to absent in barren regional Na-Ca assemblages but highly enriched at Ernest Henry. One possibility is that Ernest Henry is part of an overlapping hydrothermal system, which supports the interpretation by Mark et al (1999) that more than one fluid was responsible for Cu-Au mineralisation. Fluids responsible for sulphide mineralisation at MFC may have either been diluted by another fluid, possibly of meteoric origin, or did not mix with a more chemically complex, S-bearing fluid. Thus, while a clear distinction can be made between sulphide mineralisation at MFC and Cu-Au mineralisation at Ernest Henry both chemically and paragenetically, MFC may represent a vector towards mineralisation at Ernest Henry, because a small amount of potentially ore-bearing Ernest Henry-style fluid appears to have contributed to the MFC magnetite geochemistry.

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I declare that this thesis is my own work and has not been submitted in any other form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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