PGC PUBLISHING

Haynes, D.W. 2000 - Iron Oxide Copper (-Gold) Deposits: Their Position in the Ore Deposit Spectrum and Modes of Origin; *in* Porter, T.M. (Ed.), Hydrothermal Iron Oxide Copper-Gold and Related Deposits: A Global Perspective, Volume 1; *PGC Publishing, Adelaide*, pp 71-90.

IRON OXIDE COPPER (-GOLD) DEPOSITS: THEIR POSITION IN THE ORE DEPOSIT SPECTRUM AND MODES OF ORIGIN

Douglas W Haynes

BHP Minerals Discovery
Milton, Queensland, Australia, 4064

Abstract – Iron oxide copper (-gold) deposits consist of dominant magnetite or haematite, with one or more copper sulphides and pyrite, with associated K-feldspar or sericite or albite or biotite and chlorite predominant in the ore host rocks. The deposits display a ***unique*** association with host successions characterised by an absence of, or by very minor occurrence of, elemental carbon or reduced-carbon compounds and reduced-sulphur minerals. The relatively oxidised nature of the ore host succession is reflected in the "magnetically active" signature that usually defines iron oxide copper (-gold) mineralised districts. This signature shows that magnetite is ubiquitous and variably abundant within ore host successions. Host successions with ***discrete*** domains respectively characterised by (a) by rocks with an absence or rarity of carbon or reduced carbon minerals, and (b) by a predominance of rocks containing carbon or reduced carbon minerals, however, contain iron ***sulphide***-copper (-gold) deposits on or near the boundaries of the domains. Examples of the iron sulphide-copper (-gold) deposits are the Mt Isa and Gunpowder deposits, many small occurrences in the Eastern Fold Belt (Mt Isa Inlier), the El Soldado deposit, and others. The iron oxide copper (-gold) deposits and the iron sulphide copper (-gold) deposits display a more distant association with near coeval granites of "I" or "A" type affinities. A close association with these granites is cryptic, or is not developed, for the iron sulphide-copper (-gold) deposits within the Western Fold Belt, Mt Isa Inlier. ***All*** iron oxide copper (-gold) deposits and ***most*** iron sulphide copper (-gold) deposits display an association with extensive sodic alteration comprising albite, magnetite, chlorite or actinolite, usually with associated scapolite, haematite, epidote, calcite, and titanite. Albite, often haematite pigmented, and usually scapolite are predominant within the alteration. In iron oxide copper (-gold) mineralised districts, the sodic alteration is characteristically most intensively developed within large faults and on lithological contacts. The fault-associated alteration and that associated with the mineralisation characteristically overprints fabrics developed during peak metamorphism. The widespread late albite alteration, its relatively oxidised nature, and the association of iron oxide copper (-gold) and iron sulphide copper (-gold) deposits with it suggests a causal link. The principal hydrothermal fluid source for the iron oxide copper (-gold) deposits and the regionally associated late albite alteration, is hypothesised to be a brine or saline water stored in an overlying extensional or transtensional basin. Its circulation into the host successions is driven in part by the thermal event associated with granite emplacement. The hydrothermal fluids were most likely non-acid, because of the abundance of feldspar within the host successions, but they became acid through coupled precipitation of magnetite or haematite or sulphides and sulphate reduction during ore genesis. The mineralogy and metal budget of the ore assemblage were also controlled by the relative oxidation states of the ore host succession. The unique association of iron oxide copper (-gold) deposits with the widespread and relatively oxidised albite alteration and specific host succession mineral assemblages is inexplicable through models that invoke sources of metals alone from granites. Such models fail to explain the absence of iron oxide copper (-gold) deposits associated with granites of comparable composition within successions comprising dominant reduced-carbon-bearing rocks, or which are relatively non-reduced, but are characterised by an absence of albite alteration. The problems in identifying fluid and metal sources for iron oxide copper (-gold) deposits, and for many ore deposits has arisen through excessive reliance on studies of isotope ratios comprising elements that exchange relatively rapidly with host rocks along long fluid flow path. Isotope studies of ore forming systems characterised by long hydrothermal fluid flow paths usually fail to identify sources of hydrothermal fluid, particularly if there are "hot" rocks, for example, cooling, but sub-solidus granites ($T < 700^oC$) in the fluid flow path. Under rock-buffered hot rock conditions, isotope ratios characterise the last or later rock with which the fluid was buffered in the flow path. Careful regional scale mapping of the alteration and its Na/K ratios, and definition of Br/Cl ratios in the ore-associated alteration will provide a better guide to the understanding of the enigmatic systems responsible for genesis of iron oxide copper (-gold) deposits.

Introduction

Iron oxide copper (-gold) deposits are a recently defined ore type. They were recognised as such with publication of information on the Olympic Dam deposit after 1983 (Roberts and Hudson, 1983; Reeve *et al.*, 1990), and with publication of a number of excellent published syntheses of related ore types. The syntheses noted in particular the similarities of the geochemistry and setting of the Olympic Dam deposit with "barren" iron oxide deposits of the mid-Continent US, and of the Kiruna district (Hauck and Kendall, 1984; Hagni and Brandon, 1988; Einaudi and Oreskes, 1990; Hauk, 1990; Pratt and Sims, 1990; Hitzman *et al.*, 1992.)

Iron oxide copper (-gold) deposits consist of predominant magnetite or haematite, one or more copper sulphides, and pyrite within silicate alteration assemblages dominated by K-feldspar or sericite, or by albite and biotite, or by biotite and chlorite. The deposits also contain anomalous concentrations of the rare earth elements, P, F, U, Ba, Mo, Co, and sometimes Th, B and As. They do not, however, contain anomalous Zr or Nb. The "barren" iron oxide deposits noted above display comparable geochemistry, but they are not usually anomalous in Ba, and are characterised by an absence of economic concentrations of Cu and Au. Williams (1999 summarises pertinent features of a number of the Australian examples of iron oxide copper (-gold) deposits.

The larger iron oxide copper (-gold) deposits are listed in Table 1.

Iron oxide copper (-gold) deposits are an emerging ore type of importance to the minerals industry, as illustrated by the recent discoveries of Sossego-Sequerinho and Crystalino in the Carajas region.

There is controversy on their genesis and setting. Most research favours hypotheses invoking an orthomagmatic origin for some or all of the metals within them, either from granites or deep igneous sources (for example, Hitzman *et al.*, 1992; Blake, 1993; Pollard, 1997; 1998; Williams, 1998; 1999) or from more mafic magmas with an alkaline affinity (Johnson and Cross, 1995; Campbell *et al.* 1998). Others, for example, Einaudi and Oreskes (1990), Oreskes (1990 a, b), Oreskes and Einaudi (1990), and particularly Barton *et al.* (1993), proposed composite origins, where a hypogene, high temperature ore of an inferred dominantly magmatic hydrothermal origin was upgraded or modified by a discrete lower temperature hydrothermal event or low temperature supergene event. Williams (1999) repeated the hypothesis that the Olympic Dam deposit is the result of late events superimposed on an earlier high-temperature mineralising event, but did not present any new supporting evidence.

Fluid mixing causes of ore genesis for one important member of the class of iron oxide copper (-gold) deposits, the Olympic Dam deposit, were proposed by Haynes (in Roberts and Hudson (1983). Haynes *et al.* (1993; 1995) hypothesised that the dominant hydrothermal fluid responsible for genesis of the Olympic Dam and related deposits was sourced from saline playa lakes in an overlying extensional basin because of the likely setting in which the Olympic Dam deposit formed. Hypotheses invoking a dominant magmatic source of metals were also difficult to reconcile with the paragenesis, isotope signatures, mineralogy and geochemistry of the deposit. The absence of ore-grade copper in apparent analogues of the Olympic deposit, for example, the "barren" iron oxide deposits of the mid-Continent USA, was postulated to result from an absence of surface-derived waters of appropriate salinities and oxidation states. Barton and Johnson (1996) also hypothesised that the principal source of hydrothermal fluids responsible for genesis of the deposits were surface waters from salars (or saline lakes). Models invoking two fluids, one being a surface or near surface-derived water, for apparently related ore types, for example, the Vergenoeg Fluorite deposit (Borrok *et al.* 1998) have also been proposed.

The association of iron oxide copper (-gold) deposits with regional-scale sodic alteration dominated by albite, scapolite, magnetite, and actinolite as a characteristic feature was first described by Hitzman *et al.* (1992). A regional zonation of the assemblages from extensive sodic to more localised potassic mineral assemblages, with the ore associated alteration being more potassic in nature was also noted. Haynes (1993) noted the presence of regional sodic alteration as being an important indicator of iron oxide copper (-gold) mineralised districts, as well as noting that such alteration is an indicator of ancestral sodic brines stored within saline lakes within overlying extensional basins. Such an association was again emphasised by Barton and Johnson (1996), who also speculated on the likely causal link between the sodic alteration and the iron oxide copper (-gold) deposits.

Albite and scapolite alteration in districts which contain iron oxide copper (-gold) deposits has been described by Oliver and Wall (1987), de Jong and Williams (1995), and Oliver *et al.*, (1993; 1994), Williams (1995), Frietsch *et al.* (1997), and Marschik *et al.* (1996; 1997). Hydrothermal overgrowths on zircons in albite alteration of the Malakoff Granite, and hydrothermal biotite associated with iron oxide copper (-gold) mineralisation in the Eastern Fold Belt, Mt Isa Inlier, were noted to have the same age (Page and Sun, 1998; Perkins and Wyborn, 1998), indicating that the mineralisation and at least part of the regional albite alteration here was ***coeval***.

The descriptions of the sodic alteration, particularly those of Hitzman *et al.* (1992), drew attention to the unusual and widespread nature of this alteration within districts that host iron oxide copper (-gold) deposits and related types of copper deposit. The research on the districts containing iron oxide gold deposits together with colleagues' and the writer's observations in emerging districts, for example, Carajas, show that iron oxide copper (-gold) deposits show a ***unique*** association with districts displaying widespread, but not necessarily abundant, albite alteration, usually with associated scapolite.

An orthomagmatic source of metals from granites has been popular because iron oxide copper (-gold) deposits occur in districts which contain "late" granites, of so-called "I" or "A" type affinities. Wyborn et al (1988), Wyborn (1988; 1992), Wyborn and Heinrich (1993), Creaser (1989), Hildebrand (1986), Sims (1990 a, b), and Dallagnol *et al.* (1994) noted the occurrence of these granites in districts which contain iron oxide copper (-gold) deposits. Wyborn (1988), Creaser (1989), Sims (1990 a, b) and Dallagnol (1994) noted that the granites suites characteristically comprise oxidised, "anorogenic" or intraplate granites, although those in the Candelaria district do not, being "I" types (Ishihara *et al.*, 1984). Geochronology, for example, Johnson and Cross (1995), Creaser and Cooper (1993), Marschik et al (1997), Wyborn et al (1988), Perkins and Wyborn (1996), Pollard (1998) and Page and Sun (1998) showed that the granites and the iron oxide copper (-gold) deposits are broadly, but are not precisely, coeval. The research on the "I" and "A" type granites clearly shows they extend well beyond iron oxide copper (-gold) mineralised districts. Examples of "barren" districts containing the "I" and "oxidised" "A" type granites are abundant worldwide. Specific examples are the western Gawler Craton (Creaser 1995), parts of the Gascoyne Province, (field observation by the writer and colleagues), the western Arunta Complex (Wyborn pers. comm. 1998), and large areas of the Scandinavian Shield (for example, Mengue and Brewer, 1994). The association of oxidised "A" or "I" type granites with iron oxide copper (-gold) deposits is therefore ***not unique***.

Iron oxide copper (-gold) deposits also display other unusual characteristics that require formal definition in order to assist understanding of these enigmatic ore types. These are (a) occurrence within successions characterised by a general absence of elemental carbon (or reduced carbon minerals such as hydrocarbons), and of minerals containing reduced sulphur; (b) a regional and temporal association with iron-sulphide-copper (-gold) deposits in some districts, for example, the Eastern Fold Belt, Mt Isa Inlier, and (c) occurrence of the largest deposits within rocks that either contain dominant feldspar, or ferrous-iron minerals such as fayalite or grunerite.

Table 1

Deposit and Location	Host Age (Ga)	Ore Age (Ga)	Size (Proved, Probable, Inferred)	Sources
Salobo, Carajas Greenstone Belt, Brazil	2.74-2.68	2.57-1.88 ?	784 Mt 0.96% Cu; 0.52 g/t Au	Machado and Lindenmayer (1991); CVRD Reports
Alemao/Igarape Bahia, Carajas Greenstone Belt, Brazil	2.76-2.68	2.57-1.88?	(1) 30 Mt, 2.3 g/t Au (gold zone); (2) 30 Mt, 1.0% Cu, 1.3 g/t Au ("transition zone"); (3) 135 Mt, 1.8% Cu, 0.5 g/t Au (Alemao)	(Machado and Lindenmayer (1991); CVRD Reports
Sossego-Sequerinho, Carajas Greenstone Belt, Brazil	2.7 ?	?	355 Mt, 1.1 % Cu; 0.28 g/t Au	Informal Source; CVRD Reports
Crystalino, Carajas Greenstone Belt, Brazil	2.7 ?	?	500-800 Mt, 1.3% Cu, 0.3 g/t Au?	Informal Source; Size Very Uncertain
Sue Dianne, Great Bear Magmatic Zone, Canada	1.85	1.85	8.2 Mt, 0.8% Cu	Johnson and Hattori (1994)
Olympic Dam, NE Gawler Craton, Australia	1.59 & 1.87 ?	1.59	566 Mt, 2.0% Cu, 0.7 g/t Au; 1620 Mt, 1.3% Cu, 0.4 g/t Au	Johnson and Cross (1995); Company Reports
Ernest Henry, Eastern Fold Belt, Mt Isa Craton	1.7	1.48	167 Mt, 1.11% Cu, 0.54 g/t Au	Page and Sun (1998); Perkins and Wyborn (1998); Pollard (1998)
Osborne, Eastern Fold Belt, Mt Isa Craton	1.68	1.54	11.3 Mt, 2.9% Cu, 1.18 g/t Au	Perkins and Wyborn (1998); Pollard (1998); Company Reports
Starra, Eastern Fold Belt, Mt Isa Craton	1.68	1.50	5.4 Mt, 2.6% Cu, 5.2 g/t Au	Perkins and Wyborn (1998); Pollard (1998)
Pea Ridge, St Francois Mountains, USA	1.48	1.48		Marikos and Barton (1993)
Punta del Cobre, Central Chile	0.1?	~0.13 (Neocomian or older)	~ 55 Mt, 1.5% Cu	Marschik and Fontbote (1996) Marschik *et al.* (1997)
Candelaria, Central Chile	0.115	~0.13 (Neocomian or older)	384 Mt, 1.07% Cu 0.27 g/t Au	Marschik and Fontbote (1996) Marschik *et al.* (1997); Unpub. Reports

It is the purpose of this paper to explore the unusual characteristics of iron oxide copper (-gold) deposits further to define in part a hypothesis of ore genesis of these interesting ore types. Their position in the spectrum of ore deposits represented by iron sulphide-copper (-gold) deposits of the Mt Isa and related types, and apparently unusual deposits such as the Mantos Blancos deposit, Chile is also investigated. Considerations of the gross oxidation state of the ore host succession then leads to the conclusion that such oxidation state control is one of the principal controls on metal ratios and budgets in the ore types considered here. The paper concludes with some speculations on their genesis.

Iron Oxide Copper (-Gold) Deposits and Related Ore Types

The description here examines iron oxide copper (-gold) deposits in most detail, follows with a summary of iron sulphide copper (-gold) deposits, and concludes with a brief description of the Mantos Blancos deposit. The Mantos Blancos deposit is considered only to the extent that points of relevance to our understanding of the setting of iron oxide copper (-gold) deposits in the ore deposit spectrum can be understood. The considerations detailed here are then used to set up hypotheses of origin of iron oxide copper (-gold) deposits.

Table 2

Deposit	Host Succession Composition	Ore Host Composition	Sources
Salobo	Trondhjemitic gneiss (basement); magnetite-bearing metagreywacke; amphibole-plagioclase granofels (amphibolites) and feldspar granofels (derived from basalts and felsic volcanics respectively), magnetite-bearing quartzite, “iron formation”, feldspathic clastic sediments, and mafic dykes and sills	Magnetite, fayalite, grunerite, Fe-biotite, greenalite and Fe-stilpomelane (alteration?)	Lindenmayer (1990): Machado and Lindenmayer (1991).
Alemao & Igarape Bahia	Amphibole-plagioclase granofels (amphibolites) and feldspar granofels derived from basalts and felsic volcanics respectively, quartzite, “iron formation”, feldspathic clastic sediments, and mafic dykes and sills.	Uncertain. No detailed description of adjacent unaltered host rocks available	(Machado and Lindenmayer (1991); CVRD Reports
Sossego-Sequerinho	Gneiss (basement), amphibole-plagioclase granofels (amphibolites) and feldspar granofels derived from basalts and felsic volcanics, quartzite, “iron formation”, feldspathic clastic sediments, and mafic dykes and sills. Succession is that described for the Carajas metavolcanic belt, and is not necessarily specific to the Sossego area	Uncertain. Probably “granite breccia” in part and basement quartz-feldspar gneiss. No detailed description of adjacent unaltered host rocks available.	CVRD (unpub)
Crystallino	Amphibole-plagioclase granofels (amphibolites) and feldspar granofels derived from basalts and felsic volcanics, quartzite, “iron formation”, feldspathic clastic sediments, mafic dykes and sills. Succession is that described for the Carajas metavolcanic belt, and is not necessarily specific to the Crystallino area	Uncertain. No detailed description of adjacent unaltered host rocks available.	CVRD (unpub)
Sue Dianne	Basalts and rhyolites and overlying andesites with associated synvolcanic intermediate plutons	Felsic volcanics	Hitzman *et al.* (1992) Gandhi (1989)
Olympic Dam	Granite, with abundant K-feldspar and subordinate plagioclase, minor amphibole and biotite. Possibly adjacent to or partly enclosed by older granites and schist and amphibolites of the Hutchison Group	Granite	Reeve *et al.* (1990)
Ernest Henry	Intermediate to felsic volcanics or sub-volcanic sills (in part now plagioclase granofels), mafic volcanics, diorite	Intermediate to felsic volcanics	Craske (1995); Industry Sources (unpub)
Osborne	No information available on complete succession. Locally, sub-feldspathic and feldspathic quartzite, local banded magnetite-quartz rock (iron formations).	Sub-feldspathic and feldspathic, magnetite-bearing quartzite, local banded magnetite-quartz rock (“iron formations”).	Adshead (1993); Industry Sources (unpub).
Punta del Cobre	Andesite, dacite, minor conglomerates, minor green siltstones, limestone at top of succession	Andesite, locally in conglomerates	Ortiz (1966); Marschik and Fontbote (1996) Marschik *et al.* (1997)
Candelaria	Andesite, limestone at top of succession	Andesite	Marschik and Fontbote (1996) Marschik *et al.* (1997); Ryan and Madson (1996)

Iron oxide copper (-gold) deposits occur in host successions in which elemental carbon or reduced carbon minerals such as hydrocarbons are minor or absent. Rocks that contained either abundant feldspar or ferrous iron minerals such as fayalite usually host the deposits. These relationships are summarised in the Table 2.

An absence of dominant elemental carbon- or hydrocarbon bearing rocks also characterises ***all*** hosts successions of apparently analogous "barren" iron deposits. The absence or rarity of such rocks within the host successions of the iron deposits is particularly evident in the Kiruna district, the St Francois Mountains of the mid-Continent USA, the Chile "Iron Belt", the Avenik district of Turkey, and others such as Cerro del Mercado, Mexico (Helvaci 1984, Hitzman *et al.* 1992, Lyons 1988, and Sims *et al.* 1987). The host successions of the iron oxide copper (-gold) deposits and the "barren" iron deposits can thus be described as being relatively oxidised.

Occurrence of iron oxide copper (-gold) deposits and the barren iron deposits within relatively oxidised host successions can be readily deduced from inspection of aeromagnetic data from the host districts. Aeromagnetic data from the Gawler Craton (Fig. 1), the "domain" containing the Ernest Henry deposit, Eastern Fold Belt, Mt Isa Inlier (Fig. 2), and the Mesozoic succession which contains the Candelaria deposit (Fig. 3) all illustrate "active" signatures of the discrete "domains" that host the iron oxide copper (-gold) deposits. The aeromagnetic data, coupled with ground or drill core inspection by the writer or colleagues in many districts hosting iron oxide copper (-gold) and the "barren" iron deposits indicate that magnetite is a ubiquitous component of most but not all districts. Furthermore, inspection of the sodic alteration in the Eastern Fold Belt reveals that magnetite is of at least two ages, one of pre- or syn-peak metamorphic age, and one coeval with the D_2-fabric overprinting (~ 1500 Ma) alteration event.

Aeromagnetic data from the "domain" hosting the Candelaria deposit (Fig. 3) indicates that much of the magnetite in the Candelaria district, although not recorded in the published research on the district, is a prominent component of the sodic alteration. The data also indicate sodic alteration containing the magnetite overprints the eastern parts of the Atacama Batholith, extending several kilometres into the batholith beyond its eastern margin. These relations indicate magnetite-bearing sodic alteration assemblage, in which the Candelaria deposit is embedded, is ***younger*** than that part of the batholith adjacent to the Candelaria deposit, although field inspection and mapping is required to confirm this.

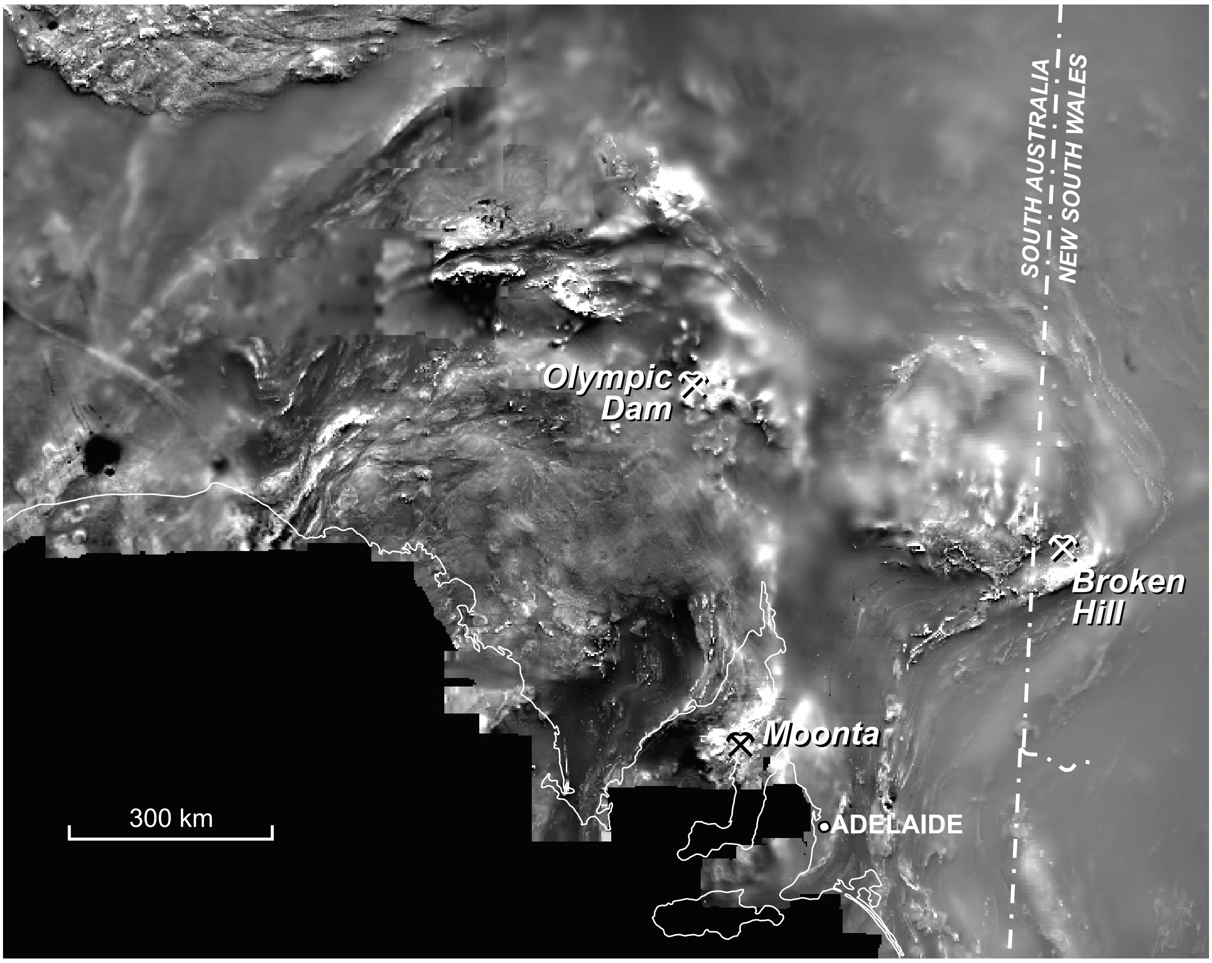

Figure 1: Aeromagnetic data image of the Gawler craton and Curnamona Province. The magnetically "active" nature of the domains containing the Olympic Dam deposit and other iron oxide copper-(gold) deposits, e.g., Moonta-Wallaroo, is clearly evident.

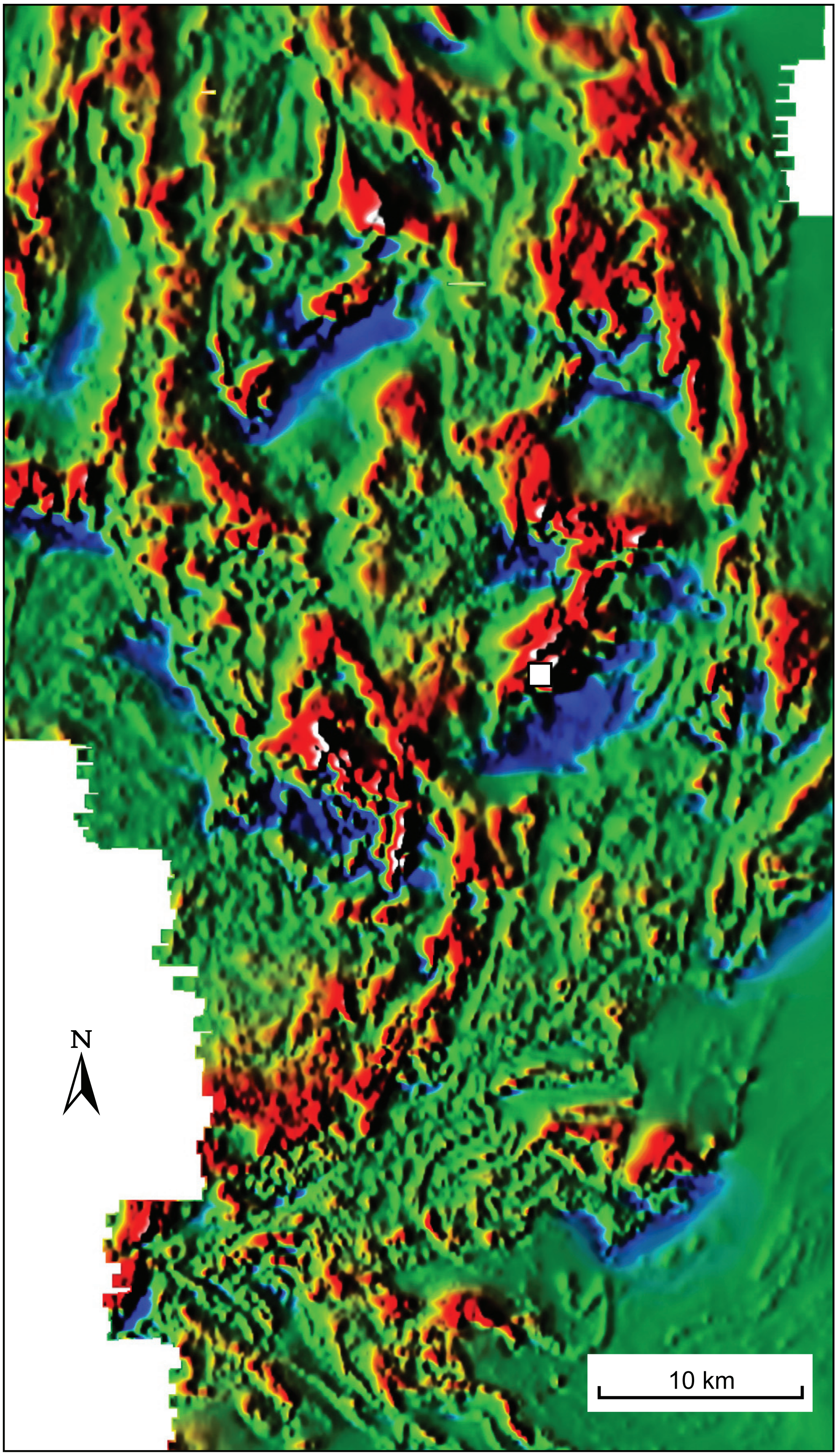

Figure 2: Image of the aeromagnetic data (reduced to pole) of part of the Eastern Fold Belt, Mount Isa Inlier. The magnetically "active" nature of the domain containing the Ernest Henry deposit is clearly evident. The location of the Ernest Henry deposit is shown as a white square.

Oliver (1995) mapped the "late" (D_2-fabric overprinting) albite alteration in the major fault zones within the Mary Kathleen belt. Observations by the writer also show that comparable late albite also occurs in a number of major faults in the Eastern Fold Belt. Aeromagnetic data, however, can also be used to indicate location of altered faults hosting late albite in the districts containing sodic alteration. The data from the Eastern Fold Belt show that such late albite is associated with distinct "valleys" or linear, short wavelength magnetic "lows" in the aeromagnetic signatures. Along the Cloncurry Fault, for example, "valleys" in the aeromagnetic signatures coincide with late, pale pink (haematite-pigmented) albite and other late alteration mineral assemblages. The aeromagnetic data (Fig. 4) also clearly support the observation that the late alteration within the Cloncurry Fault is more oxidised that the enclosing host succession. In at least two other iron oxide copper (-gold) mineralised districts, aeromagnetic data also show that some of the major faults in the areas of sodic alteration contain more oxidised alteration mineral suites than those comprising the alteration in the adjacent succession.

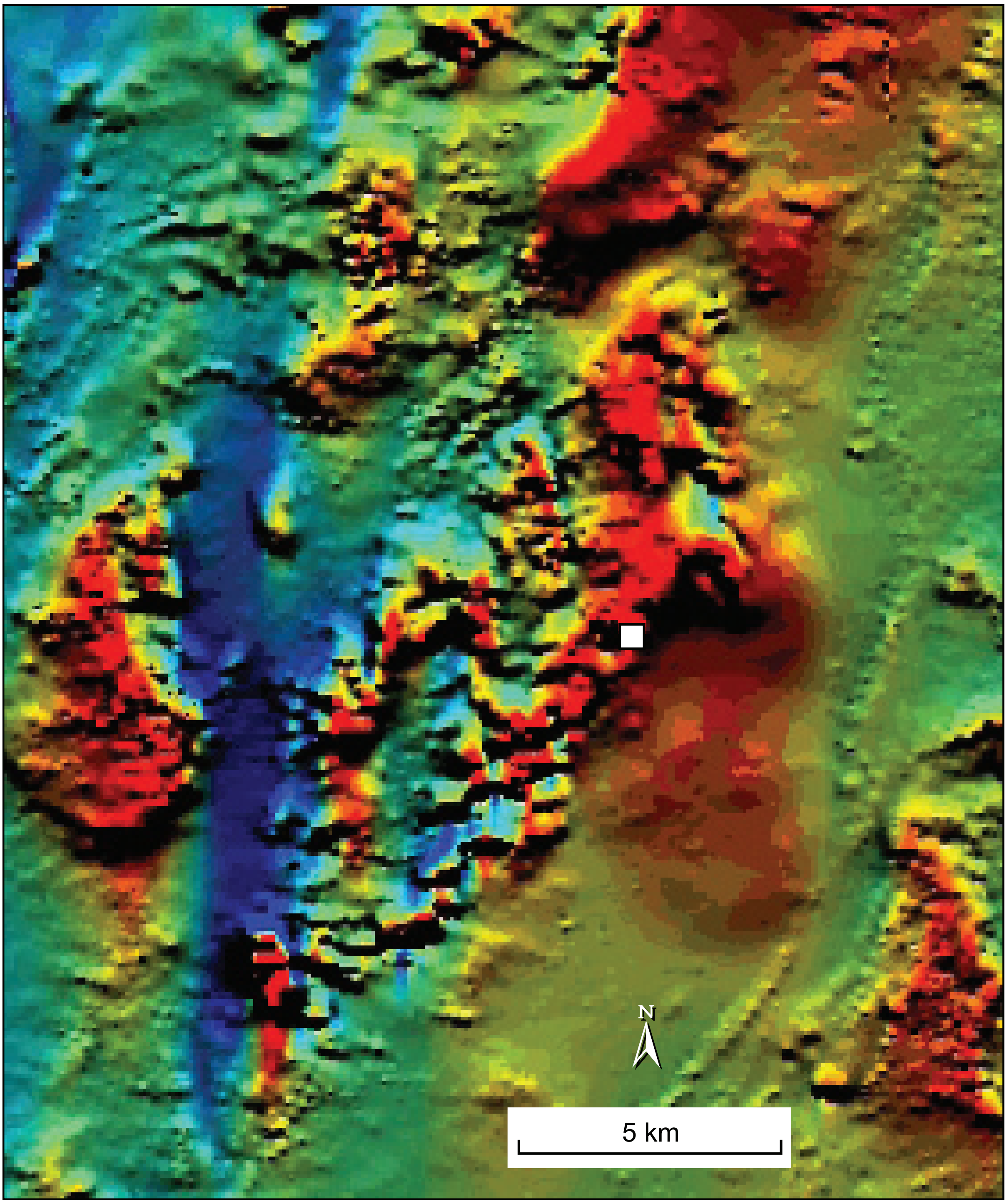

Figure 3: Image of the aeromagnetic data (reduced to pole) of part of the Candelaria area, central Chile. The magnetically "active" nature of the domain containing the Candelaria deposit (shown as a white square) is clearly evident. The margin of the Atacama Batholith, approximately 4 km west of the Candelaria deposit is overprinted by the (magnetically active) sodic alteration in which the Candelaria deposit is embedded. Mapping, is, however, required to confirm this interpretation.

Figure 4: Image of the aeromagnetic data (total magnetic intensity) of part of Eastern Fold Belt, Mt Isa Inlier. The Cloncurry Fault, a major strike fault traverses the area shown, and is evident as a discrete NNW-trending "magnetic valley" extending from the northern to southern limits of the image. The magnetic "valleys" are highlighted with the arrows. The image shows an area approximately 80 km wide.

The occurrence of relatively more oxidised sodic alteration assemblages in the major faults in the districts which host iron oxide copper (-gold) deposits is a point of fundamental importance to models of genesis of iron oxide copper (-gold) deposits, and is addressed below.

The compilations presented in Table 2 also show that large deposits are hosted either by rocks that initially contained abundant non-sulphide ferrous iron minerals, or abundant feldspar. The largest of the deposits, Olympic Dam, occurs within feldspar-rich host rocks, within ore-proximal feldspar destructive alteration being characteristic. The feldspar destructive alteration, most pronounced in the Olympic Dam deposit (Reeve *et al.*, 1990), is evidenced principally by occurrence of sericite. The "barren" iron deposits also display an association with feldspar-rich host rocks, although in most of the deposits, evidence for ore-proximal, intense feldspar-destructive alteration comparable to that seen at Olympic Dam is absent.

Iron oxide copper (-gold) deposits display a transition from magnetite-or haematite-rich end members to sulphide-rich types, or iron sulphide copper (-gold) deposits. Some important characteristics of the latter end member style, summarised in part by Williams (1998; 1999), are listed in Table 3. The deposits usually comprise abundant pyrrhotite or pyrite, and chalcopyrite, but some may also contain magnetite, or display a close association with discrete magnetite bodies, for example, Eloise. There are several of these deposits within the Eastern Fold Belt, Mt Isa Inlier, but they are all small (Fig. 5).

The first six deposits listed in Table 3 are associated with sodic alteration and ore-proximal potassic alteration that overprints the ductile deformation (D_2) fabrics of the host rocks. The alteration in the district containing the Mt Isa copper deposit, however, is restricted to faults, lithlogical contacts, and to metabasalt flow tops. It is more calcic, comprising epidote, sphene, and chlorite rather than abundant albite, although the nature of the alteration along the Mt Isa Fault and other major faults in the vicinity of the copper mineralisation is not known to the writer. The calcic alteration is characterised by copper depletion of the meta-basalt (Hannan *et al.*, 1993; Henirich *et al.*, 1993; 1995).

Geochronology of the iron sulphide copper (-gold) deposits, for example, Mt Elliott, Maronan, Eloise, and Mt Isa, shows that they are coeval with the iron oxide copper (-gold) deposits (Perkins and Wyborn, 1998; Perkins *et al.*, 1999). The largest of the iron sulphide-copper (-gold) deposits, the Mt Isa Copper, and the Gunpowder deposits, however, occur in the Western Fold Belt, Mt Isa Inlier, which does not host iron oxide copper (-gold) deposits. The Mt Isa deposit is, nevertheless, broadly coeval with the iron oxide copper (-gold) deposits in the Eastern Fold Belt, Mt Isa Inlier, with a likely age of 1505-1523 Ma (Heinrich *et al.*, 1993; 1995; Perkins *et al.*, 1999).

The iron sulphide copper (-gold) deposits in the Eastern Fold belt also display a regional, but not a specific local association with the late granites here. The largest iron sulphide copper (-gold) deposits, which are in the Western Fold Belt, do ***not*** display any evident local or distant association with the late granites however.

The iron sulphide copper (-gold) deposits are usually hosted by, or are closely associated with, graphitic or carbonaceous host rocks that comprise parts of locally more reduced "domains" within the host district. The association is pronounced for the Mt Isa, Gunpowder, Mt Dore, and Greenmount deposits, but it is not clear for the Eloise deposit. Here, carbon-bearing rocks have not been reported, but the nature of the succession, the Fullarton River Group, immediately east of the mineralisation is not well defined because of concealment by a shallow cover of younger sediments.

The carbonaceous host successions which host the iron sulphide copper (-gold) deposits form discrete "domains" within the Eastern Fold Belt, and, particularly within the Western Fold Belt. These domains contrast with the relatively more oxidised enclosing domains that are

Table 3

Deposit, Size & Location	Host Succession Composition	Ore Host Composition	Key Sources
Greenmount: 3.6 Mt, 1.5% Cu, 0.8 ppm Au; Eastern Fold Belt, Mt Isa Inlier	Calc-silicate granofels (base) (dolomitic and scapolite-bearing limestone), arenite, laminated graphitic schist (siltstone)	Graphitic schist (laminated siltstone)	Krcmarov and Stewart (1998)
Mt Isa Copper: 255 Mt, 3.3% Cu; Western Fold Belt, Mt Isa Inlier	(Meta) basalt, quartzite (base), carbonaceous and pyrite-bearing silty dolomite	Carbonaceous and pyritic silty dolomite	Hannan *et al.* (1993); Heinrich *et al.*, 1993; 1995); Perkins *et al.* (1999)
Mammoth-Esperanza: 14 Mt 4.5% Cu; Western Fold Belt	Amphibole-plagioclase granofels (amphibolites), quartzite (base); carbonaceous silty dolomite	Carbonaceous and pyritic siltstone	Van Dijk (1991); Richardson and Moy (1998)
Eloise: 3.2 Mt 5.8% Cu, 1.5 ppm Au: Eastern Fold Belt	(Meta) basalt, quartzite, meta arkose; quartz-biotite schist, quartz muscovite schist	Quartzite and quartz-biotite schist	Baker and Laing (1998) Williams (1998)
Mt Dore: 26 Mt 1.1% Cu: Eastern Fold Belt	(Meta) basalt, calc-silicate granofels, marble, quartz muscovite schist, graphitic phyllite	Carbonaceous siltstone	Van Dijk (1991); Beardsmore (1992); Williams (1998)
El Soldado: 70 Mt 1.8% Cu: Mesozoic Volcano-sedimentary succession, Chile.	Pyrrhotite-bearing and carbonaceous calcareous siltstone (base); andesite, intermediate sills and dykes	Andesite	Ruge (1985); Toro (1985)

characterised by ubiquitous magnetite or haematite or both, and a general absence of carbonaceous or graphitic rocks. These relatively reduced domains ***do not*** host the iron oxide copper (-gold) deposits: rather they host the iron sulphide copper (-gold) deposits, or are immediately adjacent to them. However, the late granites and late sodic alteration in the Eastern Fold Belt occur in all of the domains noted here.

The El Soldado deposit has been included here because it displays characteristics transitional between iron oxide copper (-gold) deposits and iron sulphide copper (-gold) deposits. It differs in not being associated with abundant magnetite or haematite, or pyrite or pyrrhotite, but it occurs within andesites displaying haematite-pigmented albite alteration within and above the mineralisation. Mineralisation, which is zoned at depth from chalcopyrite to chalcocite in the upper parts of the ore system, is restricted to the vicinity of steeply dipping faults that intersect an adjacent carbonaceous and calcareous siltstone that underlies the andesite hosts of the mineralisation. The siltstone also contains pyrrhotite and pyrite. A schematic section of the mineralisation is shown in Fig. 6.

El Soldado can be seen to occur near the boundary of an oxidised, that is haematite-stable "domain", and a reduced, that is carbon-stable and sulphide-sulphur stable "domain". It has much smaller iron contents that the other deposit styles considered here.

The last type of deposit in the spectrum of ore types to be considered here is the Mantos Blancos deposit. Summary details of the Mantos Blancos deposit are shown in Table 4 and its location in relation to the Candelaria deposit in illustrated in Fig. 7. A schematic section of the deposit is shown in Fig. 8. Mantos Blancos is characterised by a very close association with intense sodic alteration, consisting of albite, quartz, calcite and haematite. Mineralisation displays zonation from chalcocite in the upper and inner parts of the ore deposits here, through bornite to chalcopyrite, with the chalcocite bordering the haematite-pigmented sodic alteration (Chavez, 1983). Mantos Blancos occurs within a predominantly "oxidised" domain, with evidence for carbonaceous rocks absent. However, the deposit can be seen to occur on or near a boundary between "domains" of contrasting oxidation states: haematite-stable above the ore; and ferrous iron

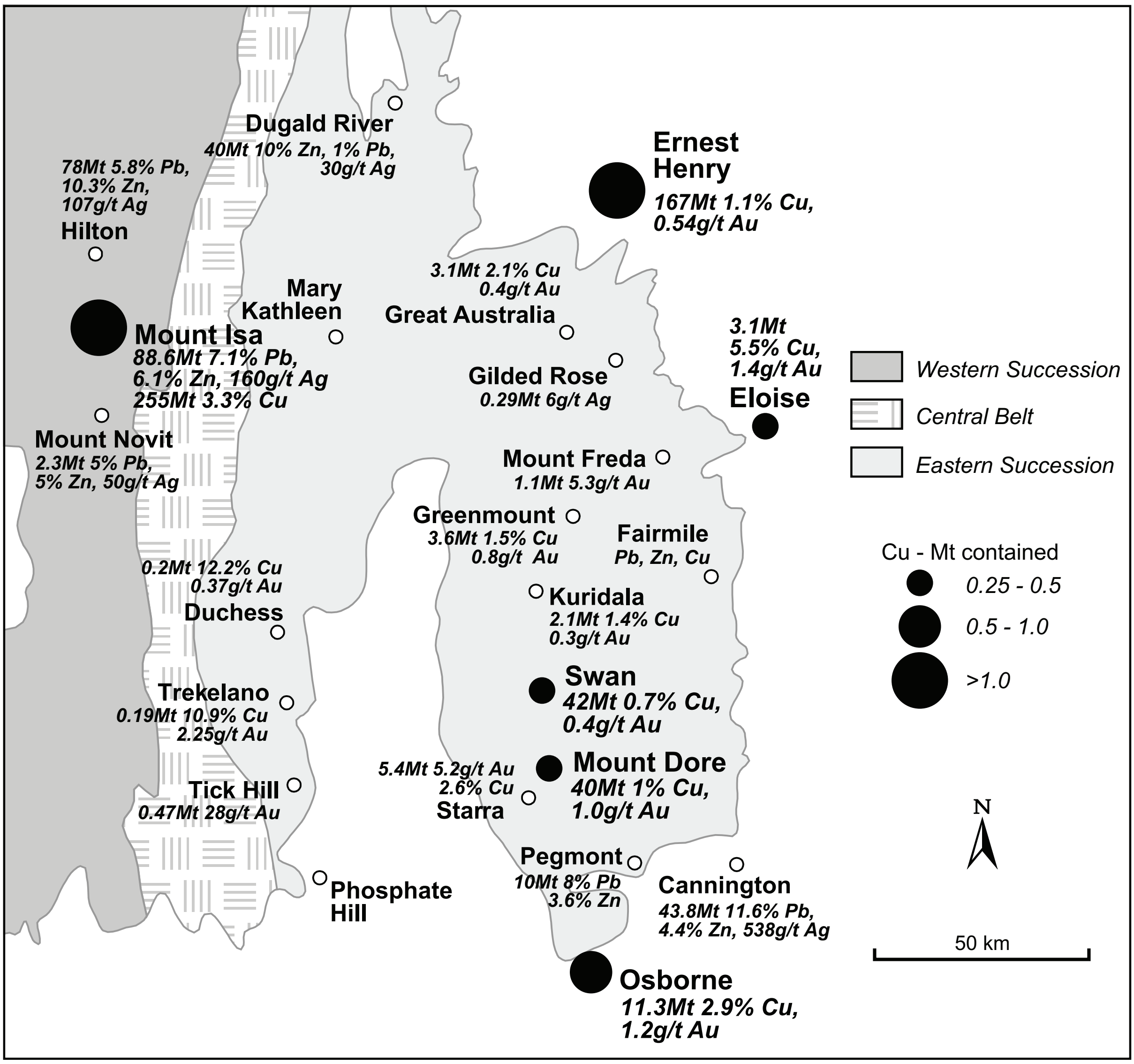

Figure 5: Location of the principal iron oxide copper (-gold) and iron sulphide copper (-gold) deposits of the Mount Isa Inlier.

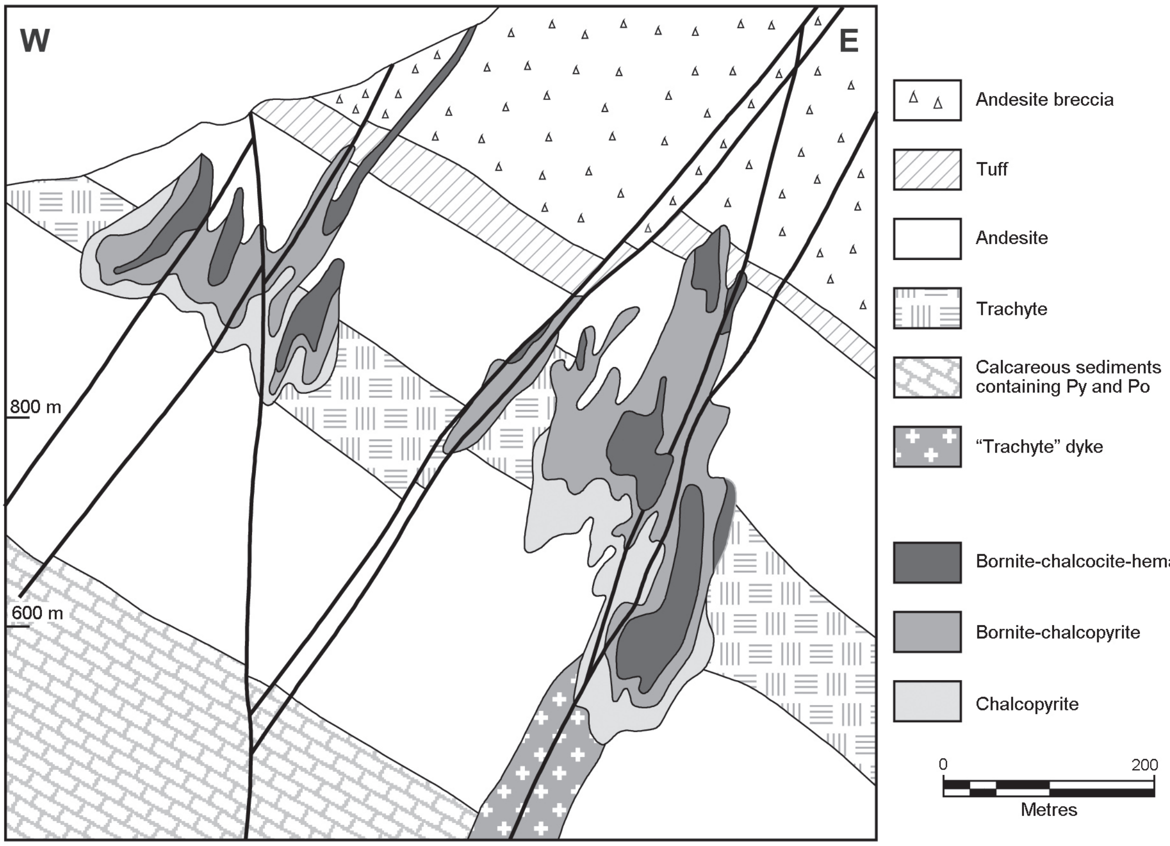

Figure 6: A schematic section of the El Soldado deposit, Chile. The calcareous sediments containing the pyrite (py) and pyrrhotite (po) are carbonaceous. The host andesite displays alteration to haematitepigmented albite. Note the zonation of the mineralisation in relation to proximity to the calcareous sediments. The El Soldado deposit represents an ore type transitional between iron oxide copper (-gold) deposits and iron sulphide copper (-gold) deposits. Section modified from Boric (1997).

(and magnetite)-stable below the ore. Aeromagnetic data (unpub.) from the Mantos Blancos district shows that the andesites in the vicinity of the orebody contain magnetite. Whether this is a component of the alteration, or is a primary component of the andesite is not known. Unlike iron oxide copper (-gold) deposits, Mantos Blancos, does not contain abundant iron oxide. However, the sulphide zonation and its relation to haematite-bearing rocks is very similar to that of the Olympic Dam deposit (Reeve *et al.* 1990), and, particularly, to the El Soldado deposit.

The Mantos Blancos deposit displays no clear spatial relation with coeval granites or other intrusives (Tassinari *et al.*, 1993). Like the El Sodado deposit, it displays a clear relation with haematite-pigmented sodic alteration, and occurs close to or on a boundary between local "domains" displaying differing oxidation states.

Genesis of Iron Oxide Copper (-Gold) and Related Ore Types.

Heinrich *et al.* (1993, 1995) presented a model in which the Mt Isa copper orebody was generated through the interaction of relatively oxidised hydrothermal fluids with carbon- and pyrite-bearing rocks of the Urquhart Shale, hosts of the Mt Isa copper deposits. Using Br/Cl rations to track the sources of the hydrothermal fluids, they concluded that the hydrothermal fluids were ultimately derived from evolved, bitterns-type evaporitic brines originally stored within overlying basins or the near-surface environment. Heinrich (2000 (unpub.)), following observations by others, noted, however, that mass balance considerations indicate a second, more reduced hydrothermal fluid sourced within the Urquhart Shale also likely contributed to the ore forming system here. One of the key elements of the model, however, is that surface-derived brines played a key role in the genesis of the Mt Isa copper deposit.

Haynes *et al.* (1993; 1995) in a study of the Olympic Dam deposit, also concluded that the major component of the hydrothermal ore forming system at Olympic Dam, and probably in other iron oxide copper (-gold) deposits, was ultimately sourced from a saline playa lake in an extensional tectonic setting. However, fluid mixing in repeated hydrothermal events coupled with wall rock reaction (hydrogen ion consumption), rather than fluid-rock reaction alone as proposed by Heinrich et al (1995) for the Mt Isa deposit, operated during ore genesis at Olympic Dam.

The difference in mineralogy between the iron oxide copper (-gold) deposits, and the iron sulphide copper (-gold) deposits can be attributed in part to the gross oxidation state differences of the respective ore host successions, and the nature of the oxidation state boundaries within the host succession. In each end member, an oxidised hydrothermal fluid is involved in ore formation, but the mechanisms of sulphide precipitation are determined by the oxidation state of the host rocks, or by the oxidation state of another interacting hydrothermal fluid or by both of these. The pH buffering capacity of the host rocks plays a very important role in the ore precipitation scenarios.

Copper sulphide precipitation in the Mt Isa copper ore forming system, and other iron sulphide copper (-gold) deposits likely occurred through reduction of a relatively oxidised hydrothermal fluid, either by fluid-rock reaction, or by fluid mixing, or by both processes (see for example, Heinrich *et al.* 1995). The reduction can be represented by reactions of the type:

$$4Cu^+ + 2SO_4^{--} + C + 2CH_4 + 4FeS_2 \rightarrow 2HCO_3^- + CO_2 + 2H^+ + 2H_2S + 4CuFeS_2$$

The reaction illustrates coupled reduction of sulphate, and oxidation of carbon in carbonaceous material and methane. The iron in the chalcopyrite in this particular reaction scheme is derived from the pre-existing pyrite. Acid produced in the reaction would be neutralised by dissolution of the host carbonate.

Copper sulphide precipitation in the Olympic Dam and other iron oxide copper (-gold) ore forming systems can be represented by the reaction:

$$2Cu^+ + SO_4^{--} + 8H_2O + 8Fe^{++} \rightarrow 4Fe_2O_3 + 16H^+ + Cu_2S$$

(Haynes *et al.* 1993; 1995)

Here, there is a coupled reduction of sulphate and oxidation of ferrous iron occurring on fluid mixing. The ferric iron generated precipitates in haematite (or magnetite). The reaction generates abundant hydrogen ion, which is

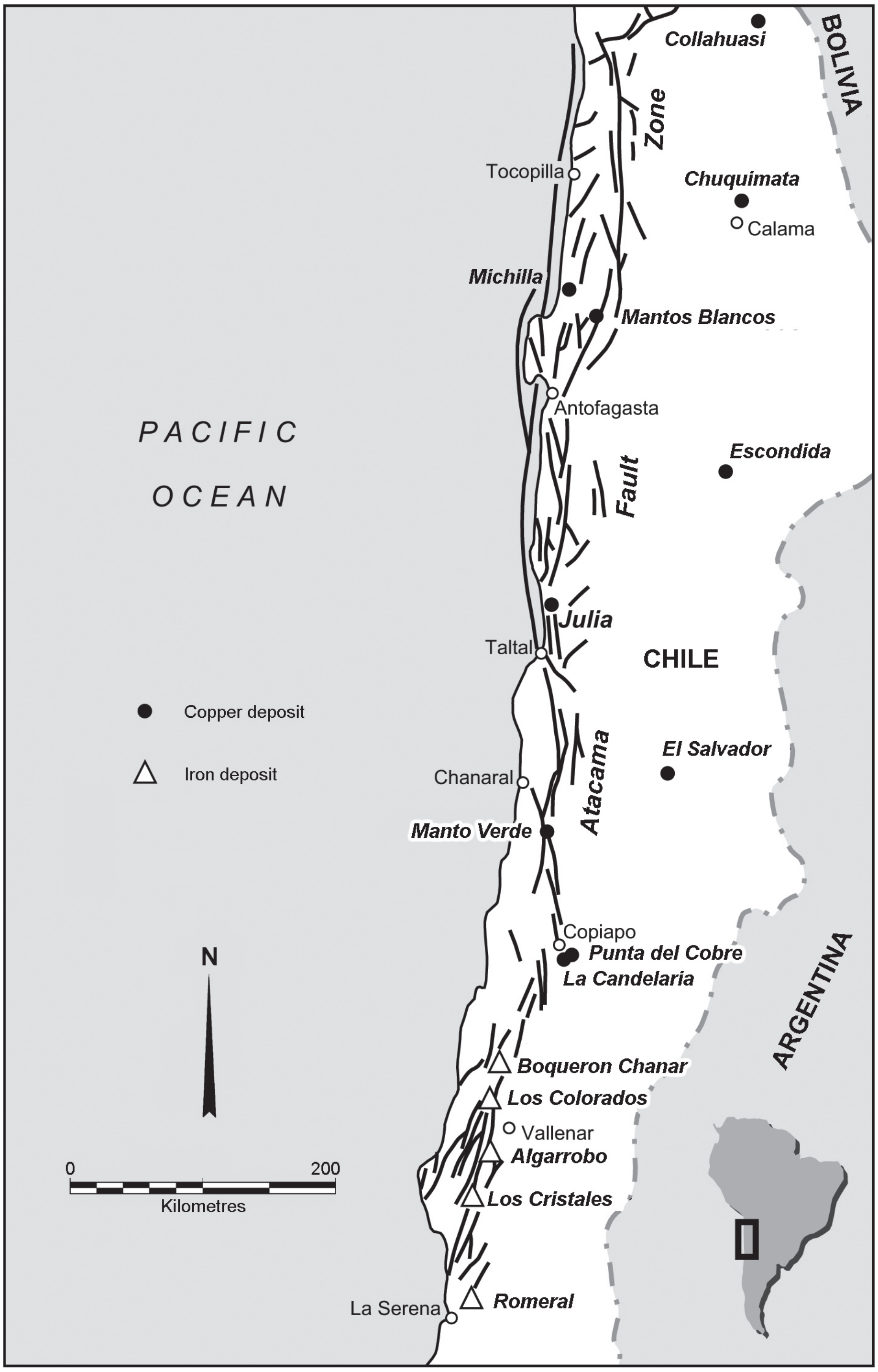

Figure 7: The iron and copper deposits of Chile, showing the location of the Mantos Blancos and Candelaria deposits in relation to the "iron belt" of Chile (after Vila *et al.* 1996 and Espinhoza *et al.*1996).

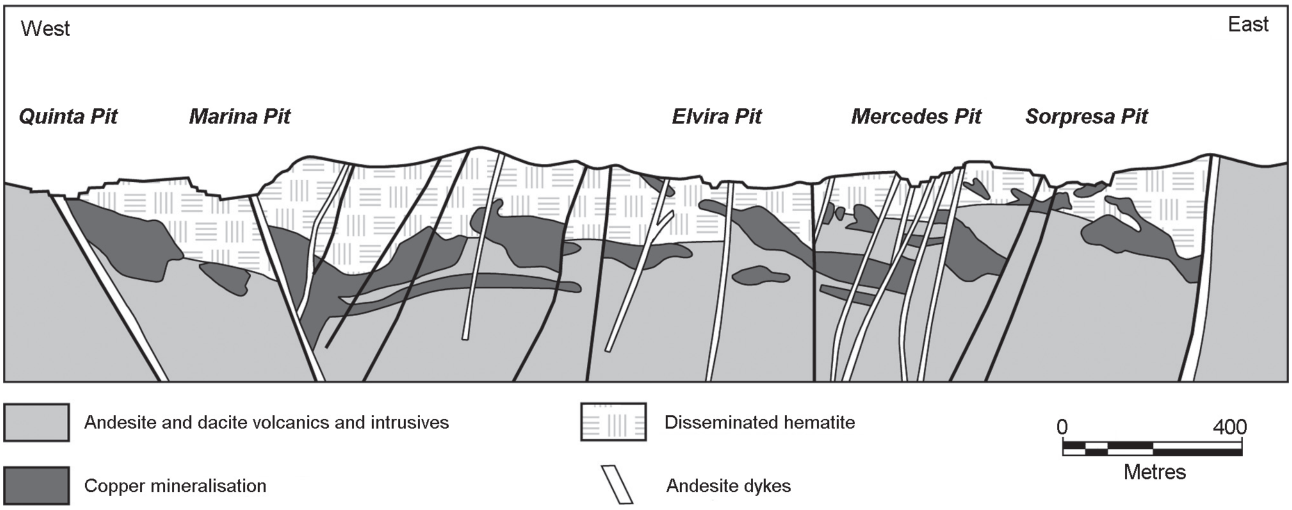

Figure 8: A schematic section through the Mantos Blancos deposit illustrating the haematite alteration in relation to the mineralisation (after Ramirez, 1993, unpub.). The zone of haematite alteration comprises albite, quartz and carbonate. Hematite is not abundant, rather the haematite and albite altered rocks are hematite pigmented. The altered zone displays pronounced depletion of the volcanic precursor in copper, lead and zinc (unpublished

neutralised by hydrolysis of feldspar. Feldspar hydrolysis drives the reaction to completion. Without a sink for hydrogen ion, the reaction does not proceed to completion (see Haynes *et al.*, 1995).

Both of the reactions listed here represent thermochemical sulphate reduction: one driven by the reduction of sulphate by methane, carbon and pyrite; and the other by reduction of sulphate by ferrous iron. Either reaction can occur through fluid mixing, (e.g. Olympic Dam), or through fluid-rock interaction (e.g. Mt Isa). However, the reduction of sulphate (in the hydrothermal fluid) can also occur through fluid-rock reaction involving ferrous iron, for example, with rocks containing ferrous-iron minerals. Magnetite or haematite or both would replace ferrous-iron minerals in the host rock, with co-precipitation of copper sulphides.

The simple hypotheses proposed here and formerly give some indication why iron oxide copper (-gold) deposits are hosted by feldspar-rich rocks, within feldspar-destructive haloes, for example, Olympic Dam, or within rocks with abundant initial ferrous iron, such as silicate or carbonate iron formations, for example, Salobo or Starra. The reactions written here also indicate that the hydrothermal fluids need not be acid prior to fluid mixing or prior to rock interaction: the acid is generated as a result of iron oxide or sulphide precipitation.

Deposits such as Mantos Blancos may have originated similarly: by the reduction of sulphate by magnetite in a precursor andesite, with the mineralisation being deposited on the oxidation state boundary represented by a change from haematite stable to magnetite stable assemblages. The occurrence of haematite and albite-altered rocks above the mineralisation, and an absence of abundant hydrothermal quartz within the alteration, suggests that the sulphate- and copper-transporting hydrothermal fluid here flowed ***downwards.*** The fluid source is invoked to be an overlying saline lake, with ore precipitation occurring in the prograde P-T part of a hydrothermal cell, as illustrated schematically in Fig. 9 (see also Tassinari *et al.*, 1993, for discussions on fluid sources). The metal depleted nature, the abundance of albite, its haematite-pigmented nature, and the absence of K-feldspar and sericite in the upper parts of the alteration system at Mantos Blancos support such a conclusion. The

Table 4: Characteristics of the Mantos Blancos deposit.

Deposit, Size, Age and Location	Host Succession Composition and Alteration	Mineralisation, Local Alteration and Ore Host Composition	Key Sources
Mantos Blancos; 331 Mt. 2.1% Cu; 100-133 Ma; Central Chile	Andesite, dacite, rhyolite; some reddish sandstone; limestone; mafic and intermediate sills and dykes; granodiorite; quartz diorite; age of volcanic host sequence ~ 175 Ma; regional sodic alteration of albite, chlorite, epidote, magnetite, haematite, actinolite, calcite, titanite; locally very intense albite. Age of alteration and mineralisation ~ 150 Ma.	Mineralisation: thread-like, to stubby veins within vein arrays, with some disseminated; chalcocite, bornite, chalcopyrite; zoned from chalcocite (upper and inner parts of individual ore bodies) to chalcopyrite (lower and outer parts of individual ore bodies). Alteration: intense texture-preserving albite alteration, with specular haematite disseminations and some veinlets, calcite, sericite (above ore), grading downwards to local sericite, albite, chlorite and deeper epidote. Hydrothermal quartz minor or absent. Hosts: andesite, rhyodacite, rhyolite; thin volcaniclastic sandstone, thin andesite dykes and dacite sills (post ore).	Chavez (1983), Tassinari *et al.* (1993); Espinhoza *et al.* (1996); Vila *et al.* (1996)

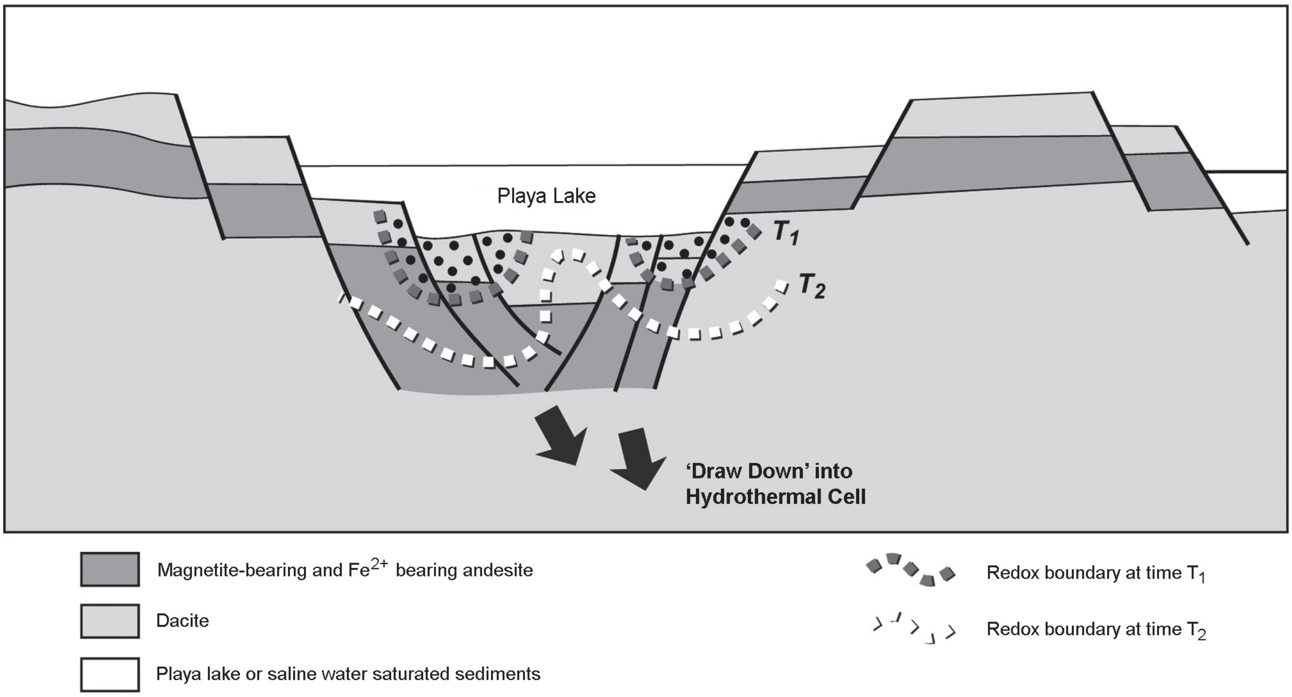

Figure 9: A speculative ore genesis scenario for the Mantos Blancos deposit. The deposit is within the "draw-down" part of a hydrothermal cell fed by saline water from an overlying playa lake. Sulphide precipitation accompanies magnetite oxidation and sulphate reduction (see text). The redoxboundary moves downward as the fluid inflow continues, resulting in a "roll-front" type of enrichment. Note analogies with the proposed genesis of the Olympic Dam deposit where an ore oxidised, and metal-transporting hydrothermal fluid is thought to have existed in the upper levels of the ore-forming system, and within an overlying saline lake within a volcanic rift valley setting (Haynes ***et al.***, 1995).

reader is referred to Dilles and Einaudi (1992), for more information on the relations of albite and K-feldspar to the prograde and retrograde P-T parts of hydrothermal fluid flow paths.

The ***unique*** association of the deposits considered here with regional sodic, and in one case, calcic, alteration suggests therefore, that all of them formed in settings which once contained surface or near-surface reservoirs of saline waters. This hypothesis is further supported by (a) the coeval or near-coeval late albite alteration and ore-proximal alteration in at least some of the iron oxide copper (-gold) deposits in the Eastern Fold Belt; (b) the relatively more oxidised late albite alteration within the major fault zones within at least some of the iron oxide copper (-gold) mineralised; and (c) Br/Cl ratios of the Mt Isa copper deposit permissively indicating an evolved evaporitic brine source.

The more oxidised nature of the late sodic alteration is very difficult to explain by metamorphic dewatering hypotheses because of the oxidation state contrast with the host successions of the major faults. The broadly coeval nature of the alteration and the "late" granites also indicates that the thermal event responsible for production of the granites also drove the hydrothermal cells sourcing the saline waters from the surface.

The saline waters were hosted by overlying extensional, transtensional or foreland basins. Evidence supporting the existence of such basins within the Eastern Fold Belt is provided by the age of the Qamby Conglomerate. It is a basal, heterolithic conglomerate occurring in a small remnant basin bounded by one of the major faults within the Eastern Fold Belt. The conglomerate has a paleomagnetic age of 1500 Ma (Idnurm and Wyborn, 1998).

A summary of interpretations and observations on the likely relations between host succession oxidation state, composition, and starter fluid compositions are illustrated in Table 5.

The controls exerted by hydrothermal starter fluid compositions on metal ratios and metal contents of the iron oxide copper (-gold) deposits are not specifically examined in Table 5. However, oxidation state variation coupled with source rock variation, for example, mafic igneous source vs felsic igneous source is an important control, as illustrated in Haynes *et al.* (1995). Hydrothermal fluids with oxidation states in manganese-oxide and haematite-stable regions, at pH values constrained by rocks containing feldspar and quartz, will tend to contain more gold, and uranium, and less copper, lead and zinc. Those with oxidation states below the manganese oxide stable regions but within the haematite-stable region will contain more copper and less uranium and gold. Hydrothermal fluids derived from provinces dominated by rocks of a felsic igneous parentage will contain more uranium and lead and lesser concentration of copper, and those from provinces dominated by mafic rocks more copper and less uranium and lead. It is through these observations that simple explanations can be made for the relatively uranium-rich nature of the Olympic Dam deposit, and the uranium-poor nature of deposits such as the Ernest Henry and Mt Isa copper deposits. A detailed examination of the oxidation state and source rock control on relevant hydrothermal fluids is in Haynes *et al.* (1995).

The pH variation is not likely to be a significant control, as pH is not likely vary within wide limits because of the ubiquitous occurrence of feldspar in host successions.

The other important variable not explicitly considered here is temperature. As has been demonstrated many times, ferrous iron and gold solubility (as chloride complexes) is strongly dependent on hydrothermal fluid pH, oxidation state, temperature, and salinity, showing a strong increase with temperature (for example, Crerar *et al.*, 1978; Yishan *et al.*, 1989; Fein *et al.*, 1992; Seyfried and Ding, 1993). The low iron and gold contents of sediment-hosted stratiform copper deposits, and other lower-temperature redox-boundary deposits such as Mantos Blancos and El Soldado, likely result from relatively low temperatures and high oxidation state of the principal hydrothermal fluid responsible for ore genesis.

A "matrix" illustrating common elements in genesis of the ore types considered here could be constructed by placing the ore-associated features noted here together. The important variables in such a matrix would be (a) the oxidation state of the host succession, and its internal variation; (b) host succession lithological composition, for example, whether it is mafic or felsic; (c) "redox" boundary contrast between individual "domains" comprising the host succession; (d) depth (or temperature) of formation; and (e) fluid-mixing vs fluid-rock controls in ore precipitation. It is emphasised that the regional sodic alteration will not be a variable: it must be present for all of the ore types to occur, although for the Mt Isa copper deposit, it may be more calcic. A consideration of the factors here, together with other factors not described here, for example, structure, will give a more direct predictor of the ore type than consideration of factors such as the composition and distribution of the "late" granites. The granites are, however, important, in that they indicate the existence of the "late" thermal event, although they are not essential, as the sodic alteration will also indicate such an event. The granites are also not regarded as being essential because of their absence from the parts of the Western Fold Belt which contain the largest known examples of iron sulphide copper (-gold) deposits.

Table 5

Province Character	Host Rock Character	Alteration Character, Dominant Hydrothermal Fluid Source	Ore Type
Magnetite-stable. Ubiquitous: hematite-stable rocks minor or absent	Abundant feldspar	Sodic and sulphate or chloride: "deep": albite, scapolite, actinolite, magnetite: **Saline: from overlying basin.**	Iron oxide copper (-gold), magnetite-bearing; some to moderately abundant hematite: e.g., Ernest Henry, Candelaria
Magnetite-stable. Ubiquitous: hematite-stable rocks minor or absent	Abundant feldspar	Sodic and sulphate or chloride: albite, hematite, chlorite, K-feldspar, phyllosilicates, carbonate: "shallow": **Saline: from overlying basin.**	Iron oxide copper (-gold), hematite-bearing: some to moderately abundant magnetite: e.g., Olympic Dam, Punta del Cobre
Magnetite-stable. Ubiquitous: hematite-stable rocks minor or absent	Abundant ferrous iron minerals	Sodic and sulphate or chloride: "deep": albite, scapolite, actinolite, magnetite: **Saline: from overlying basin**	Iron oxide copper (-gold), magnetite-bearing; some to moderately abundant hematite: e.g., Salobo, Starra
Mixed, but discrete domains: magnetite-stable and carbon-pyrite-(or pyrrhotite)-stable	Variable: carbon and pyrite-bearing; carbonate containing carbon-and pyrite most appropriate	Sodic and sulphate or chloride: "deep": albite, scapolite, actinolite: **Saline: from overlying basin**	Iron sulphide copper gold: e.g., Eloise, Greenmount, Kuridala
Mixed, but discrete domains: magnetite-stable and carbon-pyrite-(or pyrrhotite)-stable	Variable: carbon and pyrite-bearing; carbonate containing carbon-and pyrite most appropriate	Probably mixed calcic and sodic, but sodic nature needs confirmation: "intermediate depth": (e.g., along Mt Isa Fault): albite (?) epidote, chlorite, carbonate: **Saline: from overlying basin**	Iron sulphide copper gold: e.g., Mt Isa, Gunpowder
Mixed but discrete domains: hematite-stable and carbon-pyrite- (or pyrrhotite)-stable	Abundant feldspar	Sodic: "shallow": hematite-pigmented albite, carbonate, chlorite: **Saline: from overlying basin**	Iron oxide copper (-gold), low iron: e.g., El Soldado
Mixed but discrete domains: hematite- and magnetite-stable	Abundant feldspar	Sodic: "shallow": hematite-pigmented albite, carbonate, chlorite: **Saline: from overlying basin**	Iron oxide copper (-gold), low iron: e.g., Mantos Blancos
Mixed but discrete domains: hematite- and carbon-stable	Variable: carbon and pyrite-bearing; carbonate containing carbon-and pyrite most appropriate	Sodic: "shallow": hematite-pigmented albite, carbonate, illitic clays: **Saline: from host basin**	Iron sulphide-copper peposits: low iron: e.g., Kupferschiefer, Zambian Copperbelt.
Dominant carbon-pyrite-stable OR mixed with: ferrous iron mineral stable; none or very minor magnetite- or hematite-stable.	Highly variable; some preference for magnetite- or ferrous iron mineral – bearing.	Sodic: "deep" albite, with chlorite and carbonate: **Saline to dilute: surface or near-surface "reservoir"**	Mesothermal gold: e.g., Muruntau, Homestake, Tanami, Bendigo, Gympie, Cerro Pelada, and many others.

In Table 5 there is a hint that gross oxidation state of the host successions also determines the presence or absence of mesothermal gold deposits. A survey of the literature indeed reveals that this is the case. However, the implications of such an empirical relationship, for example, its incompatibility with hypotheses of deep crustal metamorphic fluid dewatering, and its relations to the absence of iron oxide copper gold deposits in similarly reduced host successions are beyond the scope of this paper.

The isotope systematics of the hydrothermal systems responsible for the genesis of the deposits considered here indicate a provinciality of signature for fluid sources, with no specific source rock indicated. Such a signature also characterises mesothermal gold deposits. As pointed out by Ridley (2000), if hydrothermal fluid flow paths are long, as they were for many mesothermal gold deposits, then the signatures reflect the later and last rocks along the fluid flow paths which buffered the hydrothermal fluids. The giant sodic alteration systems in the provinces which host iron oxide copper (-gold) and iron sulphide copper gold deposits also indicate that hydrothermal fluid flow paths were likely to have been long, with the consequence that isotope systematics will generate the same ambiguity in interpretation.

Precisely similar conclusions apply to hydrothermal fluid compositions, including the controls on their salinities. Apart from the obvious controls on fluid salinities - host succession evaporites, surface saline water sources, and gas phase separation - exchange of water from the hydrothermal fluids with anhydrous rocks can be a cause. For example, hydrothermal fluids traversing sub-solidus granites ($T < 700^{o}C$) under anhydrous, rock-buffered conditions will also be driven to high fluid salinities because of exchange of water through precipitation of hydrous phases such as biotite and actinolite along the fluid flow paths (M H Reed, pers. comm. 1995). The resulting hydrothermal fluid will be indistinguishable from an "orthomagmatic" fluid.

It is suggested that fluid flow paths be traced by mapping Na/K and Br/Cl ratios in the sodic alteration systems. These will provide a stronger indication of hydrothermal fluid origins, as Br and Cl tend not to fractionate during water-rock interaction, and as Na/K ratios will give an indication of fluid flow along prograde P-T paths (albite and occurrence of haematite) or retrograde P-T paths (K-feldspar or sericite) (for example, Dilles and Einaudi, 1992). Fluid flow path mapping to define the retrograde and prograde parts of the fluid flow paths, particularly along the major and second order faults in the host districts, will help to define targets for blind or poorly exposed deposits of the type sought here.

Acknowledgements

The writer acknowledges the generous help given by many former and present colleagues, particularly Frank Bunting and Anthony O'Sullivan, in improving and refining the ideas described here. The assistance of geophysical colleagues in particular in understanding potential field data has been of great benefit in generation of the ideas.

The generous assistance provided by Bob Melsom in constructing the diagrams, is acknowledged with gratitude. Sue Buckley, whose efforts in providing numerous copies of papers in the research referenced here, is also acknowledged with thanks. BHP are thanked for providing kind permission to publish the renditions of the aeromagnetic data illustrated here.

Fugro Airborne Survey SA, of Enrique Foster Sur 153, Las Condes, Santiago, Chile are thanked for their kind permission to publish the aeromagnetic image of the Candelaria area illustrated in this paper.

References

Adshead, N.D., 1993 - Mineralization and alteration styles at the Osborne Deposit, NW Queensland: *In*: Mid- to Lower-crustal Metamorphism and Fluids Conference, Mount Isa, 1993: *Geological Society of Australia – Abstracts*, v. 35, pp. 52-53.

Barton, M, Marikos, M.A. and Johnson, D.A., 1993 - A comparison of felsic and mafic Fe-P (REE-Cu) Deposits; Geological Society of America, North-Central Section, 27th Annual Meeting. Rolla, MO, U.S., March 29-30, 1993, *Geological Society of America. Abstracts with Programs*, v. 25, p. 5.

Barton, M. and Johnson, D.A., 1996 - Evaporitic-source model for igneous related Fe oxide-(REE-Cu-Au-U) mineralization: *Geology*, v. 24, pp. 259-262.

Bell, C.M., 1989 - Saline lake carbonates within an Upper Jurassic-Lower Cretaceous continental red bed sequence in the Atacama region of northern Chile; *Sedimentology*, v. 36, 4, pp. 651-663.

Blake, K., 1993 - The Kiirunavaara magnetite-apatite deposit; a high temperature magmatic-hydrothermal deposit; *in* Mid- to Lower-Crustal Metamorphism and Fluids Conference, Mount Isa, *Geological Society of Australia, Abstracts*, v. 35, p. 25.

Boric, R., 1997 - Nuevos antecedentes sobre el modelo geológico del yacimiento de cobre El Soldado, Chile Central; *Actas Congreso Geológico Chileno,* Departamento Ciencas Geológicas, Universidad Catolica del Norte, v. 2, pp. 862-866.

Borrok, D.M., Kesler, S.E., Boer, R.H. and Essene, E.J., 1998 - The Vergenoeg magnetite-fluorite deposit, South Africa: support for a hydrothermal model for massive iron oxide deposits; *Economic Geology*, v. 93, pp. 564-586.

Campbell, I.H., Compston, D.M., Richards, J.P. and Kent, A.J.R., 1998 - Review of the application of isotope studies to the genesis of Cu-Au mineralisation at Olympic Dam and Au mineralisation at Porgera, the Tennant Creek District and the Yilgarn Craton; *in* Mc Naughton, N.J., Campbell, I.H. and Groves, D.I., (eds.), Application of Radiogenic Isotopes to the Study of Australian Ore Deposits, *Australian Journal of Earth Science,* v. 45, pp. 201-218.

Chavez, W., 1983 - The geologic setting of disseminated copper sulfide mineralisation of the Mantos Blancos copper-silver district, Antofagasta Province, Chile; *Society of Mining Engineers*, Preprint Number 83-193, pp. 1-20.

Craske, T.E., 1995 - Geological aspects of the discovery of the Ernest Henry Cu-Au deposit, northwest Queensland; *Australian Institute of Geoscientists Bulletin,* v. 16, pp. 95-109.

Creaser, R.A., 1989 - The geology and petrology of middle Proterozoic felsic magmatism of the Stuart Shelf, South Australia; Unpublished, PhD Thesis, *La Trobe University, Melbourne*.

Creaser, R.A., 1995 - Neodymium isotopic constraints for the origin of Mesoproterozoic felsic magmatism, Gawler Craton, South Australia; *in* Brandon, A.D. and Goles, G.G., (eds.), A special issue in memory of Richard St John Lambert*, Canadian Journal of Earth Sciences*, v. 32, pp. 460-471.

Creaser, R.A. and Cooper, J.A., 1993 - U-Pb geochronology of middle Proterozoic felsic magmatism surrounding the Olympic Dam Cu-U-Au-Ag and Moonta Cu-Au-Ag deposits, South Australia; *Economic Geology*, v. 88, pp. 186-197.

Crerar, D.A., Susak, N.J., Borcsik, M. and Schwartz, S., 1978 - Solubility of the buffer assemblage pyrite + pyrrhotite + magnetite in NaCl solutions from 200 to 350 degrees C; *Geochimica et Cosmochimica Acta*, v. 42, pp. 1427-1438.

Dallagnol, J.M., Lafon, J.M. and Macambira, M.J.B., 1994 - Proterozoic anorogenic magmatism in the central Amazonian Province, Amazonian Craton - geochronological, petrological and geochemical aspects: *Mineralogy and Petrology*, v. 50, pp. 113-138.

De Jong, G. and Williams, P.J., 1995 - Giant metasomatic system formed during exhumation of mid-crustal Proterozoic rocks in the vicinity of the Cloncurry Fault, north-west Queensland; *Australian Journal of Earth Science,* v. 42, pp. 281-290.

Dilles, J.H. and Einaudi, M.T., 1992 - Wall-rock alteration and hydrothermal flow paths about the Ann-Mason porphyry copper deposit, Nevada: a 6-km vertical reconstruction; *Economic Geology*, v. 87, pp. 1963-2001.

Einaudi, M. and Oreskes, N., 1990 - Progress towards an occurrence model for Proterozoic iron-oxide deposits - a comparison between the ore provinces of South Australia and southeast Missouri; *in* Pratt, W.P. and Sims, P.K., (eds.), The Midcontinent of the United States - Permissive Terrane for an Olympic Dam-Type Deposit, *U.S. Geological Survey*, Bulletin 1932, pp. 58-69.

Espinoza, S., Veliz, H., Esquivel, J.L., Arias, J.F. and Moraga, A., 1996 - The cupriferous province of the coastal range, northern Chile; *in* Camus, F., Sillitoe, R.H. and Petersen, R., (eds.), Andean Copper Deposits: New Discoveries, Mineralization, Styles, and Metallogeny, *Society of Economic Geologists,* Special Publication 5, pp. 19-32.

Fein, J.B., Hemley, J.J., d-Angelo, W.M., Komninou, A. and Sverjensky, D.A., 1992 - Experimental study of iron-chloride complexing in hydrothermal fluids; *in* Helgeson, H.C., (ed.), The Robert M. Garrels Memorial Issue: *Geochimica et Cosmochimica Acta*, v. 56, pp. 3179-3190.

Frietsch, R., Tuisku, P., Martinsson, O. and Perdahl, J.A., 1997 - Early Proterozoic Cu-(Au) and Fe ore deposits associated with regional Na-Cl metasomatism in northern Fennoscandia; *Ore Geology Reviews*, v. 12, pp. 1-34.

Gandhi, S.S., 1989 - Rhyodacitic ignimbrites and breccias of the Sue Dianne and Mar Cu-Fe-U deposits, southern Great Bear magmatic zone, Northwest Territories; *Geological Survey of Canada*, Special Paper 89-1C, pp. 263-273.

Hagni, R.D. and Brandom, R.T., 1988 - Comparison of the Boss-Bixby, Missouri, and Olympic Dam, South Australia ore deposits, and the potential for these deposits in the mid-continent region; *in* Kisvarsanyi, G. and Grant, S.K., (eds.), Tectonic Controls of Ore Deposits and Vertical and Horizontal Extent of Ore Systems, *Conference Proceedings, Oct. 6-8, 1987*, *University of Missouri, Rolla,* pp. 333-345.

Hauck, S.A., 1990 - Petrogenesis and tectonic setting of Middle Proterozoic iron oxide-rich ore deposits - an ore deposit model for Olympic Dam-type mineralization; *in* Pratt, W.P. and Sims, P.K., (eds.), The Midcontinent of the United States - Permissive Terrane for an Olympic Dam-type Deposit, *U.S. Geological Survey*, Bulletin, 1932, pp. 58-69.

Hauck, S.A. and Kendall, E.W., 1984 - Petrogenesis and tectonic setting of Middle Proterozoic iron oxide-rich ore deposits, Mid-continent U.S.A., South Australia, Sweden, and the People's Republic of China; *13th Annual Institute in Lake Superior Geology, Wausau, Wisconsin*, Abstract, pp. 17-18.

Haynes, D.W., 1993 - Olympic Dam ore genesis: a fluid mixing model; *Society Economic Geologists Distinguished Lecture Presentation,* Boston, 1993.

Haynes, D.W., Cross, K.C., Bills, R.T., Reed, M.H.,1995 - Olympic Dam ore genesis; a fluid-mixing model; *Economic Geology*, v. 90, pp. 281-307.

Heinrich, C.A. andrew, A.S., Wilkins, R.W.T. and Patterson, D.J., 1989 - A fluid inclusion and stable isotope study of synmetamorphic copper ore formation at Mount Isa, Australia: *Economic Geology*, v. 84, pp. 529-550.

Heinrich, C.A., Bain, J.H.C., Fardy, J.J. and Waring, C.L., 1993 - Br/ Cl geochemistry of hydrothermal brines associated with Proterozoic metasediment-hosted copper mineralization at Mount Isa, northern Australia; *Geochimica et Cosmochimica* Acta, v. 57, pp. 2991-3000.

Heinrich, C.A., Bain, J.H.C., Mernagh, T.P., Wyborn, L.A.I., Andrew, A.S. and Waring, C.L., 1995 - Fluid and mass transfer during metabasalt alteration and copper mineralization at Mount Isa, Australia; *Economic Geology*, v. 90, pp. 705-730.

Helvaci, C., 1984 - Apatite-rich iron deposits of the Avnik (Bingöl) region, south eastern Turkey: *Economic Geology*, v. 79, pp. 354-371.

Hildebrand, R.S., 1986 - Kiruna-type deposits: their origin and relationship to intermediate subvolcanic plutons in the Great Bear Magmatic zone, northwest Canada: *Economic Geology* v. 81, pp. 640-659.

Hitzman, M.W., Oreskes, N. and Einaudi, M.T., 1992 - Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-Au-REE) deposits; *Precambrian Research*, v. 58, pp.214-287.

Idnurm, M. and Wyborn, L., 1998 - A Mesoproterozoic age for the gold-bearing Quamby Conglomerate, Queensland; *Australian Geological Survey Organisation, Research Newsletter*, v. 28, pp.6-7.

Ishihara, S., Ulriksen, C.E., Sato, K., Terashima, S., Sato, T. and Endo, Y., 1984 - Research on calc-alkaline magmatism and related mineralisation in Chile; *in* Report of Research and Development Cooperation ITIT Projects No. 7911: *Geological Survey of Japan, Sefvicio Nacional de Geologia y Mineraia*, pp. 1-33.

Johnson, J. and Hattori, K., 1995 - Geological setting and fluid souces for the Sue Dianne deposit, Great Bear Magmatic Zone: Sm-Nd isotopic constraints; *Geological Association of Canada - Mineralogical Association of Canada Joint Annual Meeting,* Program with abstracts, p. A54.

Johnson, J.P. and McCulloch, M.T., 1995 - Sources of mineralising fluids for the Olympic Dam Deposit (South Australia); Sm-Nd isotopic constraints; *Chemical Geology*, v. 121, pp. 177-199.

Johnson, J.P. and Cross, K.C., 1995 - U-Pb geochronological constraints on the genesis of the Olympic Dam Cu-U-Au-Ag deposit, South Australia; *Economic G*eology, v. 90, pp.1046-1063.

Krcmarov, R.L. and Stewart, J.I., 1998 - Geology and mineralisation of the Greenmont Cu-Au-Co deposit, southeastern Marimo Basin, Queensland; *Australian Journal of Earth Sciences*, v. 45, pp. 463-482.

Lindenmayer, Z.G., 1990 - Salobo Sequence, Carajas, Brazil; geology, geochemistry and metamorphism; Unpublished PhD Thesis, *University of Western Ontario, London, ON, Canada*, 428p.

Lyons, J.I., 1988 - Volcanogenic iron oxide deposits, Cerro de Mercado and vicinity, Durango; *Economic Geology*, v. 83, pp. 1886-1906.

Machado, N., Lindenmayer, Z., Krogh, T.E. and Lindenmayer, D., 1991 - U-Pb geochronology of Archean magmatism and basement reactivation in the Carajas area, Amazon Shield, Brazil; *Precambrian Research*, v. 9, pp. 329-354.

Marikos, M.A. and Barton, M.D., 1993 - Sm-Nd and Rb-Sr isotopic systematics of the Pea Ridge Fe-P deposit and related rocks, Southeast Missouri; Geological Society of America, North-Central Section, 27th Annual Meeting. Rolla, MO, United States. March 29-30, 1993, *Geological Society of America* Abstracts with Programs, v. 25, p. 65.

Marschik, R. and Fontboté, L., 1996 - Copper (-iron) mineralization and superposition of alteration events in the Punta del Cobre belt, northern Chile; *in* Camus, F., Sillitoe, R. H. and Petersen, R., (eds.), Andean Copper Deposits: New Discoveries, Mineralization, Styles, and Metallogeny, *Society of Economic Geologists,* Special Publication 5, pp. 171-190.)

Marschik, R., Singer, B.S., Munizaga, F., Tassinari, C., Moritz, R. and Fontboté, L., 1997 - Age of Cu(-Fe)-Au mineralization and thermal evolution of the Punta del Cobre district, Chile; *Mineralium Deposita*, v. 32, pp. 531-546.

Menuge, J.F. and Brewer, T.S., 1994 - Mesoproterozoic anorogenic magmatism in southern Norway; *in* Brewer, T.S., (ed.), Precambrian Crustal Evolution in the North Atlantic region: *Geological Society Special Publications*, v. 112, pp. 275-295.

Oliver, N.H.S., 1995 - Hydrothermal history of the of the Mary Kathleen Fold Belt, Queensland, Australia; *Australian Journal of Earth Sciences*, v. 42, pp. 267-279.

Oliver, N.H.S., Cartwright, I., Wall, V.J. and Golding, S.D., 1993 - The stable isotope signature of kilometre scale fracture dominated metamorphic fluid pathways, Mary Kathleen, Australia; *Journal of Metamorphic Geology*, v. 11, pp. 311-331.

Oliver, N.H.S., Rawling, T.J., Cartwright, I., Pearson, P.J., 1994 - High-temperature fluid-rock interaction and scapolitization in an extension-related hydrothermal system, Mary Kathleen, Australia; *Journal of Petrology*, v. 35, pp. 1455-1491.

Oliver, N.H.S. and Wall, V.J., 1987 - Metamorphic plumbing system in Proterozoic calc-silicates, Queensland, Australia; *Geology*, v. 15, pp.793-796.

Oreskes, N. and Einaudi, M.T., 1990 - Origin of rare earth element-enriched haematite breccias at the Olympic Dam Cu-U-Au-Ag deposit, Roxby Downs, South Australia; *Economic Geology*, v. 85, pp. 1-28.

Oreskes, N. and Einaudi, M.T., 1992 - Origin of hydrothermal fluids at Olympic Dam: preliminary results from fluid inclusions and stable isotopes; *Economic Geology* v. 87, pp.64-90.

Ortiz, F., Araya, R., Franqueza, F., Moraga, A. and Zentilli, M., 1966 - Informe geologico del distrito minero de Punta del Cobre; *Instituto de Investigaciones Geológicas,* Publicación Especial, No. 1.

Page, R.W. and Sun, S-S., 1998 - Aspects of geochronology and crustal evolution in the Eastern Fold Belt, Mt Isa Inlier; *Australian Journal of Earth Sciences*, v. 45, pp. 343-361.

Pratt, W.P. and Sims, P.K., 1990 - The midcontinent of the United States - permissive terrane for an Olympic Dam-type deposit?: *U.S. Geological Survey*, Bulletin 1932, 81p.

Perkins, C., Heinrich, C.A. and Wyborn, L.A., 1999 - $^{40}Ar/^{39}Ar$ geochronology of copper mineralization and regional alteration, Mount Isa, Australia; *Economic Geology*, v. 94, pp. 23-36.

Perkins, C. and Wyborn, L., 1996 - The age of Cu-Au mineralisation, Cloncurry District, Mount Isa Inlier, as determined by $^{40}Ar/^{39}Ar$ dating; *Australian Geological Survey Organisation, Research Newsletter*, v. 25, pp. 8-9

Pollard, P.J., 1997 - AMIRA Project P438: Cloncurry Base Metals and Gold, Final Report; Unpublished, *National Key Centre in Economic Geology, School of Earth Sciences, James Cook University, Townsville, Qld.*

Pollard, P.J., 1997: AMIRA Project P438 - Cloncurry Base Metals and Gold, Final Report: *National Key Centre in Economic Geology, School of Earth Sciences, James Cook University, Townsville, Qld., 4811*)

Reeve, J.S., Cross, K.C., Smith, R.N., Oreskes, N., 1990 - Olympic Dam copper-uranium-gold-silver deposit; *in* Hughes, F.E., (ed.), Geology of the Mineral Deposits of Australia and Papua New Guinea, *Australasian Institute of Mining and Metallurgy, Melbourne*, Monograph 14, v. 2, pp. 1009-1035.

Richardson, S.M. and Moy, A.D., 1998 - Gunpowder Copper Deposits; *in* Berkman, D.A. and Mackenzie, D.H., (eds.), Geology of Australian and Papua New Guinean Mineral Deposits, *Australasian Institute of Mining and Metallurgy, Melbourne*. pp. 743-752.

Ridley, J., 2000 - Why geochemical tracers have failed us in our search for the source of the mesothermal gold ore fluid; 15th Australian Geological Convention, Sydney, July, 2000, *Geological Society of Australia,* Abstracts, p. 418.

Ryan, P.J. and Madson, J.L.T., 1996 - Candelaria; low cost copper-gold producer in Chile; *Mining Engineering*, v. 48, pp. 35-41.

Roberts, D.E. and Hudson, G.R.T., 1983 - The Olympic Dam copper- uranium-gold deposit, Roxby Downs, South Australia: *Economic Geology* v. 78, pp.799-822.

Ruge, H.R., 1985 - Geologia y mineralizacion del yacimiento de cobre El Soldado V Region; *in* Arias, F.J., Campano, B.P. and Espinoza, R.S., (eds.), *Actas, IV Congreso Geologico Chileno*, August 19-24, 1985, Universidad del Norte Chile, Departamento de Geociencias, Facultad de Ciencias Antofagasta, Chile, v. 4, pp. 3854-3872.

Seyfried, W. E. and Ding, R., 1993 - The effect of redox on the relative solubilities of copper and iron in Cl- bearing aqueous fluids at elevated temperatures and pressures - an experimental study with application to subseafloor hydrothermal systems; *Geochimica Cosmochimica Acta*, v. 57, pp. 1905-1917.

Sims, P.K., 1990 - Geologic setting and ages of Proterozoic anorogenic rhyolite-granite terranes in the central United States; *in* Pratt, W.P. and Sims, P.K., 1990, The Midcontinent of the United States - Permissive Terrane for an Olympic Dam-type Deposit, *U.S. Geological Survey,* Bulletin 1932, pp. 40-47.

Sims, P.K., Kisvarsanyi, E.B. and Morey, G.B., 1987 - Geology and metallogeny of Archean and Proterozoic basement terranes in the northern midcontinent, U.S.A.- An overview: *U.S. Geological Survey*, Bulletin 1815, 51p.

Tassinari, C.C.G., Munizaga, F. and Ramirez, R., 1993: Rb-Sr isotopic age and geochemistry of the Mantos Blancos copper deposit - temporal relations of the Jurassic magmatism; *Revista Geologica de Chile*, v. 20, pp. 193-205.

Toro, R.A., 1985 - Eventos intrusivos en el yacimiento cuprifero El Soldado, V Region; *in* Arias, F.J., Campano, B.P. and Espinoza, R.S., (eds.), *Actas, IV Congreso Geologico Chileno*. Antofagasta, Chile. Aug. 19-24, 1985: Universidad del Norte Chile, Departamento de Geociencias, Facultad de Ciencias. Antofagasta, Chile, v, 3, pp. 3752-3773.

van-Dijk, P.M., 1991 - Regional syn-deformational copper mineralization in the western Mount Isa Block, Australia; *Economic G*eology, v. 86, pp. 278-301.

Vila, T., Lindsay, N. and Zamora, R., 1996 - Geology of the Manto Verde copper deposit, northern Chile: a specularite-rich, hydrothermal tectonic breccia related to the Atacama Fault Zone; *in* Camus, F., Sillitoe, R.H. and Petersen, R., (eds.), Andean Copper Deposits: New Discoveries, Mineralization, Styles, and Metallogeny, *Society of Economic Geologists*, Special Publication 5, pp. 157-170.

Williams, P.J., 1998 - Metalliferous economic geology of the Mt Isa Eastern Succcession, Queensland; *Australian Journal of Earth Sciences*, v. 45, pp. 329-341.

Williams, P.J., 1999 - Fe-oxide-Cu-Au deposits of the Olympic Dam/Ernest Henry-Type; *in* Hodgson, C.J. and Franklin, J.M., (eds.), New Developments in the Geological Understanding of Some Major Ore Types and Environments, with Implications for Exploration: *Short Course Proceedings, Prospectors and Developers Association of Canada*, March 13, 1999, pp. 1-43.

Wyborn, L.A.I., Page, R.W. and McCulloch, M.T., 1988 - Petrology, geochronology, and isotope geochemistry of the post-1820 Ma granites of the Mount Isa Inlier: mechanisms for the generation of Proterozoic anorogenic granites; *in* Wyborn, L.A.I. and Etheridge, M.A., (eds.), The Early to Middle Proterozoic of Australia, *Precambrian Research*, v. 40/41, pp. 509-541.

Wyborn. L., 1992 - The Williams and Naraku Batholiths, Mt Isa Inlier: an analogue of the Olympic Dam granites?; *Bureau of Mineral Resources, Geology and Geophysics, Research Newsletter*, v. 16, pp.13-16.

Wyborn, L., 1998 - Younger *ca* 1500 Ma granites of the Williams and Naraku Batholiths, Cloncurry district, eastern Mt Isa Inlier: geochemistry, origin, metallogenic significance and exploration indicators; *Australian Journal of Earth Sciences*, v. 45, pp. 397-411.

Wyborn, L. and Heinrich, C., 1993 - Empirical observations on granite-associated gold + or - base-metal mineral deposits in the Proterozoic of Australia; delineating exploration criteria; *Australian Geological Survey Organisation, Research Newsletter*, v. 19, pp. 3-4.

Wyborn, L.A.I., Wyborn, D., Chappell, B.W., Sheraton, J., Tarney, J.F., Collins, W.J. and Drummond, B.J., 1988 - Geological evolution of granite composition with time in the Australian Continent-implications for tectonic and mantle processes: *Geological Society of Aust*ralia, abstract., v. 21, pp. 434-435.

Yishan, Z., Ruiyang, A. and Fengzhen, W., 1989 - Solubility of the magnetite+hematite buffer assemblage and iron speciation in sodium chloride solutions at 300 degrees C and 500 bars; *Geochimica et Cosmochimica* Acta, v. 53, pp. 1875-1882.