Carew, Michael John (2004) ***Controls on Cu-Au mineralisation and Fe oxide metasomatism in the Eastern Fold Belt, N.W. Queensland, Australia.*** **PhD thesis, James Coook University.**

CHAPTER 1:

INTRODUCTION

1.1. RATIONALE

Fe oxide (Cu-Au) deposits (IOCG) have been a major exploration target over the last decade. They represent a family of deposits that vary significantly in mineralogical, chemical and structural characteristics. The discovery of the giant Olympic Dam (Cu-U-Au-Ag-REE) deposit in the Gawler Craton, South Australia in 1975, followed by subsequent underground mining in 1983, helped define this recently classified style of deposit, and resulted in the reclassification of previously discovered deposits that also fall into the IOCG category. Further work found that the IOCG family encompassed deposits that vary widely in size (100 Mt to >1000 Mt) and are associated with a diverse range of commodities (e.g. Au, Cu, Ag, Co).

Globally, some of the more significant IOCG deposits include the La Candelaria Fe oxide (Cu-Au-Zn-Ag) deposit in Chile hosted in biotite-quartz-magnetite altered andesite volcanic and volcaniclastic rocks. Mineralisation occurred at 112 to 110 Ma, coeval with the emplacement of an Early Cretaceous granitoid intrusion (Marschik et al., 2000). The NICO (Cu-Co-Bi) and Sue Dianne (Cu-Ag) deposits of the Great Bear magmatic zone in Canada are hosted in iron and potassium altered brecciated sedimentary rocks and a well-zoned diatreme breccia complex respectively (Goad et al., 2000). Paragenetic studies at both deposits indicate a progression from reduced, high-temperature mineral assemblages to oxidised, low-temperature assemblages. The proximity of both deposits to continental volcanics (1867 Ma) and rapikivi granite intrusions (1856 Ma) suggest a genetic relationship (Goad et al., 2000). In the SE Missouri Iron Metallogenic Province, USA, eight major magnetite and hematite deposits are currently known, and hosted in Mid Preoterozoic rhyolites, trachytes and andesites. Small, unrecovered deposits including Pea Ridge (REE ± Au) and Boss (Fe-Cu) are prime examples of the potential for this province to produce significant Fe oxide (Cu-Au) (Seeger, 2000).

Australia is also host to a number of IOCG deposits, including the Warrego and White Devil (Au-Cu-Bi) deposit in the Tennant Creek Inlier of the Northern Territory and the Copper Blow and Kalkaroo (Cu-Au) deposits of the Curnamona Province in South Australia and New South Wales. The Cloncurry District in North West Queensland contains a number of Fe oxide (Cu-Au) deposits that vary in both size and commodity (Fig. 1.1).

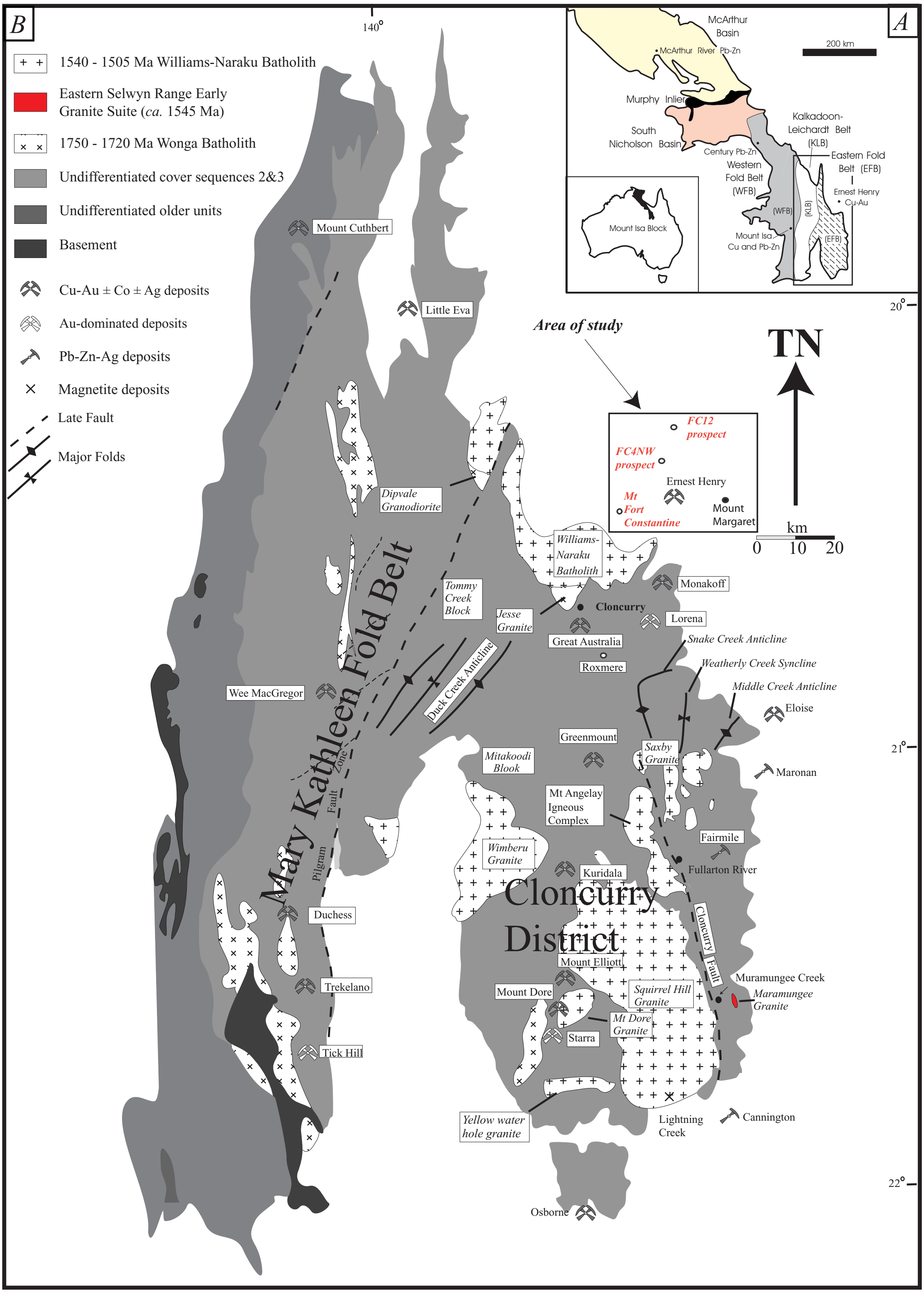

Figure 1.1. A. Tectonostratigraphic divisions of the Mount Isa Inlier, Queensland. B. Enlargement and simplified geology of the Eastern Fold Belt with localities of mineral deposits. Compiled from published AGSO maps and modified by Williams (1998). Includes locations of areas relevant to this study.

Examples include the Au-rich Starra (Au-Cu) deposit and the Ernest Henry (Cu-Au) deposit, the largest in the Eastern Fold Belt (EFB).

The textural, structural and mineralogical diversity associated with IOCG deposits prompted Hitzman et al (1992) to suggest that IOCG deposits and magnetite-apatite ("Kiruna type") deposits form end-members of a continuum, although more recently Hitzman (2000) suggested both form from distinctly different origins. Particularly pertinent is the variation in timing of Fe oxide formation and Cu-Au mineralisation between different deposits commonly within one district. Some deposits show evidence for early Fe oxide-rich rocks overprinted by later Cu-Au mineralisation (e.g. Osborne and Starra), where oxidised (Cu-Au-bearing) fluids were thought to interact with reduced (magnetite-bearing) wall rocks to deposit ore (Adshead, 1995; Rotherham, 1997). In other deposits such as Ernest Henry, Fe oxides precipitated synchronous with Cu-Au mineralisation (Mark et al., 1999). Debate over the origin of Fe oxide-rich rocks (ironstones) hosting Cu-Au mineralisation in the Osborne and Starra Cu-Au deposits has caused much controversy, with both syngenetic (Davidson et al., 1989; Davidson, 1994) and epigenetic (Williams, 1994; Rotherham, 1997; Rotherham et al., 1998) models proposed. To date, the underlying relationship between Fe oxide-rich rocks and the deposition of Cu-Au mineralisation is still unresolved.

Globally, a variety of sources have been implicated for fluids containing the necessary ligand-forming complexes and metals for Fe oxide (Cu-Au) deposition, with both magmatic (Rotherham et al., 1998; Mark et al., 1999; Pollard, 2000; Williams and Skirrow, 2000) and non-magmatic models (Barton and Johnson, 1996; 2000) proposed. This controversy is compounded by the proximity of igneous intrusions and regional hydrothermal activity to many IOCG deposits (Hitzman et al., 1992; Gow et al., 1994; Barton and Johnson, 1996; Oliver et al., 2004).

The Mount Fort Constantine (MFC) exploration lease surrounding Ernest Henry has been targeted for exploration for some time (~20 years) (Fig 1.1). Two prospects in particular contain mineral assemblages associated with Fe oxide-rich rocks and minor sulphide mineralisation. Similar alteration assemblages are also found in outcrop, in addition to a large quarry containing Fe oxide-rich rocks. The proximity of the Fe oxide-rich rocks at MFC to the Ernest Henry (Cu-Au) deposit makes them of particular interest, as the MFC rocks may indicate vectors towards Cu-Au mineralisation. This thesis looks at the paragenetic history of the MFC area, with particular emphasis on sulphide mineralisation and Fe oxide deposition, and relates this to both regional-scale hydrothermal alteration and alteration observed at the Ernest Henry deposit. The chemistry and potential source of the fluids as well as the mass transfer of components associated with alteration will be investigated. The Fe oxide-rich rocks at MFC are then geochemically compared to other occurrences throughout the EFB to better constrain the different processes that may be involved in their formation and their possible relationship(s) to Cu-Au mineralisation. Laser Ablation ICP-MS is employed to determine the trace element content of Fe oxide and Fe sulphides from various styles of Fe oxide (±Cu-Au) mineralisation throughout the EFB. Not only can these trace element signatures provide valuable information regarding the important conditions governing the precipitation of Fe oxide (±Cu-Au) mineralisation, but may also represent a valuable tool for further exploration of these deposits.

1.2. OBJECTIVES OF RESEARCH

The main objectives of the project are:

- To understand the detailed paragenetic evolution of the MFC exploration lease;
- To determine the spatial relationship between Fe oxide and sulphide mineralisation by providing geological maps and cross-sections of rock types and hydrothermal alteration at MFC;
- To determine the chemistry and potential source of fluids responsible for hydrothermal alteration and sulphide mineralisation at MFC by use of conventional microthermometric analysis, PIXE and laser Raman spectromentry;
- To determine the geochemical mass transfer associated with sulphide-bearing Na-Ca veining and alteration using whole-rock geochemistry (XRF);
- To establish criteria for identifying Fe oxide-rich rocks formed by different formational processes both within the MFC area and elsewhere within the EFB and determine their possible relationships to Cu-Au mineralisation;
- To determine the fluid chemistry and other physicochemical factors required for Cu-Au mineralisation to occur by analysing the trace element composition of

magnetite, hematite, pyrite and chalcopyrite from various Fe oxide-bearing mineral associations; and

- To generate a model for the formation of Fe oxide-rich rocks and sulphide mineralisation within the MFC area and how this fits into the regional context of other Fe oxide (±Cu-Au) deposits in the EFB.

1.3. METHODS

This study initially focussed on geological mapping and logging of diamond drill core from 15 holes within the FC12 and FC4NW prospects of the MFC exploration lease. The resulted paragenesis was then compared to the paragenesis at Ernest Henry (Mark et al., 1999). Representative samples of all hydrothermal alteration stages were taken with particular emphasis on areas displaying good textural relations and sufficient material for geochemical analysis. Fe oxide-rich samples were also collected from outcrops near Roxmere homestead, MFC and Monakoff mine (chapter 5). X-ray Fluorescence (XRF) and Neutron Activation analysis (INAA) were undertaken on Fe oxide-rich rocks from FC4NW, FC12, MFC outcrop, Roxmere and Monakoff. The same techniques were also applied to Na-Ca alteration and veining and their unaltered equivalents from the FC12 prospect. In both cases, the isocon method was employed to determine both the genetic relationship between Fe oxide-rich rocks and their adjacent hosts, and the mass transfer associated with alteration. In total, 170 polished thin sections (70 from FC4NW, 76 from FC12, 25 from outcrop and 6 from other Fe oxide-rich rock samples) were made with some samples undergoing microprobe analysis. Doubly polished thin sections (~200 µm thick) were made and later broken down to wafers for microthermetric studies, Proton Induced X-ray Emission (PIXE) and laser Raman spectrometry on fluid inclusions. Laser ablation (ICP-MS) analysis was undertaken on various samples containing magnetite, hematite, pyrite and chalcopyrite to determine their trace element content. These samples were taken from the MFC exploration lease, as well as from some of the major IOCG deposits in the Cloncurry district including Ernest Henry, Starra, Osborne, Mount Elliott and the Lightning Creek Cu-Au occurrence. A discriminant analysis was performed on the geochemical data obtained from Laser Ablation-ICP-MS to determine important elements that distinguish between different hydrothermal systems.

1.4. THESIS OUTLINE

Chapter 1: Introduction.

Chapter 2: Hydrothermal alteration and mineralisation of the Mount Fort Constantine area: Implications for the evolution of the Ernest Henry Fe oxide (Cu-Au) system.

Chapter 2 investigates the paragenesis of hydrothermal alteration and sulphide mineralisation observed in outcrop and within the FC12 and FC4NW prospects of the MFC exploration lease. In particular, the spatial and temporal relationships between hydrothermal alteration and sulphide mineralisation at MFC and the nearby Ernest Henry (Cu-Au) deposit (Mark et al., 1999) are compared to determine possible factors which may have inhibited significant Cu-Au mineralisation at MFC.

Chapter 3: Fluid-rock interaction and sulphide mineralisation within the Mount Fort Constantine exploration lease, NW Queensland, Australia.

In chapter 3, small scale mass transfer patterns associated with weakly mineralised Na-Ca veining and alteration is explored to better understand the origin and behaviour of specific chemical components, with particular emphasis on Cu, S and Fe. These patterns are then compared to previous work on mass transfer associated with regional Na±Ca alteration assemblages and Fe oxide metasomatism (Oliver and Bons, 2001; Rubenach and Lewthwaite, 2002; Oliver et al., 2004). The intent is to determine to what extent the mass transfer relationships give an indication as to the proximity or nature of Cu-Au mineralisation at Ernest Henry.

Chapter 4: Physicochemical characteristics of fluids at the Mount Fort Constantine exploration lease, NW Queensland, Australia.

Chapter 4 examines the chemical makeup of fluids associated with sulphide-bearing Na-Ca alteration at the FC4NW prospect and compares these results to fluids associated with regional barren Na-Ca assemblages from Mount Angelay and Fe oxide (Cu-Au) mineralisation from previous work. This work utilises microthermometric analysis of fluid inclusions to define trapping temperatures and salinities, while Proton Induced X-ray Emission (PIXE) was used to determine their chemistry. Continuing on from chapter 3, the main focus of this chapter is to compare fluids associated with sulphide mineralisation at FC4NW and fluids responsible for Cu-Au mineralisation at Ernest Henry to determine whether a genetic link exists between the two.

Chapter 5: The geochemistry of Fe oxide-rich rocks in the Proterozoic Eastern Fold Belt, NW Queensland: Implications for exploration.

Chapter 5 addresses the issue pertaining to the origin of Fe oxide (±Cu-Au)-rich rocks in the Eastern Fold Belt and offers textural and geochemical criteria to distinguish between different formation processes. These processes include Fe oxide-rich rocks formed from orthomagmatic crystal fractionation, chemical sedimentation (BIF) and hydrothermal processes (infill and replacement). For Fe oxide-rich rocks formed by hydrothermal processes, these results are compared to geochemical mass transfer patterns associated with Na-Ca alteration and other Fe oxide-rich rocks in the EFB (Rubenach and Lewthwaite, 2002; Oliver et al., 2004). Finally, the possible relationships between different Fe oxide-forming processes and Cu-Au mineralisation is investigated.

Chapter 6: Trace element geochemistry of magnetite, hematite, pyrite and chalcopyrite associated with various Fe oxide (±Cu-Au) mineralised systems: Insights into the geochemistry of ore-forming fluids

Chapter 6 utilises Laser Ablation (ICP-MS) technology to determine the trace element content of magnetite, hematite, pyrite and chalcopyrite associated with various mineral assemblages both directly associated with, and distal to, Cu-Au mineralised systems. The trace element content of the aforementioned minerals can provide insight into the geochemistry of fluids associated with Cu-Au mineralisation and 'background' hydrothermal alteration, as well as important physicochemical parameters important for triggering the precipitation of sulphides. This technique also has the potential to be an important exploration tool.

Chapter 7: Controls on Cu-Au mineralisation and Fe oxide metasomatism in the Eastern Fold Belt

Chapter 7 provides a synthesis of the previous five chapters and presents:

- Criteria for distinguishing Fe oxide-rich rocks that have formed from different mechanisms;
- A model illustrating the hydrothermal history associated with sulphide-bearing Na-Ca alteration at FC4NW and FC12 and its relationship to Cu-Au mineralisation at the Ernest Henry deposit;

- A summary of the key trace element signatures in magnetite, hematite, pyrite and chalcopyrite that differentiate between Cu-Au mineralised systems and systems that are barren or weakly mineralised, and how they relate to fluid chemistry and other physicochemical parameters; and
- Models and useful criteria for better defining potential exploration targets for Fe oxide (Cu-Au) mineralisation.