

THE SELWYN LINE TABULAR IRON-COPPER-GOLD SYSTEM, MOUNT ISA INLIER, NW QUEENSLAND, AUSTRALIA

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Abstract - The Selwyn Line is the name adopted for an open arcuate zone of iron-copper-gold mineralisation, located ~150 km southeast of Mount Isa, in the Mount Isa Proterozoic inlier, northwest Queensland, Australia. Since the discovery of gold mineralisation in the Selwyn Hills in the 1970's, 5 small mines have been operated. These exploited high grade ironstone hosted gold-copper mineralisation, located within a zone of poly-aged shearing and complex alteration. The mines are located within the Starra Shear which has a history of ductile-brittle, brittle-ductile and brittle deformation. The structure is altered over widths of between 100 m and 500 m, and for over 10 km along strike. The alteration involved early albite + quartz + calcite + scapolite + actinolite replacement of the host sheared meta-sediments of the Staveley Formation. This was followed by a magnetite/hematite+biotite+quartz(+pyrite) overprint, and finally post tectonic oxidation of the magnetite, and chlorite-calcite alteration with associated chalcopyrite and gold mineralisation, and limited pyrite formation (Rotherham 1997). The high grade zones exhibit indications of strong structural controls. They typically plunge steeply to the north along magnetite bearing extensional duplex structures and shear planes which include portions of the hanging wall bounding shears and link structures to the footwall bounding shears. The dimensions of the mined and mineable resource (<8 mt) have always been regarded as small for typical Fe-Cu-Au systems. However resource work done on lower cut-off grades indicates that the system is more typical of the large systems of this sort found elsewhere in the district, with a pre-mining global resource of at least 29 mt at 2.5g/t Au and 1.4% Cu (at a 1.5% Cu Equivalent cutoff using a factor of ~0.8 depending on where the ore is from), 49 mt at 1.76 g/t Au and 1.05% Cu using a 1.0% cut off, or 95mt at 1.1g/t Au and 0.74%Cu at a 0.5% cutoff. These are embraced within a larger mineralised system with a global resource of 253 mt @ 0.48g/t Au and 0.34% Cu at measured, indicated and inferred categories, to a depth of ~300m below surface (using a 0.2% Cu Equivalent cut off).

The main observations made in this paper are: 1). The Selwyn Line is fairly typical of iron-copper-gold systems in NW Queensland in that it is part of a very large alteration system containing large tonnes of mineralised magnetite ironstones with associated low tenor Cu and Au grades; 2). In the Selwyn Line (excluding the 222 Mine) the ore grade zones discovered to date have been confined to duplexes within crudely tabular "tramway" shear systems, in which multiple localised sites for ore mineral deposition were generated. The cumulative tonnage of these sites is substantial but still remains constrained by the overall tightness of the late (brittle-ductile) strain zones which were dominated by flattening (D4). The dimension of ore grade zones in these systems is mostly a function of the volume of the zones in which late extensional deformation was developed (D4 to D6, Adshead-Bell, 2000); 3). At 222 Mine to the south, the structural location is more complex with multiple "north" trending S2/S4 shears intersecting the S1 'hinge zone' shear and its associated intra-folial ironstones at higher angles. This has provided a site for greater volumes of late stage alteration and mineralisation. The resultant lower grade tonnages drilled to date have already intersected larger orebodies here (>5mt), and suggest there is further potential for the delineation of a major deposit in this system.

Introduction

The Selwyn Line is the name adopted for an arcuate zone of iron-copper-gold mineralisation, located in north west Queensland, Australia (Figure 1), some 150 kilometres south east of Mt Isa. This linear zone contains 5 dormant iron-copper-gold mines which were exploited from May 1988 until March 1999. This mining principally exploited high grade gold (and copper) mineralisation hosted by

sheared iron oxide-feldspar-chlorite-silica-carbonate (\pm biotite and sericite) altered metasediments. On the basis of the mineral and metal associations observed within these deposits, the Selwyn deposits were grouped by Hitzman et al. (1992) into the iron-copper-gold metallogenic family of deposits, including Olympic Dam as one end member and the Kiruna iron deposits as another.

In total only 6.84 million tones of ore at 4.6 g/t Au and 2.1% Cu, were removed from the 5 Selwyn deposits in

was also arrived at independently by the current operating company during 2000. A full review of the existing data was undertaken resulting in scoping and feasibility studies during 2000 and 2001, with the decision to proceed with the exploitation of the resultant enlarged resource being made in the final quarter of 2001. This paper endeavours to present an update on the setting of the Selwyn Line and convey the outcome of the resource review.

It is noted at this point that in the literature, the mines of the Selwyn Line have historically been called both the Starra Mines and the Selwyn Mines. To avoid further changes and confusion the author and current mining company have retained the name adopted by the previous mining company, namely the "Selwyn Mines".

Regional Setting

The Selwyn Line is hosted by highly altered, sheared metasediments of the Staveley Formation of the Mary Kathleen Group and Maronan Supergroup. These units are located in the eastern tectono-stratigraphic domain of the Proterozoic aged Mount Isa Inlier. This eastern domain has been variously referred to as the Eastern Succession, the Eastern Fold Belt and more recently as the Eastern Mount Isa Block (Laing, 1998) and is indicated in Figure 1. Regionally the area of interest is underlain by a package of metamorphosed shales, siltstones, pelites, calcic metasediments, evaporites, and metavolcanics intruded by several generations of felsic and mafic magmatism. The bulk of the stratigraphy of the Mount Isa Inlier is thought to be composed of 4 main units (Beardsmore et al. 1988; Blake and Stewart 1992; Page and Sun, 1996), as follows:

- 1) A pre-1875 Ma *gneissic and schistose basement*. In the Selwyn area the Double Crossing Metamorphics and the gneissic components of the Gin Creek "Granite" (Figure 2) were interpreted as being part of this basement (Blake, 1987). Eastward of this, the highly deformed Answer Slate unit was thought to form part of this early "basement" although this interpretation has been questioned by newer work. Dating in recent years has suggested these units are younger, falling within the same time bracket as the last phases of Cover Sequence 1 and the early phases of Cover Sequence 2 listed below (Page and Sun, 1998). Never the less, the Answer Slate still forms part of a higher grade (amphibolite facies) "basement" to the upper greenschist facies Cover Sequence 2 and 3 rocks in the Selwyn Line Area across a tectonised contact.
- 2) The *Isan Cover Sequence 1*, which is dominated by felsic meta-volcanic rocks of between 1875 and 1850 Ma age (Blake, 1987). These are not developed in the Selwyn district.
- 3) The *Isan Cover Sequence 2*, composed of calc-silicates, metasediments, and both mafic and felsic metavolcanic suites. Importantly these also include the carbonaceous shales, evaporites, and carbonate formations of the Mary Kathleen Group.
- 4) The *Isan Cover Sequence 3*, composed of mafic metavolcanics, turbidites, psammites, and assorted

amphibolites, schists and gneisses of the Soldiers Cap Group. A date of 1677 ± 9 Ma was established by Page, 1994 for the Fullarton River Group which conformably underlies the basal Soldiers Cap strata.

Age dating by Nisbet et al. (1983), Wyborn et al. (1988), Pearson et al. (1992), Page (1994), Page and Sun (1996), and Pollard and McNaughton (1997) combined with petrographic, geochemical, and structural data have grouped the principal intrusive bodies in the region into three main affiliations.

- 1) The *Wonga Batholith* involved extensive A and I type bimodal magmatism in the western parts of the Eastern Fold Belt, during the pre-Isan extensional deformation (1760-1720 Ma, Pearson et al. 1992).
- 2) The *Naraku Batholith* which includes a pre-peak metamorphic microgranite phase of plutons dated at 1754 ± 25 Ma (Wyborn et al. 1988), foliated granodiorite of 1752 ± 8 Ma (Pollard and McNaughton, 1997), and coarse grained unfoliated hornblende-biotite sodic/calcic granite plutons with an age range of 1508 ± 70 Ma (Wyborn et al. 1988). These are typically strongly fractionated A-type intrusives, located in the northern and eastern parts of the Eastern Fold Belt.
- 3) The *Williams Batholith* dominates the southern parts of the Eastern Fold Belt. It is also composed of at least two main phases. The older is a foliated leucogranite while the younger post dates the main regional deformational events. The main older phase observed in the Selwyn District is the Gin Creek Granite which was dated by Page and Sun (1996) at ~ 1740 Ma. The younger Williams intrusives typically comprise coarse grained unfoliated granites. The Selwyn district was intruded by numerous granitoids of this generation including the Mount Dore, Yellow Waterhole, Mount Cobalt, Squirrel Hills, Belgium, Saxby and Wimberu granite bodies. The Mount Dore granite was dated at 1509 ± 22 Ma by Nisbet et al. (1983) and 1510 ± 10 Ma by Pollard and McNaughton (1997). Further south the Yellow Waterhole granite was dated at 1480 ± 28 Ma (Page, 1994), and 1510 ± 8 Ma (Pollard and McNaughton, 1997). Eastward the Squirrel Hills have an age of 1514 ± 5 Ma (Pollard and McNaughton, 1997). Pollard et al. (1998) recognised that these granitoids were distinctly potassic, meta-aluminous, and sub-alkaline in character, and belonged to a Super-suite of A-type granitoids within the Williams Batholith. Modelling of gravity and magnetic data indicates the Williams batholith has flat upper and lower bounding surfaces, implying sheet-like emplacement or thrusting. The seismic profiles support this (Wyborn et al. 1996). Modelling of CSAMT data and drilling information (Selwyn Operations Pty Ltd unpublished data, 2001) across the western margin of the Mount Dore granite body supports the view that at least towards their margins, these granites are not emplaced as deep plutonic or diapiric bodies, but rather form sheet-like features, due to thrusting and/or crudely tabular igneous emplacement.

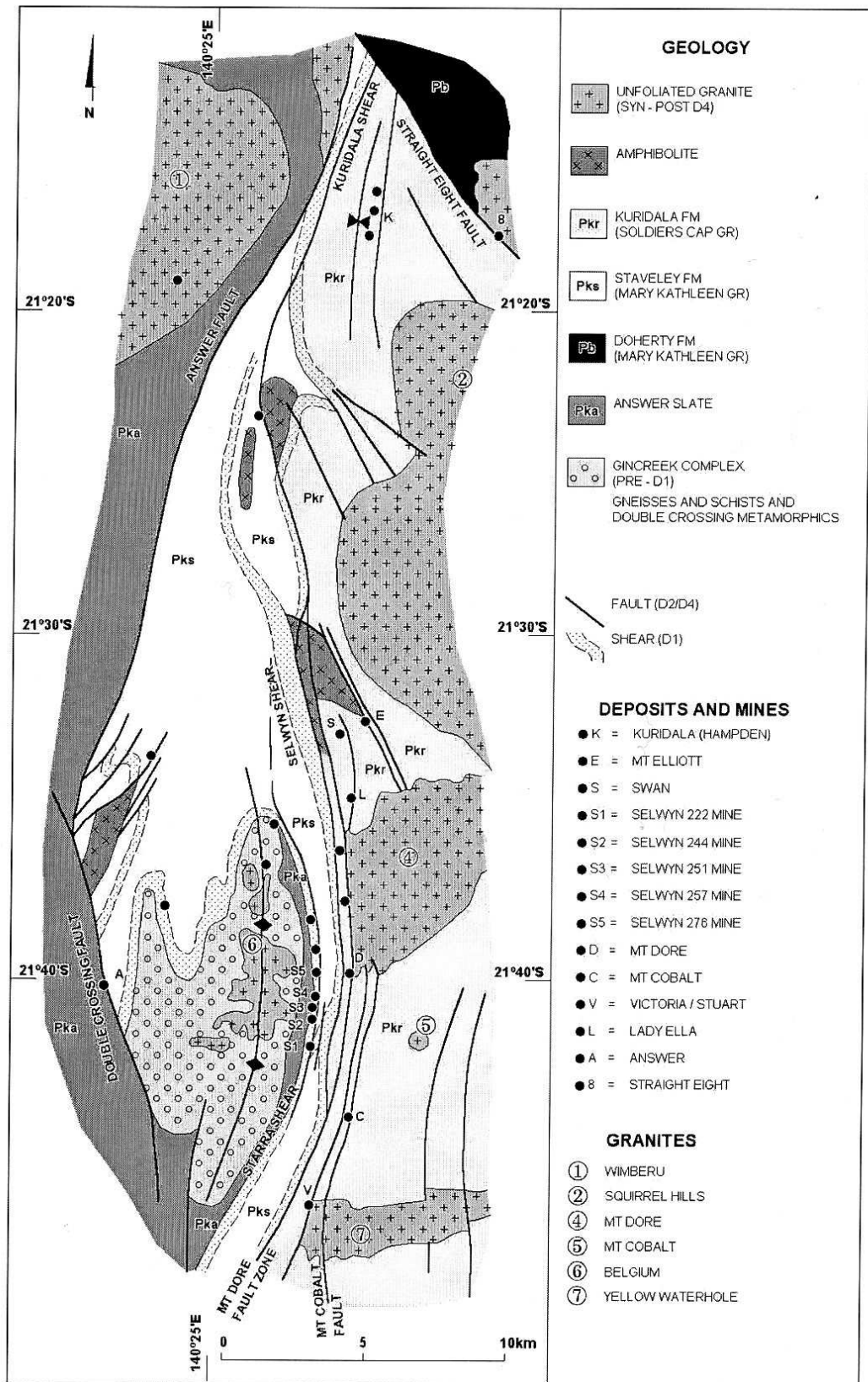


Figure 2: District geology (modified from Switzer et al.1988, and Beardsmore 1992)

Throughout the region there are also numerous intrusive mafic bodies for which no collective name has been given. They are emplaced as dykes, sills and pods, and belong to several age groupings. These include earlier pre- and syn-tectonic metadolerite and amphibolite, and later gabbroic and dioritic dykes considered to be coeval with the ~1500 Ma unfoliated granite phases of the Williams and Naraku batholiths (Pollard et al., 1996).

Tectono-stratigraphic Framework of the Eastern Fold Belt

The Double Crossing Metamorphics, dated at 1840 ± 20 Ma (Page and Sun, 1998), and possibly the Gin Creek granite gneisses and the Answer Slate are the oldest units exposed in the Selwyn region of the Eastern Fold Belt. Their age,

combined with their comparatively high metamorphic grade and un-correlated early structural history, suggests they were probably emplaced and deposited late during the first major tectonic event to influence the region, namely the Barramundi Orogeny, which was bracketed at between 1880-1850 Ma by Etheridge et al. (1987).

The main stratigraphic units in the Eastern Fold Belt belong to the second and third supracrustal cover sequences. These are interpreted as having been emplaced during a prolonged period of ensialic extensional and strike slip tectonics (Loosveld, 1989) between 1725 Ma (Page, 1994) and 1650 Ma (Page, 1993; Page and Sun, 1996). These supracrustal sequences were then subjected to 3 major regional compressional events (Page and Bell, 1986) which comprise the second main orogeny to effect the region, namely the Isan Orogeny. This occurred between 1590 Ma and 1500 Ma (Blake et al., 1990) with peak metamorphism at ~1545 Ma (Page and Bell, 1986).

The first compressional event, (D1) is most evident in the development of regionally extensive, flat lying mylonite zones deformed by subsequent D2 and D3 aged folds (Laing, 1998), and east-west trending fold-thrust complexes (Bell, 1983). One of these mylonite zones (the Starra Shear) is interpreted to separate the sheared greenschist facies Staveley metasediments, from the amphibolite facies Gin Creek-metamorphic "basement" to the west (Figure 2).

The second deformation (D2) produced the prominent north-south trending, regional fabric and fold axis orientation, evident in most regional geological maps. D2 deformation involved strong east-west shortening which generated north trending, steeply west verging to upright folds with a well developed axial planar foliation and sub-parallel ductile-brittle shears.

D3 was also compressional in an east-west orientation and also resulted in north-south trending upright folding. This event caused east over west rotation of the D2 aged folds (Adshead-Bell, 1998) and activation of the north-south trending faults in a more brittle environment.

This is a simplistic framework, with many areas in both the western and eastern Isan domains exhibiting several additional phases of local deformation (Bell and Hickey, 1998; Adshead-Bell, 2000). Laing 1998, using seismic profiles as support, suggests the entire Eastern Fold Belt is an allochthonous block, composed of interleaved carbonate and siliclastic units separated by listric faults. Structural and seismic data suggests these are eastward dipping but become flat dipping along a major detachment plane at depth. Bett and Lister (2001) and MacCready et al. (1998) suggest that towards the end of the Isan Orogeny, there was a transition from thin to thick skinned tectonics, and wrenching. This was marked by the development of increasingly brittle deformation (Drummond et al., 1998). In the western parts of the Mount Isa Inlier, economically important "master faults" were identified as zones where earlier basin forming structures were overprinted by deep penetrating, brittle, strike slip, reverse slip and wrench faults (Lister et al., 1999). In the Eastern Fold Belt similar

reactivated "master faults" were also identified although they are in a different structural domain (Blake, 1987; De Jong and Williams, 1995; Oliver, 1995). Prominent structures of this sort in the Selwyn region include the Mt Dore and Cloncurry fault systems (Beardsmore et al., 1988), which are spatially closely associated with many of the principal deposits in the region. The Starra Shear which hosts the Selwyn mines, is interpreted to be a similar feature. It involves a zone containing several steeply dipping S2 aged reverse shears. On the western side these overprint an earlier S1 decollement structure. The S2 structures are themselves over printed by "D3" (local D4 aged) aged zones of high flattening strain (Adshead-Bell, 2000). These stresses induced both normal and oblique slip movement along the earlier structures. This interpretation of the Starra Shear is supported by modelled CSAMT and magnetic data, which indicate the shear zones are more steeply dipping than the ironstone altered shears, which themselves form duplex features linking 'hangingwall and footwall' displacement planes.

Metallogenic Setting

There is an abundance of copper and copper-gold deposits associated with late epigenetic fluid systems utilising structures along the length of the Eastern Fold Belt, with at least 25 significant deposits and mines discovered to date. Numerous mapping and research programs through the last 80 years have established that the region has been influenced by extensive and in many areas very powerful fluid systems of several generations, with distinct characteristics. Where these fluids have been introduced under the right physical and chemical conditions they have shown the capacity to generate substantial metal accumulations. Many of these copper-gold deposits exhibit characteristics common to the iron-copper-gold systems found elsewhere in the world.

The deposits of this style found to date within the Eastern Fold Belt range in size from several hundred thousand, to more than 150 million tonnes (Table 2 and Figures 1 and 2). They are characteristically reduced iron-copper-gold systems, but invariably most contain portions which are dominated by hypogene oxidised ore and gangue assemblages. These typically include hematite, low-iron copper sulphides, copper "oxides" and even native copper as the predominant ore species. These deposits are commonly associated with district scale master faults.

Textural data from black shale hosted copper deposits in the Selwyn area suggest many of them formed due to the passage of late to post deformational mineralising fluid into brecciated zones within the "master faults". The Mt Dore deposit is an example. This timing is apparently similar to that characteristic of the iron-copper-gold deposits (late to post regional D3). In the latter, iron oxides already in the host unit provided the reductive environment to capture economic metals. Fluids entering black shales in the absence of earlier iron oxide alteration, produced iron sulphides (pyrrhotite and pyrite) as the preferred iron alteration species (over oxides) and copper was confined

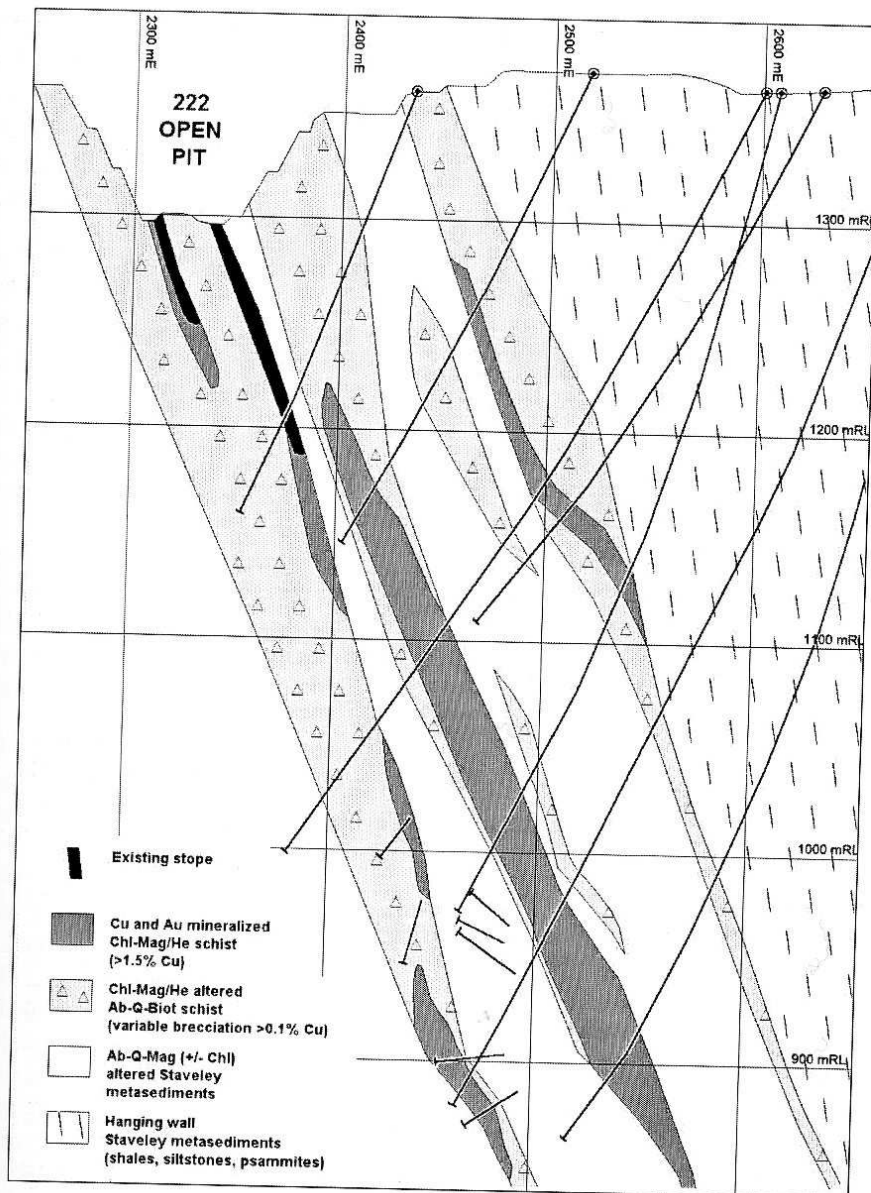


Figure 3: Section 7850N in 222 Mine – simplified E-W cross section illustrating the distribution of grade within altered breccia zones. The higher grade zones plunge steeply northward into the section.

Mine, all exhibit the same basic alteration and lithological cross section. There are however, local variations in the dominance of different alteration minerals, and structural complexities, within the Selwyn Line system. These variations are observed both vertically and laterally.

Lithologies

The stylised section through the line from the east (hanging wall) to the west (footwall) involves :

Metasediments

This is the mine term used collectively, for the package of interlayered carbonate bearing meta-psammities and metapelites belonging to the Staveley Formation and located in the hanging wall of the main mineralised zones. They exhibit variable quartz-albite-calcite-magnetite/hematite \pm scapolite, pyrite and biotite alteration, overprinting an earlier greenschist facies metamorphic assemblage. The metasediments are increasingly strained to the west, as demonstrated by local intensification of shear fabric and breccia development. Westward, clasts in the breccias are

increasingly flattened and imbricated or parallel to the host shear fabric. The clasts are dominantly composed of quartz and albite (Rotherham 1997a, Adshead-Bell 2000), and westward the matrix is increasingly replaced by biotite/chlorite, and magnetite/hematite. In many parts of the Selwyn Line the brecciated hangingwall and footwall metasediments are overprinted by calcite matrix crackle breccias, with dominant orthogonal tensional fractures indicating a strong post-foliation flattening strain at high angles to the dominant north-south foliation. These are similar in orientation and character to breccias and fracture sets observed in the altered black shales adjacent to the western faulted contact of the Yellow Water Hole granite and the Mount Dore granite, at the Victoria and Mount Dore copper deposits. The increased deformation to the west is attributed to the development of the hangingwall bounding shears of the main Starra Shear zone. The metasediments commonly overlie extensive lenses of near massive ironstones. These contacts are typically sheared, with the development of chlorite and clays defining the change in unit.

DEPOSIT		PRE-MINING RESOURCE TONNES & GRADE (MEASURED & INDICATED) * denotes reserve						
Name	Type	Cut off	Mt	Au g/t	Cu %	Cu/Au ratio	Source	
Selwyn	Fe-Au-Cu	high (>3g/t Au Eq)	6.9*	4.6	2.1	0.5	Selwyn Prospectus and Annual Reports, 2000 & 2001	
Ernest Henry	Fe-Cu-Au - Global Fe-Cu-Au	mod (>1.5% CuEq) Low (>0.4% Cu)	14.6* 166.0 127.0*	2.1 0.5 0.55	1.1 1.6 1.1	0.5 3.0 2.0	Selwyn Annual Report, 2001 Ryan 1998 Ernest Henry Mines Annual Report, 2001	
Eloise	Fe-Cu-Au	High	3.2*	1.5	5.8	3.9	Baker and Laing 1998	
Osborne	Fe-Cu-Au (skarn? & ironstone?)	mod (>1.5% CuEq)	36.0	1.0	2.0	2.0	Adshead 1995	
Mt Elliott	Fe-Cu-Au skarn & black shales	high (>3% Cu) * high (>2.5%Cu)	15.2* 6.3*	1.1 1.8	3.0 4.6	2.9 2.6	Gauthier et al., 2001	
Swan	Fe-Cu-Au calcsilicate & black shales	mod (>1.5% CuEq)	11.0	1.2	2.9	2.5	Selwyn Prospectus and Annual Reports, 2000 & 2001	
Greenmount	Cu-Au calcsilicate & black shales	v.low (0.3% Cu) low (0.5% Cu)	13.5 3.6	0.5 0.8	0.9 1.5	1.8 1.9	Selwyn Annual Report, 2001 Selwyn Annual Report, 2001	
Trekelano	Cu-Au calcsilicate (skarn?)	?	20-30	?	0.5	?	Homestake Quarterly Report, March 1995.	
Mt Dore	Cu - black shales	?	3.6	0.7	2.7	3.9	Hodgson 1998	
Victoria	Cu - black shales	v. low (0.2%Cu) low (0.5% Cu)	27.3 2.4	0.1 0.2	0.7 1.3	6.6 6.5	Shepherd, 1953 Selwyn Annual Report, 2001 Selwyn Annual Report, 2001	

Table 2. Tonmages and grades of several Fe-Cu-Au and related deposits in the Eastern Fold Belt, Mt Isa Inlier.

Massive Ironstones

These are developed as crudely tabular or lentic bodies composed of variable proportions of magnetite and hematite, with quartz, albite, calcite, sulphides and chlorite in their matrix. The majority of the massive ironstones are typically medium to coarse grained, and dominated by granular hematite. The hematite is however variably replaced by concordant and discordant, coarse grained magnetite/martite. The latter are commonly associated with chalcopyrite or bornite. In portions of the Selwyn Line, the hematite ironstones delineate hangingwall and footwall bounding shears in the S2 Starra Shear zone. These tend to be relatively straight zones. Internal to these "tramway" structures and in areas where the Starra Shear is dislocated, or develops splays or flexures, the magnetite replacement becomes dominant (excluding the effects of weathering). The magnetite ironstones are typically developed along obliquely discordant, sigmoidal structures linking hangingwall to footwall structures, both along strike and down dip. These typically strike at 10° to 15° east of the principal hematitic S2 shears (Figure 4).

The hematitic ironstones occur in both massive and brecciated forms. Both the massive form, and the clasts in the breccias, are usually granular with a moderately developed internal fabric. The magnetite dominated ironstones typically exhibit both concordant and discordant replacement along the main S1 and S2 foliations, folding of these foliations, S4 foliation and crosscutting shear structures (Adshead-Bell, 2000). In several areas the earlier fabric is folded about S2/S4 axes, but the textural evidence supports the iron replacement postdating the formation of the folds, with iron oxides and sulphides penetrating the associated axial planar cleavage. This replacement can be observed on scales from millimetres to tens of metres in width, and over hundreds of metres down dip and along strike. The influence of the magnetite replacement is particularly evident in the 276, 257, 251 and 244 deposits. It is of note that in many zones the magnetite has undergone partial to complete hypogene oxidation to martite (Rotherham, 1997a).

The Starra Shear Schists

This is new terminology for the mine, and is used to describe the chlorite/biotite-magnetite/hematite-albite-quartz-carbonate schists that comprise the central portions of the Starra Shear zone. They represent the altered and sheared Staveley Formation metasediments that are developed in the main zones of dislocation within the Starra Shear. The proportions of chlorite, feldspar, magnetite and hematite in this unit vary significantly along the Selwyn Line. In many parts the texture and alteration mineral composition is closely linked to the type of mineralisation present. The distribution of the alteration minerals is also strongly linked to the development of structures. In the south at the 222 deposit high proportions of chlorite \pm biotite \pm sericite define broad breccia zones and shear fabrics (Figure 3) which demarcate north through to north east trending shears. These are accompanied by coarse magnetite/martite disseminations which are commonly accompanied by chalcopyrite with minor gold. Gold grades increase in the

presence of bornite, high concentrations of chalcopyrite and in reworked, non-sulphidic, massive hematite breccias which are both sub-parallel with, or subtly discordant to, the principal foliations.

Further north at 244 Starra Shear Schists are chlorite dominated and developed in elongate duplexes and lenses within the main shear, but are typically still located in the footwall of the massive magnetite ironstones that mark portions of the principal hangingwall bounding shears. These chlorite dominated Starra Shear Schists are mineralised to ore grades in parts, and overlie the dominantly hematitic massive ironstones and the albite-quartz-magnetite \pm pyrite \pm scapolite schists which form the western or footwall stratigraphy of the Selwyn Line. In many areas these schists become increasingly deformed westward until they form a mylonitic straightening zone which together with the hematitic footwall ironstones forms the western bounding shears.

Further north at the 276 deposit, chloritic schists are less well developed compared to the magnetite bearing metasediments and footwall feldspar-quartz-magnetite schists.

Feldspar-Quartz-Magnetite Schists

This unit is separated from the Starra Shear Schists by its distinctive mineralogy (only minor biotite/chlorite). They are typically developed in the footwall of the main shear zone but are also present as extensive lenses and zones within the body of the shear. The unit is variably brecciated, and the degree of strain is crudely related to the amount of chalcopyrite present. These schists typically contain zones of abundant coarse deformed pyrite \pm scapolite in the vicinity of the footwall bounding shears. The contact with the Answer Slates in its footwall is not well exposed, but is interpreted as an alteration front across shear boundaries. These schists are typically between 50 and 100 m in thickness, and this combined with their abundance of disseminated magnetite, results in their close correspondence with the regional magnetic anomaly. It is noted at this point that the relatively non-magnetic Eastern Ironstones do not exhibit the abundant albite-magnetite alteration evident in the Western Ironstones.

Amphibolites

Amphibolite masses are developed as concordant and discordant bodies within the metasediments on both the eastern and western sides of the Selwyn Line. They are not observed to crosscut the mineralised units, preferring instead to remain within the fabric of the sediments. The amphibolites are medium to fine grained actinolite (after pyroxene) - plagioclase - magnetite bearing rocks. They exhibit a weak fabric associated with chlorite development along their margins but tend to be ophitic within the body of the intrusives.

Ore Mineralogy

Through out the Selwyn Line the ore mineralogy is broadly similar with the main variations derived from local differences in oxidation state. These changes in oxidation

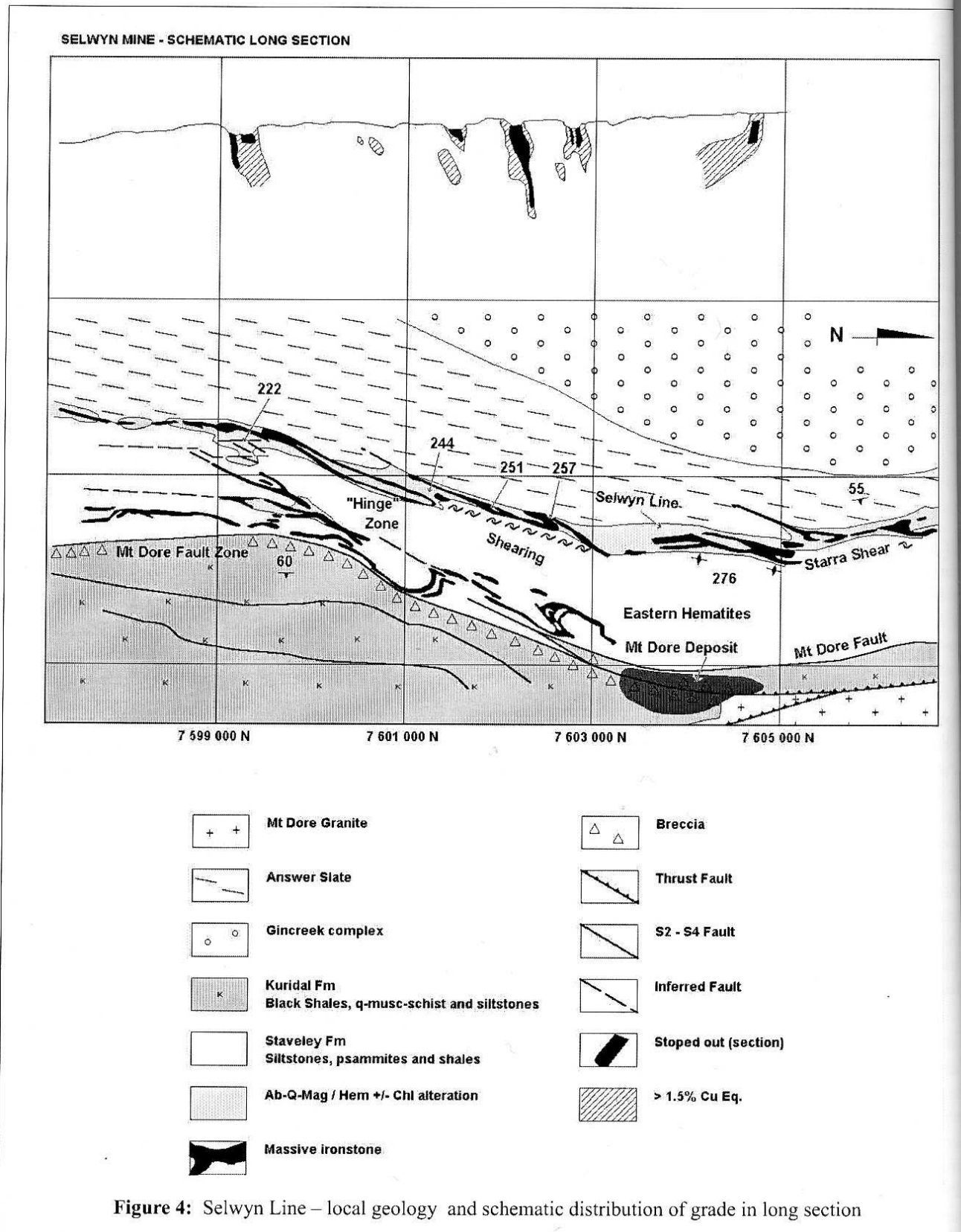


Figure 4: Selwyn Line – local geology and schematic distribution of grade in long section

state are observed over both sub-horizontal and sub-vertical boundaries. The main primary copper ore minerals are chalcopyrite and bornite with trace chalcocite. Principal weathered zone "oxide minerals" include malachite, chrysocolla, chrysoprase, cuprite, a variety of cupriferous sulphur-salts, while in many areas native copper is a prominent ore mineral. Petrographic studies on the gold distribution indicate it is mostly $<50\mu\text{m}$ (Kary and Harley 1990). Gold is commonly present as intergranular particles, and is also included within chalcopyrite, bornite, magnetite,

martite, hematite, hematized rims to magnetite, pyrite, calcite and quartz (Adshead-Bell, 2000; Rotherham 1997a).

Primary gangue minerals include magnetite, martite, hematite, quartz, calcite/anchorite, barite, sodic feldspar, potassic feldspar, scapolite, actinolite, biotite, chlorite, sericite, pyrite, tourmaline, apatite, and trace scheelite.

The alteration paragenesis and its relationship to structure and the mineralisation are indicated in Table 3.

Structure

The structural record within the Selwyn Line is complex, with evidence of both major regional orogenic deformations as outlined in Section 2, and local or district specific deformation. Numerous workers have studied the structure within the Selwyn District. The most recent and most comprehensive detail was provided by Adshead-Bell (2000) who's work is summarised in the Table 1. The principal difference between Adshead-Bell's work that of earlier workers lies in the detailed interpretation of specific micro- and meso- scale structures. Adshead-Bell interprets the Starra Shear as being of both D2 and D4 age while others such as Blake (1987) and Laing et al. (1989) perceive it as being the product of a D2 remobilisation of a D1 aged decollement zone. This latter view is supported by a difference in metamorphic grade from greenschist facies assemblages east of the Selwyn Shear (and Mount Dore fault) to amphibolite facies assemblages west of the Starra Shear.

Originally Laing et al. (1989) indicated the Selwyn Line of deposits as being located on the eastern side of a 2 km wide zone of ductile shearing known as the Starra Shear (Figures 2 and 4). Beardsmore (1992) and Adshead-Bell (2000) identified 2 main shears in proximity to the Selwyn Line, namely the Starra Shear in the west and the Selwyn Shear 2 km to the east, abutting but still west of the more brittle Mount Dore fault zone. High flattening strains and zones of intense straightening are evident in the Starra Shear, but there is less evidence for the same intensity of straightening in the Selwyn Shear. It is notable that the bulk of the Selwyn Shear, which to date is apparently poorly mineralised, does not host the intense albite-magnetite alteration prevalent in the Starra Shear.

The distribution of many of the principal S2 aged shears in the Selwyn Line is typically highlighted by massive hematite dominated iron oxide replacement of the original sheared metasediments. It is postulated that the S4 aged shears tend to be traced by magnetite dominated replacement ironstones, but several are less obvious and are traced by local intensification in S4 foliation, and shear fabric.

Geometry

Of the 5 mined deposits of the Selwyn Line, three are located in the southern half arc, namely the 244, 251 and the 257 orebodies. The high grade portions of each are typically developed in broad ribbon-like shoots within near massive ironstone lenses, extending for more than 600 m down plunge, between 50 and 300 m along strike and are 2 to 30 m in width. They plunge consistently at between 60° and 80° to the north-northeast, and clearly reflect a relatively constant structural regime along this portion of the line. The geometry of these high grade shoots is spatially associated with the junction zone of the principal north-northeast trending hanging wall shears, and prominent southwest trending link structures developed beneath this shear within the body of the Starra Shear zone. Lower grade mineralisation is commonly developed in the footwall

and along strike from the high grade zones, in intervals of less massive iron replacement, and more abundant chlorite and biotite development. In several areas the mineralised zones hosted in the "footwall" Starra Shear Schist are developed as sizeable higher grade zones such as the "B-zone" in the 244 Mine open pit.

The southernmost deposit in the Selwyn Line (the 222 Mine) is located in the junction zone of the main north to north-northeast trending (S2/S4) Starra Shear structures, and a northeast-southwest trending (S1?) cross shear (the "hinge zone"). The latter was originally interpreted by previous workers (Switzer et al., 1988; Kary and Harley, 1990; Davidson et al., 1989; Beardsmore et al., 1988) as an S2 aged fold closure, deforming the early ironstones. Later work by Switzer et al. (1988), Beardsmore (1992) and Adshead-Bell (2000), has this zone incorporated in the Selwyn Shear as it tracks southward to link onto the Starra Shear. It is interpreted in this paper, as being part of the S1 aged Starra Shear system which is largely defined by iron replacement parallel to the S0/S1 fabric. Crudely north-south trending S2 upright shears intersect the S1 structure in several locations, and are themselves overprinted by S4 aged E-W compressional strain associated with the shearing in the main Selwyn Line. The north-south structures are also characterised locally by iron oxide replacement, and intense feldspar, silica, chlorite and carbonate alteration. At 222 the orebodies are located within multiple zones of alteration, which form broad envelopes. The high grade zones mined to date involve tabular ironstones which extend down dip for >500 m, along strike for 250 m and which are 2 to 20 m wide. These plunge at 60° to 80° to the northeast. Recent drilling combined with existing data however, indicates the mined zones at 222 are only a part of the economically mineralised system, and that far greater widths (up to 100 m) are developed, particularly to the northeast along the strike from the "hinge zone". At lower cut offs (eg. 1.5 g/t Au or 1.5% Cu) multiple large shoots are evident, plunging at 75° to the northeast. These define the junction lineation between the north to north-northeast trending S2 and S4 shearing and the northeast trending S1 aged "hinge zone" structures. This supports the continued use by mineralising fluids, of zones where early sodic-silica-calcic alteration in S1/S2 structures, have been overprinted by more brittle S4 structures. Drilling to-date has not closed off these systems and the potential for significantly larger deposits still exist.

In the northern arc of the Selwyn Line, only the 276 deposit has been mined to date (Figure 4). Here the exploited high grade ore zone is located in the junction zone of an eastward dipping (70°) hanging wall shear (magnetite/martite dominated) where it converges on the main S1-S2 Starra Shear (pre-D4 hematite dominated replacement). The geometry of this deposit is not fully defined as yet due to a lack of definitive drilling. Indications are that the northern end of the high grade zone is controlled by the steep southward plunging junction lineation of the two shears. This converges at depth (>400 m) with a second controlling intersection lineation formed where the eastward dipping hangingwall ore zone is incorporated into a near vertical

Stage	Alteration Type	Alteration Paragenesis	Mineralisation	Structure	Magmatism	Comment
1	Na - Ca metasomatism	Albite, quartz, scapolite, actinolite, apatite		Used mainly D2 Faults and foliation (replacement of ductile-brittle structures)	Fluids associated with early Williams granites?	Changed laminated host rocks prone to deformation by simple shear, into more massive textured brittle rocks
2a				D4 brecciation of brittle sodic altered rocks		Tectonic brecciation
2b	K - Fe metasomatism	Biotite, magnetite, hematite, quartz, pyrite, tourmaline, apatite	Pyrite - no associated Au or Cu minerals	Mostly replacement of D1 foliation and shearing, and D2-D4 structures, fabric and breccias.	Associated with emplacement of Mt Dore aged granites ? (~1510Ma?)	<ul style="list-style-type: none"> o Replacement and hydraulic breccia textures, overprinting earlier breccia o Main development of the bulk of the ironstone units
3a -early	Au - Cu mineralization & Si-Ca alteration	Quartz, calcite, chlorite, magnetite, hematite, anhydrite, sericite/k-spar	Au (2 sub-stages?), pyrite, barite, bornite, & chalcocopyrite	D2/D4 structures - mineralization of available low pressure areas. Fluid overpressure.	Late phases of Mt Dore aged intrusives ? (~1500Ma?)	Magnetite/martite overprinting earlier iron-oxides, and associated with chalcocopyrite. Au with martite, calcite, quartz ± pyrite
3b -late	Au-Cu mineralization associated Ca-K ?	Calcite, chlorite, epidote, sericite	Au, chalcocopyrite & pyrite	D5/D6 - overprinting earlier mineralization/alteration	Waning system (cooler)	Au & chalcocopyrite in late calcite-silica-Mg chlorite veins
4	Supergene oxidation	Hematite, siderite, goethite, limonite, kaolin, smectite, illite	Native Cu, cuprite, malachite, chalcocite chrysocolla.	Existing faults, joints and fractures - commonly sub-horizontal, but dipping sub-vertically into faults	Weathering	

Table 3. Alteration, mineralization and structure : sequence of events (modified after Rotherham (1997a), and Adshead-Bell (2000))

(S4 aged?) shear. The mineralised magnetic hangingwall ironstone is poorly developed within this shear due to attenuation and/or weaker iron replacement. Movement indicators suggest the main magnetite ore body developed in a regime of east over west reverse faulting (typical of S2?). This was overprinted by a subsequent (S4?) west side up normal displacement which resulted in decreasing dip and structural thickening of the hangingwall magnetite shear as the subvertical S4 shear is approached. Once in the shear, the dip then steepens and the ironstones become dismembered and/or attenuated. This junction zone has a shallow southward plunge (15° to 35°). The 276 mineralised system clearly exhibits a different geometry to the deposits to the south, and this is apparently linked to a different set of structural conditions and orientations. As per the other deposits in the Selwyn line, the economic mineralisation in the 276 system is larger than the high grade zones mined to date, with abundant slightly lower grade copper dominated ore developed in the hangingwall magnetites, down dip and along strike, and down plunge towards the south of the current workings.

Timing

Comprehensive studies on the timing of the copper and gold mineralisation by Rotherham (1997a) and Adshead-Bell (2000) have laid to rest many of the uncertainties suffered by previous workers. Metallogenic models originally proposed followed the typical "syngenetic versus epigenetic" lines of debate, and ranged from variably remobilised exhalative styles (Davidson 1989) through various shear hosted epigenetic models (Ransom, 1986; Laing et al., 1989). Rotherham (1997b) and Adshead-Bell (2000) integrated petrographic, geochemical, textural and structural data, and provided a solid control on the timing of alteration and mineralisation in the Selwyn Line. This is summarised in the Table 3, which indicates that the economic metals were introduced late and post D4 by hot dominantly magmatic derived fluids, emplaced into a brecciated structural environment. The brittle character was derived from a combination of the post peak metamorphic (cooler) conditions during S4/S5/S6, and by the intensive to pervasive early alteration of rocks within the large S2 aged shears (Starra and Mt Dore) by albite and silica, which decreased the capability of the host rocks to deform by simple shear. Various degrees of hydraulic brecciation are also associated with the emplacement of the mineralising fluids, but the principal pathways were tectonic in origin.

The timing of mineralisation is also seemingly linked to the emplacement of the non-foliated granites in the region. In the Selwyn area these include the Mount Dore granite to the east, the Yellow Water Hole granite further south, and the Belgium granite which intrudes the older foliated Gin Creek granite west and north of the Selwyn Line. Drill holes through the western margins of the Mount Dore granite and mapping by Beardsmore (1992) and Leishman (1990) has indicated that the basal contact of the granite is tectonically brecciated. Kinematic indicators combined with modelled CSAMT, magnetic and gravity data suggests the Mount Dore granite was thrust westward post-S2, along

a number of listric thrust planes, in a series of sheets, rather than emplaced as a simple diapiric body. This relationship is complicated by the fact that most of the western contact of the granite is planed straight by the Mount Dore fault (Beardsmore, 1992) which is interpreted as a syn to post S4 remobilisation of the S2 aged, steeply dipping, regional Mount Dore fault system. This may have been in response to the ongoing intrusion of the granites further to the east (ie. the granite emplacement, thrusting and remobilisation of the Mount Dore shear may have all taken place as a single evolving event during S4). Similar planing of the western margin of the Yellow Waterhole Granite further south is also observed. Here there is evidence from aeromagnetic and spectral data, that the Yellow Waterhole Granite is also a composite intrusive with indications of westward thrusting.

The westward thrusting of the Mount Dore granite is interpreted to have been a fundamental factor in the strong development of the S4 aged high strain shears in the Selwyn Line (Adshead-Bell, 2000). The east-west stress field set up by the westward displacement of the Mount Dore granites resulted in increased crushing of the Staveley Formation metasediments and the interbedded amphibolites against the Gin Creek Granite buttress in the west. Similar buttressing effects are reported by Betts and Lister (2001), for the deformation of the Mt Isa and Twenty Nine Mile faults around the Sybella granite buttress. In this later case the faults and sediments are arched around the curvature of the buttress granite in a similar fashion to the S2 Starra Shear and the Staveley metasediments north of Selwyn. Betts and Lister (2001) invoke high strain zones associated with the buttressing. At Selwyn similar higher strain zones are observed and mapping by Leishman (1983) and by Beardsmore (1992) indicates these coincide spatially with the distribution of a discrete zone of increased calc-silicate and "granofels" alteration developed in the Staveley Formation metasediments.

The timing of the economic mineralisation is proposed by Adshead-Bell (2000) and Rotherham (1997a) as being late to post D4. This is also late to post Mount Dore granite (1516 ± 10 Ma, Pollard and McNaughton, 1997) emplacement and it is proposed that the special conditions under-which the main zone of mineralisation in the Selwyn Line developed, where largely due to the more intense S4 strain features developed in the compressed zone west of the Mount Dore granite body, and east of the Gin Creek buttress. Brittle deformation of the already intensely albitised-silicified Starra Shear, created structural pathways for deeply tapped fluids associated with the last phases of the "Mount Dore aged" regional magmatic event (~1500 Ma).

The Selwyn Line Resource

Perceptions

Throughout the life of these deposits the indications were that the best economics have been associated with the mining of small tonnes at high grades. This enabled the

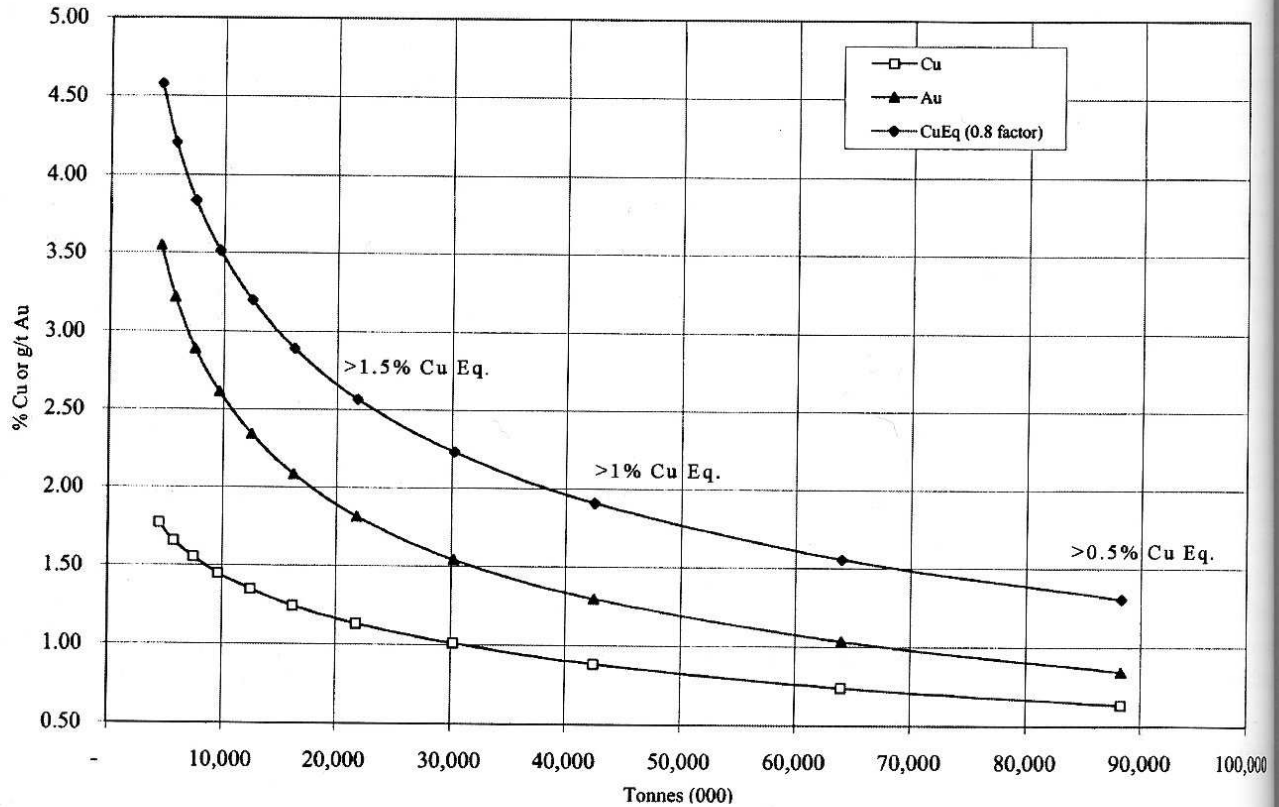


Figure 5: Grade tonnage curve for the post mining Selwyn Line Resource

	Cut off Cu Eq %	Tonnes (000s')	Cu Eq %	Cu %	Au g/t	Cu (t)	Au (oz)	Cu:Au Ratio
Mined	3.5	6 840	5.78	2.1	4.6	143 640	1 011 704	0.46
Post-mined	1.50	21 786	2.56	1.13	1.81	246 182	1 267 931	0.62
	1.00	42 463	1.91	0.88	1.3	373 674	1 774 981	0.68
	0.50	88 270	1.30	0.63	0.84	556 101	2 384 141	0.75
Global	0.2	253 000	0.72	0.34	0.48	860 200	3 917 419	0.71
Pre-mined	1.50	28 626	3.3	1.36	2.48	389 822	2 279 635	0.55
	1.00	49 303	2.4	1.05	1.76	517 314	2 786 685	0.60
	0.50	95 110	1.6	0.74	1.11	699 741	3 395 846	0.66
Global	0.2	259 840	0.9	0.39	0.59	1 003 840	4 929 124	0.66

Assumes : Cu Equivalence = (Cu% + (0.8*Au g/t)) & Global includes measured, indicated and inferred

Table 4: Selwyn Line June 2001 resources (Selwyn Mines June 2001 Resource Statement).

declines to be sunk and the construction to proceed. The resultant perception has thus been that this is what these systems are comprised of. Examination of the entire data set however suggests this is not the case, and these high grade shoots only form parts of far larger systems which are mineralised to economic grades, by processes not dissimilar to those understood for the large Ernest Henry deposit 160 km to the north of the Selwyn Mine.

Resources

Initial resource studies for the 276 Mine in mid 2000 produced a relatively open grade tonnage curve. This prompted a global resource study for the Selwyn Line from the 222 Mine in the south to the 280 area, 5.8 km to the north using the ~168 km of drilling data available, during late 2000. Using a 0.2% Cu Equivalent cut off to define

the mineralised zones, a resource of 253 mt @ 0.48g/t Au and 0.34% Cu in measured, indicated and inferred categories, was identified above ~300m depth below surface (~local RL of >1000 m). The shape of this grade tonnage curve provoked a more detailed revision of the resources, which was completed by June 2001. The resultant grade tonnage curve for measured, indicated and inferred post mining resources, is indicated in Figure 5 and the simplified numbers behind them in Table 4. Studies indicated that the steeply dipping and largely tabular geometry of the Selwyn Line system, precluded the large open pit option for the mining of bulk tonnes, and forced the economics toward higher grade bulk mining underground. Subsequent resource studies focusing on each deposit have identified the current optimal economic cut off at ~1.5% Cu Equivalent. Using this the calculated resources for the Selwyn Line as at July 2001 are ~22 mt @ 1.81 g/t Au and 1.13% Cu (Selwyn Mines Annual Report, 2001). Combining this with the already mined resources for the 5 known deposits in the Selwyn Line, results in a pre-mining global resource of ~29 mt @ 2.48g/t Au and 1.36% Cu (containing 71.5 t, or 2.3 million oz. Au, and 390 000 t Cu metal). There is also a high probability that this resource will be substantially increased once the open ended portions of the 222, 244, and 276 systems are drilled out. In addition, there are indications that at the lower cutoffs, new deposits in the mineralised gaps between the main zones mined to date, will become evident. The transformation in the image of the Selwyn systems is due to the simple application of reduced grade cutoffs within a large mineralised system. A graphic example of this is the 222 mine reserve which changed from a post mining reserve of zero in 1999 to 5 mt @ 1.61g/t Au and 0.77% Cu in 2001, with open ended mineralised shoots to the northeast and at depth. It is also of note that the Cu: Au ratios (Table 4) from the high grade zones are enriched in gold relative to copper, compared to the ratios for the global tonnes.

Conclusion

The Selwyn orebodies are unusual for iron-copper-gold systems in that they have high grade gold rich zones and relatively low cobalt, rare earth and uranium concentrations. Their petrological and metallogenic indicators suggest however that the mineralised system is not far removed from that at Ernest Henry. The late to post regional D3 timing, the character of the alteration, and the style of mineralisation at Ernest Henry are also very similar to those features in the Selwyn Line deposits.

The main controlling factors on the dimensions of the economic deposits in the Selwyn Line have been structural. The high flattening strains at Selwyn during the local D4 event, may have generated numerous planar less voluminous low pressure zones compared to the wider breccia zone common in large deposits such as Ernest Henry. Indications of larger mineralised breccia zones within the Selwyn Line are evident where the Starra Shear type alteration is developed away from zones exhibiting the most intense D4 flattening, but which still retain significant late fragmentation. These areas hold potential

for the development of broader breccia complexes, and the resultant larger deposits.

The Selwyn Line iron-copper-gold system prior to mining was host to nearly 5 million oz. of gold and a million tonnes of copper. Conversion of these resources to reserves is largely only viable by under ground mining. It is anticipated that approximately half of this will have been removed by the end of the current phase of mining.

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