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THE MOUNT ELLIOTT IOCG SYSTEM, EASTERN FOLD BELT, MOUNT ISA INLIER, NORTHWEST QUEENSLAND

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Abstract - The Mount Elliott iron oxide copper-gold (IOCG) system is located within the Eastern Fold Belt (EFB) of the Palaeo- to Mesoproterozoic Mount Isa inlier. It lies within a major high-strain corridor, the Mount Dore Fault (MDF) zone, one of a network of anastomosing structural zones that are developed within the EFB over intervals of tens to hundreds of kilometres, and which appear to influence the distribution of regional calcic-sodic alteration and IOCG mineralisation. The Mount Elliott IOCG system is hosted within a succession of altered siliciclastic and carbonatic sediments and volcanics within the upper of three rift basin cover sequences that overlie a Palaeoproterozoic to Neoarchaean basement, and occur within an enclave between batholiths of 1550 to 1500 Ma A-type granitoids and gabbroids. The steeply east-dipping, reverse MDF, also defines the boundary between the broadly equivalent eastern siliciclastic dominated Soldiers Cap Group and the carbonate-bearing Young Australia Group of the 1680 to 1610 Ma Cover Sequence 3, and as such may represent a rejuvinated synsedimentary rift basin margin structure.

Mineralisation is hosted by both calcsilicates of the Staveley Formation of the Young Australia Group, and intensely skarn altered shales and meta-mafic rocks of the structurally overlying, but stratigraphically older Kuridala Formation of the Soldiers Cap Group. The bulk of the deposit is hosted within breccias, including a polymictic pipe-like mass cutting calcsilicates and amphibolites (after "diorite") within the Staveley Formation, and a megabreccia with clasts of from 0.1 to 20 m across within phyllites and meta-mafic rocks of the Kuridala Formation. Mineralisation also occurs as a replacement of adjacent banded calcsilicates, replacement of infill to breccias and as late carbonate-sulphide veins. Alteration comprises early, pre-breccia pervasive hematite-stained albite-silica, followed by multiple pulses of fracturing, brecciation and alteration, each composed of initial diopside-scapolite, followed by the deposition of actinolite and mineralisation, resulting in an assemblage of chalcopyrite, actinolite, scapolite ±andradite ±tourmaline ±allanite ±apatite ±magnetite ±pyrite ±pyrrhotite and very abundant calcite and anhydrite, as well as minor biotite, chlorite and K feldspar. Skarn alteration closely associated with the main copper-gold-bearing sulphides has been dated at 1510±3 Ma, close to the age of the nearby batholithic granitoids, while stable isotope data are consistent with dominantly magmatic fluids during mineralisation, possibly influenced by a metamorphic fluid component.

Mineralisation has been known and sporadically exploited at Mount Elliott since 1899, while an offshoot of the historic deposit, the Corbould zone, was discovered in 1995. Exploration in the vicinity during the 1980s and 1990s had also encountered the SWAN and SWELL prospects, neither of which have been brought to production. A reevaluation of the existing resource and an intense deep drilling campaign focused on the SWAN resource since 2003 has shown that it coalesces at depth with the other three zones of mineralisation, all of which represent higher grade cores within a large envelope of copper-gold mineralisation, as defined by a 0.25% $Cu_{equiv.}$ cut-off. Published total resources are 570 Mt @ 0.44% Cu, 0.26 g/t Au at 0.3% $Cu_{equiv.}$ cut-off, extending over a strike length of more than 1.5 km, width of ~500 m and to a depth of 1200 m, and includes 62 Mt @ 1.01% Cu, 0.4 g/t Au at a cut-off of 1.0% $Cu_{equiv.}$.

Introduction

The Mount Elliott iron oxide copper-gold (IOCG) system is situated approximately 140 km southeast of Mount Isa, and 90 km south of Cloncurry, within the Eastern Fold Belt of the Palaeo- to Mesoproterozoic Mount Isa Inlier, in northwestern Queensland (Fig. 1).

Exploration focused on the previously known SWAN deposit by Ivanhoe Cloncurry Mines since 2003, has shown that it extends to coalesce at depth with the adjacent Mount Elliott, Corbould and SWELL copper-gold deposits to form a single large IOCG system. As a consequence, this system will be referred to in subsequent sections of this paper as the Mount Elliott system (or deposit), incorporating what were previous regarded as four separate deposits, as zones of the single larger entity.

Exploration and mining has been undertaken in the Eastern Fold Belt since 1867, when a prospector named Ernest Henry discovered copper oxide mineralisation at Great Australia, immediately to the south of Cloncurry (Fig. 1). In 1899, James Elliott, a gold prospector, encountered copper oxides in several trenches he had dynamited into the hill now known as Mount Elliott. Small scale mining commenced in 1901, and after changing hands, Mount Elliott Ltd was floated on the London Stock Exchange to exploit the deposit. Mining and on-site smelting of high grade ore continued until 1921-22 when labour unrest, low grades and copper prices resulted in the closure of the mine. During that period, approximately 24 800 tonnes of copper and 1 tonne of gold were produced by the Mount Elliott smelter, from 0.268 Mt of ore that also included material from the Hampden Consols and Kuridala mines 25 km to the north (Blainey, 1960).

Little subsequent work on the area has been recorded until 1952, from when a number of companies undertook limited exploration programs, including Broken Hill South (BHS) - seven drill holes, Mount Isa Mines (MIM) - three holes and Rio Tinto Southern (RTS) - two holes (Fortowski and McCracken, 1998). The best intersections included 18.8 m @ 4% Cu, 2.2 g/t Au (BHS); 7 m @ 3.71% Cu, no Au assay (MIM); and 17.7 m @ 2.9% Cu, no Au assay (RTS). In 1972, a joint venture between Union Miniere and

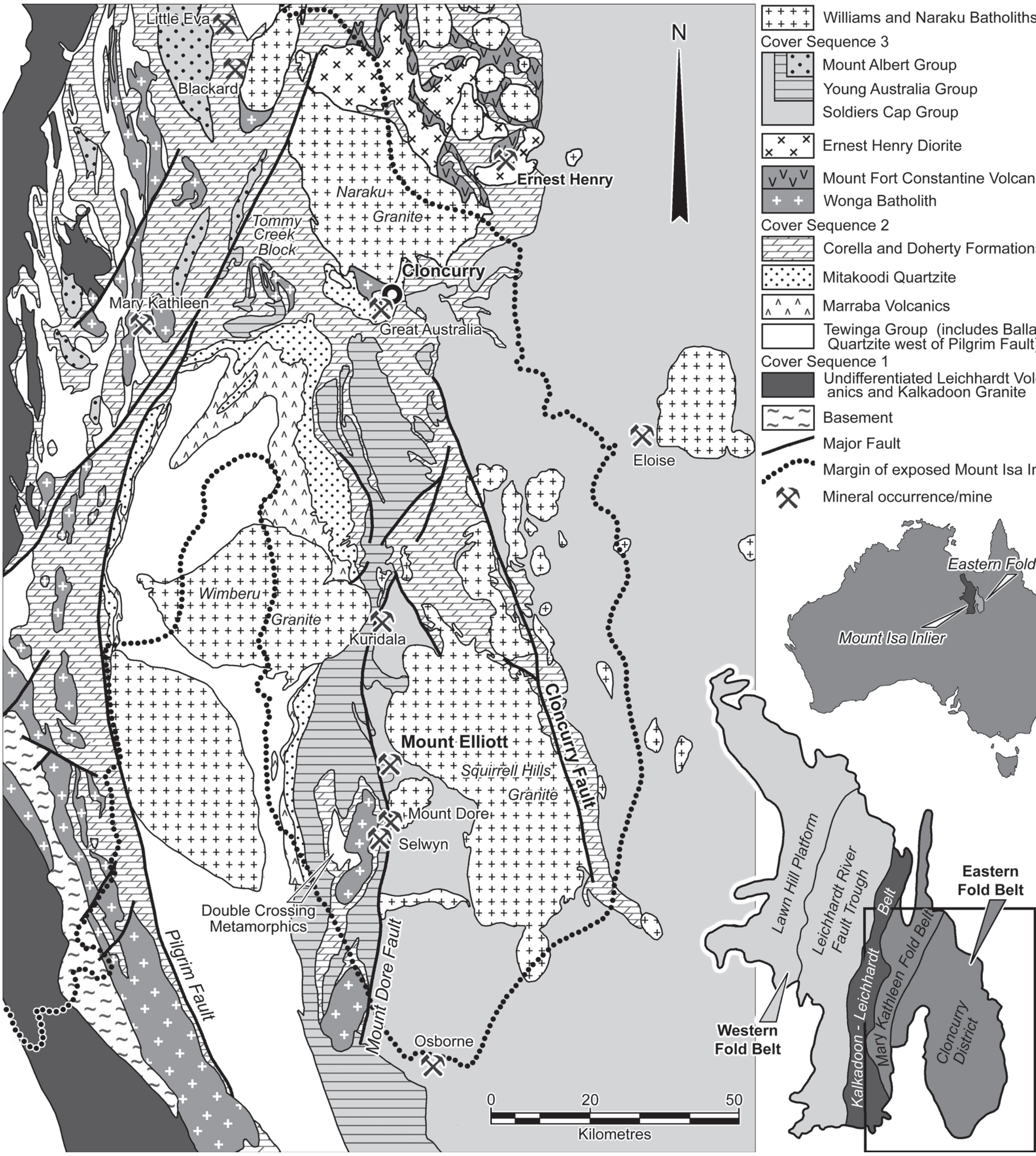

Figure 1: Location and geological summary of the Eastern Fold Belt of the Mount Isa Inlier, northwest Queensland, illustrating the setting and location of the Mount Elliott IOCG system (after Foster and Austin, 2008 and previous sources quoted therein).

Anaconda Australia commenced exploration targeting, in particular, the Reward Pipe of the Mount Elliott zone and a coincident geochemical and circular magnetic feature known as the Southwest Magnetic Anomaly (to become the acronym SWAN) 500 m to the west-southwest. While some reasonable drill intersections (~1% Cu, 1 g/t Au) were obtained, the JV partners withdrew after their drill program was concluded in 1975, to concentrate on the more promising Starra (later to be known as Selwyn) string of deposits, 15 km to the south (Fortowski and McCracken, 1998).

In 1978, the Selwyn Mining Project partners, comprising Amoco Minerals Australia (later to become Cyprus Minerals) Arimco NL and Elders Resources NL acquired title to the area and carried out detailed resource definition drilling, and in 1989 released a resource estimate for SWAN of 13.5 Mt @ 0.9% Cu, 0.5 g/t Au, at a 0.3% Cu cut-off (Selwyn Mines Annual Report, 2001), while a resource of 2.9 Mt @ 3.33% Cu, 1.47 g/t Au had been outlined at Mount Elliot (Fortowski and McCracken, 1998). In 1993, Australian Resources Ltd purchased the Mt Elliott title from Cyprus Minerals and commenced developing a decline into the deposit, with the first ore being produced in 1994. In 1995, the Corbould zone was discovered, immediately to the southwest of the Mount Elliott upper and lower zone orebodies, containing a resource of 0.55 Mt @ 3.35% Cu, 1.5 g/t Au (Fortowski and McCracken, 1998).

In March 1999, Australian Resources went into receivership and the mine closed until purchased by Selwyn Mines Limited in 2000. The new owner reevaluated the reserves and resources, supported by additional drilling, and restarted mining at Mount Elliott, in conjunction with the Mount Dore and Selwyn group of mines some 15 km to the south as a single operation with shared treatment facilities. The revised resource base at Mount Elliott at the commencement of mining was 11 Mt @ 2.9% Cu, 1.2 g/t Au at a 1.5% $Cu_{equiv.}$ cut-off (Sleigh, 2002a) within a global resource of 20 Mt @ 1.11% Cu, 0.57 g/t Au at a 0.5% $Cu_{equiv.}$ cut-off (Sleigh, 2002b). During this period, a reevaluation of SWAN, including two diamond drill holes, resulted in a resource estimate of 43 Mt @ 0.58% Cu and 0.4 g/t Au at a 0.5% $Cu_{equiv.}$ cut-off. However, low copper and gold prices conspired to force closure of the operation again in 2003. During the period 1993 to 2003, the Mount Elliot mine produced approximately 5.06 Mt of ore at 2.90% Cu, 1.5 g/t Au (Ivanhoe Australia website, 2010).

The Selwyn Mines Limited mining leases and associated exploration tenements were acquired by Ivanhoe Cloncurry Mines Pty Ltd in December 2003. A number of options were considered at the still undeveloped SWAN resource between 2003 and 2006, including: (1) a heap leach operation based on the oxide zone, which was rejected on the basis of poor recovery from metallurgical testing; (2) a search for down dip extensions of the transition zone from oxide to sulphide mineralisation to the south, which was discontinued after insufficient encouragement was received from the drilling program; and (3) in 2006 a proposal was generated to test for a northern depth extension of the transition zone. This latter option was based on a reinterpretation of the geology after the previous southern extension drilling program encountered its best intersection of 147 m @ 0.69% Cu, 0.38 g/t Au, including 13m @ 1.92 % Cu, 0.56 g/t Au, in mixed chalcocite and chalcopyrite from the northernmost of the holes drilled. This long intercept of transitional mineralisation was interpreted to reflect a possible large primary sulphide zone at depth (Brown and Kirwin, 2009).

Subsequent drilling returned significant results, with numerous long intercepts, the most notable of which was MEHQ061096, planned to end at 500 m, but which encountered long intercepts of moderate grade mineralisation, with repeated peaks of higher-grade and strong alteration resulting in it being continued to a depth of 1000 m below the surface. This hole was important in that it confirmed the likely size of the system. Drilling in 2007 showed that the original SWAN resource in the south, was essentially an approximately 200 m thick, flat lying blanket, with a steeply plunging extension to the north and northwest (Fig. 6). The highlight of this program were holes such as MEHQ071130 in the western portion of northern SWAN which encountered 90 m @ 1.94% Cu, 1.3 g/t Au, including 34 m @ 4.1% Cu, 2.61 g/t Au, and MEQ071194 on the eastern flank that intersected 342 m @ 1.21% Cu, 0.79 g/t Au. These were followed by step-out pattern drilling that defined a cohesive high grade core to the emerging resource. Further drilling during 2007 and 2008 continued to outline the deposit and revealed that the Mount Elliott, Corbould, SWELL (Southwest Elliott) and SWAN 'deposits' represented high grade zones within a broad lower grade 0.25% $Cu_{equiv.}$ envelope representing a single large mineralised system (Brown and Kirwin, 2009).

By September 2008, testing had proceeded to the stage where a JORC compliant resource was released for the Mount Elliott deposit of 475 Mt @ 0.5% Cu, 0.3 g/t Au at a 0.3% $Cu_{equiv.}$ cut-off (Brown and Kirwin, 2009). The current indicated + inferred resource at 1 September, 2010 is 570 Mt @ 0.44% Cu, 0.26 g/t Au at a 0.3% $Cu_{equiv.}$ cut-off, including a high grade resource of 62 Mt @ 1.01% Cu, 0.4 g/t Au at a cut-off of 1.0% $Cu_{equiv.}$ (Fig. 10). For the 2010 resource grades, $Cu_{equiv.} = Cu\% + 0.7 \times Au$ g/t. The total drilling to September 2010 comprises 2969 holes for a total of 304 930 m (Ivanhoe Australia website).

Regional Setting

The Mount Elliott IOCG System lies within the Eastern Fold Belt, one of three sedimentological and structural domains that constitute the Mount Isa Inlier. These are, from west to east: (1) the Western Fold Belt (WFB); (2) the central Kalkadoon-Leichhardt Belt (KLB); and (3) the Eastern Fold Belt (EFB) (Fig. 1; Blake, 1987; Blake and Stewart, 1992; Page and Sun, 1998; Page *et al.*, 2000; Foster and Austin, 2008).

The Mount Isa Inlier is characterised by Palaeo- to Mesoproterozoic metasedimentary, rhyolitic and basaltic meta-volcanic rocks, gabbro, dolerite and widespread I- and A-type granitoids. An early history of basement formation and deformation was followed by several episodes of intracratonic rifting, accompanied by the development of a series of superbasins and the deposition of three cover sequences (e.g., Blake and Stewart, 1992; Page and Sun, 1998; Southgate *et al.*, 2000). The dominant period of deformation took place during the Isan Orogeny from ~1600 to 1500 Ma (Page and Bell, 1986; Holcombe *et al.*, 1991; Blake and Stewart, 1992). These sequences are intruded by five main periods of magmatism, ranging from 1860 to 1490 Ma.

The KLB separates the WFB and EFB, and comprises a core of predominantly older Cover Sequence 1 felsic volcanic and related intrusive rocks that correspond to the 1870 to 1850 Ma Barramundi Orogeny of northern Australia. Sparse basement rocks are exposed in the form of migmatites, gneisses, quartzites and micaschists within the southern WFB and the KLB, as well as the limited exposure of the Double Crossing Metamorphics to the west of Selwyn in the southern EFB. However, Foster and Austin (2008) have now suggested that the latter are correlates of the lower units of Cover Sequence 2. These basement metamorphics (with the exception of the Double Crossing Metamorphics) are overlain by Cover Sequence 1 rocks and related intrusions in the KLB. On the basis of zircon dating, they are believed to be late Archaean to Palaeoproterozoic in age, although the oldest inherited zircons from one block in the WFB are dated at 3.6 to 3.3 Ga, suggesting Archaean crust below at least the western Mount Isa Inlier, or alternatively Palaeoproterozoic sediments that included Archaean provenance clastics (Bierlein *et al.*, 2008).

The WFB is largely composed of 1800 to 1595 Ma sediments and volcanics of Cover Sequences 2 and 3, deposited in three superbasins. It is principally divided into the Leichhardt River Fault Trough immediately to the west of the KLB, and the Lawn Hill Platform further to the west, each separated from its neighbour by a major north-south trending terrane boundary fault zone (Blenkinsop *et al.*, 2008; Foster and Austin, 2008).

The EFB is divided into the western Mary Kathleen Fold Belt, and eastern Cloncurry District, separated by the Pilgrim Fault (Fig. 1). Another major, northnorthwest trending, deep seated structure, the regional Cloncurry Fault bisects the Cloncurry District (Blenkinsop *et al.*, 2008; Foster and Austin, 2008).

Most of the rocks of the Eastern Succession within the EFB were formed between 1790 and 1500 Ma and include sedimentary and volcanic rocks of Cover Sequences 2 and 3 (CS2 and CS3), deposited between 1790 and 1690 Ma and from 1680 to 1610 Ma respectively (Fig. 1). CS2 includes the rift fill succession of predominantly clastic sediments and felsic volcanics that constitute the Tewinga Group (Argylla Formation); the Malbon Group (comprising the basaltic Marraba Volcanics with siltstones and sandstones, and the Ballara and Mitakoodi Quartzites), which are all overlain by the laterally more extensive platformal evaporitic carbonates (with minor volcanic and clastic rocks and the Overhang Jaspilite at the base) of the Corella and Doherty formations. The Corella and Doherty formations are now dominantly sodic-calcic altered calc-silicates. The lower rift phase members of the CS2 were deposited diachronously from west to east. The sequence was extensively intruded by the 1750 to 1730 Ma Wonga Granite, while the coeval Mount Fort Constantine volcanics separate the Corella and Doherty formations in the north.

Figure 2: Geology and structural setting of the Selwyn-Mount Elliott district (after Geological Survey of Queensland - IRTM). The outline of Fig. 4 is shown surrounding the Mount Elliott deposit.

Minor tonalites, granitoids and diorite emplaced between CS2 and 3 have been dated at 1686 to 1660 Ma (including the Ernest Henry Diorite). The first significant deformation to affect CS2 (but not CS3) was the 1750 to 1735 Ma Wonga extensional event (Blake, 1987; Blenkinsop *et al.*, 2008; Foster and Austin, 2008).

Cover Sequence 3, which extends further to the east than does CS2, is composed of quartzites, pelites, volcanic rocks and carbonates belonging to the broadly coeval, Soldiers Cap, Young Australia and Mount Albert groups, distributed respectively from east to west. The Soldiers Cap Group commences with arenites and pelites, minor carbonates, volcanic rocks and ironstones of the Kuridala Formation to the west of the Cloncurry Fault, and the equivalent Gandry Dam Gneiss further to the east. To the east, the succeeding section comprises the quartzites, conglomerates and iron formations of the Mount Norna Quartzite and the overlying basaltic Toole Creek volcanics which also includes calc-silicates and ironstones. The Young Australia Group, between the Soldiers Cap Group and the Pilgrim Fault, is a thinner sequence, commencing with the less well developed Kuridala Formation equivalent, the Roxmere Quartzite, overlain by the Answer Slate, and in turn by the Staveley Formation which comprises variably calcareous sandstone, siltstone and shale with minor basic volcanics and ironstones, and then the Agate Downs siltstone, followed by the uppermost unit, the Marimo Slate. To the west of the Pilgrim Fault, in the Mary Kathleen Fold Belt, the Mount Albert Group, a reduced succession, equivalent to the upper units of the Young Australia Group only, is composed of the Knapdale Quartzite and the overlying Lady Claire Dolomite. A hiatus in the upper CS3 was followed by emplacement of the minor 1625 Ma Tommy Creek microgranite and sediments mapped as the Tommy Creek Sequence and the upper Marimo Slate, with the Quamby Conglomerate to the west of the Pilgim Fault (Blake, 1987; Blenkinsop *et al.*, 2008; Foster and Austin, 2008).

Deposition of CS3 in the EFB was terminated by the onset of the Isan Orogeny at ~1600 Ma, which was dominated by east-west compression and persisted until ~1500 Ma. The exact nature of Isan D_1 deformation is uncertain, but seems to have involved overall north-south thrusting (Betts *et al.*, 2006), and resulted in a regional, steep, east-west foliation (Rubenach *et al.*, 2008). Greenschist to upper amphibolite peak metamorphism occurred between 1600 and 1580 Ma (D_2) involving positive reactivation of basin-bounding structures and the development of anatectic pegmatites (e.g., the Osborne Pegmatite), followed by several retrograde deformations (D_3, D_4). The most significant crustal structures produced during the orogeny were kilometre scale upright folds and steep faults of D_{2a} (Blenkinsop *et al.*, 2008). D_3 deformation was broadly synchronous with emplacement of the ~1550 to 1500 Ma Williams and Naraku batholiths, and included conjugate northeast- and northwest-trending open folds, predominantly north-south trending shear and fault zones, and widespread breccias which were best developed within Corella Formation strata (Marshall and Oliver, 2008). This resulted in: (1) anastamosing shear zones that varied from a few to ~500 m wide and up to 50 km in strike length, (2) locally intense zones of veining, and (3) broad intervals of hydrothermal brecciation (Fig. 3; Marshall and Oliver, 2008; Rusk *et al.*, 2010). While discordant, polymict, transported breccias are locally common in the EFB, the most widespread breccias are confined to the Corella Formation, with negligible clast transport or mixing (Marshall and Oliver, 2008).

The Williams and Naraku batholiths resulted from a number of pulses of voluminous mafic and felsic potassic magmatism and were emplaced as tabular bodies at mid-crustal levels. Despite having A-type geochemical signatures, these granites are syn-tectonic and derived from high temperature crustal melting at pressures not exceeding 1000 MPa (Mark *et al.*, 2005a). Rubenach *et al.* (2008) propose that mafic rocks emplaced into the lower crust of the EFB (and elsewhere across the Mount Isa Inlier) caused the 1600 to 1580 Ma high temperature (580 to 670ºC), low pressure (400 to 600 MPA) metamorphism and partial melting at the peak of metamorphism, and later contributed to the formation of the Maramungee Granites (Fig. 3; 1547 to 1545 Ma) and the 1550 to 1500 Ma Williams and Naraku batholiths. They support this proposition with the observation that most mafic rocks in the Inlier are predominantly high-Fe tholeiites, and therefore are unlikely to be direct mantle melts, but rather magmas that resided and fractionated in the lower crust, and produced a significant lower crustal thermal anomaly over an extended period.

The Mount Elliott IOCG system is located within a regional, north-south aligned corridor of focused strain, extending for more than 100 km from Cloncurry in the north to the southern limit of Proterozoic exposure in the EFB (Fig. 3; Laing 1998; Williams *et al.*, 1998). In its southern half, this zone of high strain generally corresponds to a significant lithological break between calcareous/calcsilicate bearing sequences of the Young Australia Group to the west, and metasiliciclastic (commonly carbonaceous) dominated successions of the Soldiers Cap Group in the east, implying long-lived structures that also influenced basin architecture during deposition (Wang and Williams, 2001; Foster and Austin, 2008; Blenkinsop *et al.*, 2008).

This high strain corridor has also been a focus of alteration and mineralisation, and is part of a network of major, generally longitudinal, partly anastomosing high-strain zones within the EFB (Fig. 3). These zones form the core of regionally pervasive, mid-crustal, multiple phase, sodic-calcic alteration and metasomatism, which are locally overprinted by potassic alteration associated with IOCG mineralisation. Much of the regional alteration and the bulk of the IOCG mineralisation, formed during the latter half of the ~1.6 to 1.5 Ga Isan orogeny, broadly coincident with the Willams-Naraku batholiths (de Jong and Williams, 1995, Kendrick *et al.*, 2008 and multiple references quoted therein). A study of noble gas plus halogen data from the EFB, in conjunction with stable isotope constraints, are compatible with district scale convection of sedimentary formation waters, driven by heat from the Williams-Naraku batholiths which contributed minor magmatic fluids, focused by these high-strain corridors (Kendrick *et al.*, 2008).

The high-strain corridor with which the Mount Elliott IOCG system is associated, the Mount Dore Fault (MDF) zone, controls the location of a number of other mineralised centres, including Kuridala (18 km north of Mount Elliott), Mount Dore and Selwyn/Starra. The Selwyn (formerly known as Starra) IOCG system, which extends over a strike length of ~6 km within the Starra shear zone, some 10 to 15 km south of Mount Elliott (Fig. 2), contains an estimated global resource (not JORC compliant) of 253 Mt @ 0.34% Cu, 0.48 g/t Au, at a 0.2% $Cu_{equiv.}$ cut-off, enclosing a measured + indicated JORC resource of 22 Mt @ 1.13% Cu, 1.81 g/t Au, at a 1.5% $Cu_{equiv.}$ cut-off, in a series of high grade gold-copper shoots. These shoots are developed in structural loci within a large, tabular, copper-gold mineralised system, characterised by intense alkali-iron oxide-silica-carbonate alteration (Sleigh, 2002b). Production from the five main Selwyn deposits (276, 257, 251, 244 and 222; Fig. 2), prior to this estimate, amounted to 6.84 Mt of ore @ 2.1% Cu, 4.6 g/t Au (Selwyn Mines Prospectus, 2000).

The recently discovered high-grade Merlin molybdenum-rhenium deposit (measured + indicated + inferred resource of 6.7 Mt @ 1.33% Mo, 23.1 g/t Re; Ivanhoe Australia website, 2010) is located in the footwall of the Mount Dore copper deposit which occurs in the same structural and stratigraphic position as Mount Elliott, and is 1250 m east of the northeastern margin of the Selwyn IOCG system. The Merlin mineralisation is a late phase, associated with silica-albite alteration and interstitial clay, and was emplaced along reactivated fractures and shear zones, replacing the matrix of structurally controlled breccias that

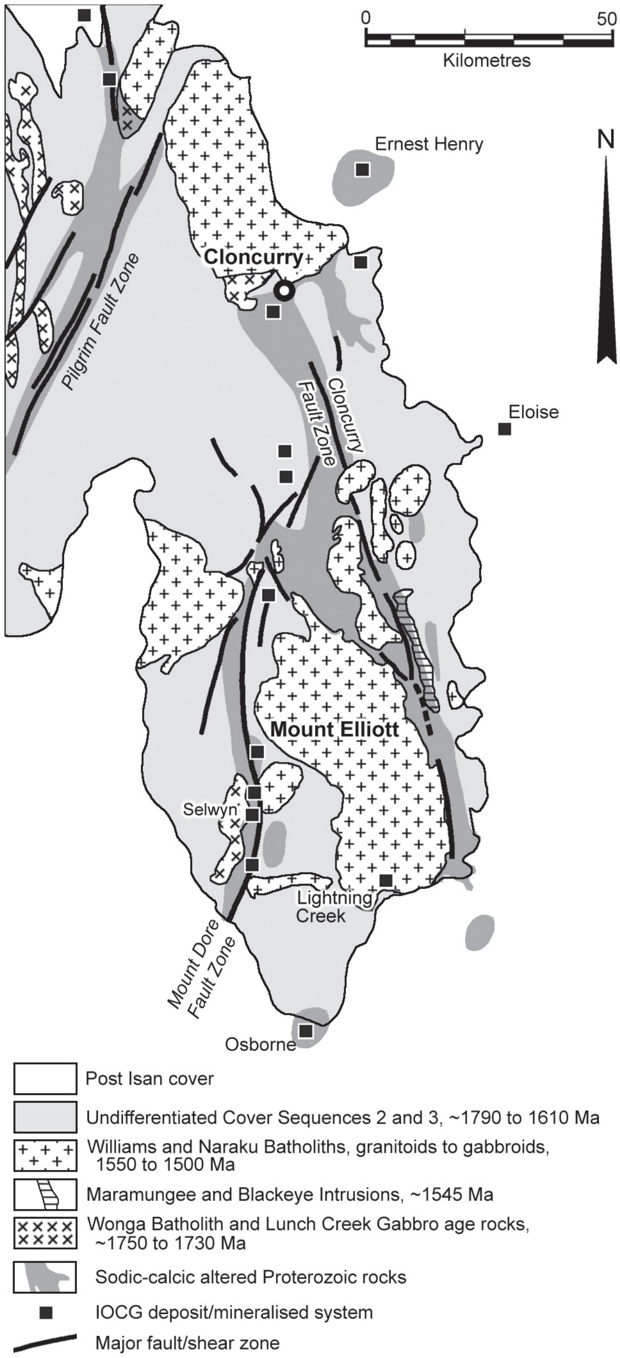

Figure 3: Distribution of structural elements, regional calcic-sodic alteration (partly schematic) and IOCG mineralisation within the Eastern Fold Belt of the Mount Isa Inlier, and the location of the Mount Elliott IOCG system within this framework (after Kendrick *et al.*, 2008; Mark *et al.*, 2005; Oliver, 1995).

occur in carbonaceous shale and metasiltstone, and host the copper-zinc sulphides at Mount Dore. At Mount Dore (indicated resource of 86.5 Mt @ 0.55% Cu, 0.09 g/t Au, 0.24% Zn, 5.3 g/t Ag, 0.01% Mo, 0.1 g/t Re; Ivanhoe Australia website, 2010), early regional scale sodic-calcic alteration is cut by K feldspar and quartz veining, succeeded by brecciation which hosts the earliest episode of primary copper mineralisation. A second phase of brecciation was followed by a hydrothermal event that deposited mainly dolomite with chalcopyrite, pyrite, sphalerite, cobaltite and bornite, with trace galena, arsenopyrite and molybdenite (Lazo and Pal, 2009). In the upper 180 m thickness of the ore zone, primary sulphides have been converted to chalcocite, which has subsequently been oxidised to chrysocolla, native copper, cuprite and pseudomalachite, resulting in the an upper copper-oxide zone overlying a narrow chalcocite dominated transition to primary sulphides without significant iron oxides (Ivanhoe Australia website, 2010).

Deposit Geology

The Mount Elliott IOCG system mineralisation is developed within a north-south oriented zone of high strain, hosted by brecciated and veined Cover Sequence 3 rocks, within an enclave of the Williams-Naraku batholith, and is accompanied by dykes and sills of amphibolite and diorite (Fig. 2: Brown *et al.*, 2009; Wang and Williams, 2001; Sleigh, 2002b; Blenkinsop *et al.*, 2008; Fortowski and McCracken, 1998).

The hosts to the Mount Elliott deposit are flanked by the foliated pre-tectonic Gin Creek (1741±7 Ma; Page and Sun, 1998; Wonga Batholith equivalent) granite to the southwest, and by the non-foliated, post-tectonic, uranium-rich, A-type Mount Dore (1516±10 Ma; Foster *et al.*, 2008) and Squirrel Hills (~1510 to 1490 Ma, Page and Sun, 1998) granites to the south and east respectively (Fortowski and McCracken, 1998).

The rocks in the Mount Elliott area are metamorphosed to lower amphibolite facies and have been subjected to complex ductile deformation. The most significant structural feature is the generally north-south oriented Mount Dore Fault (MDF), represented by a zone of complex ductile and brittle deformation to the west of the deposit (Wang and Williams, 2001). The MDF is part of the major corridor of focused strain, described in the previous section, that extends from Cloncurry to the southern margin of the EFB (Fig. 3), and was re-activated as a D_3 structure, possibly reflecting an earlier, syn-depositional rift bounding normal fault. Where constrained at Mount Dore (Beardsmore, 1992), the MDF was shown to be associated with a 500 to 1000 m reverse displacement on steeply east-dipping surfaces.

Immediately to the west of the deposit area, Sleigh (2002b) shows the MDF to be represented by a zone of faulting and shearing, including the Selwyn Shear, over a width of approximately 1 to 2 km. To the west the mapped country rocks are variably calcareous, calc-silicate bearing, ferruginous, feldspathic and siliceous interbedded sandstone, siltstone, phyllite, shale and mudstone, interpreted to belong to the Staveley Formation, underlain 10 km further west by the Answer Slate (Fig. 2; Sleigh, 2002a; 2002b; Foster and Austin, 2008). Both units are members of the Young Australia Group (Foster and Austin, 2008). The same structure, marks the western margin of exposed Kuridala Formation, which is predominantly composed of siliciclastics with lesser mafic volcanic rocks and iron formations, and is interpreted to be part of the Soldiers Cap Group (Foster and Austin, 2008; Wang and Williams, 2001). Within the immediate deposit area, calc-silicate dominated rocks, correlated with the Staveley Formation, structurally underlie the older Kuridala Formation siliciclastics (Figs. 4 and 5). This relationship implies the contact between the two units is either an earlier, pre-D_3 fault or shear, or alternatively an overturned transgressive unconformity,

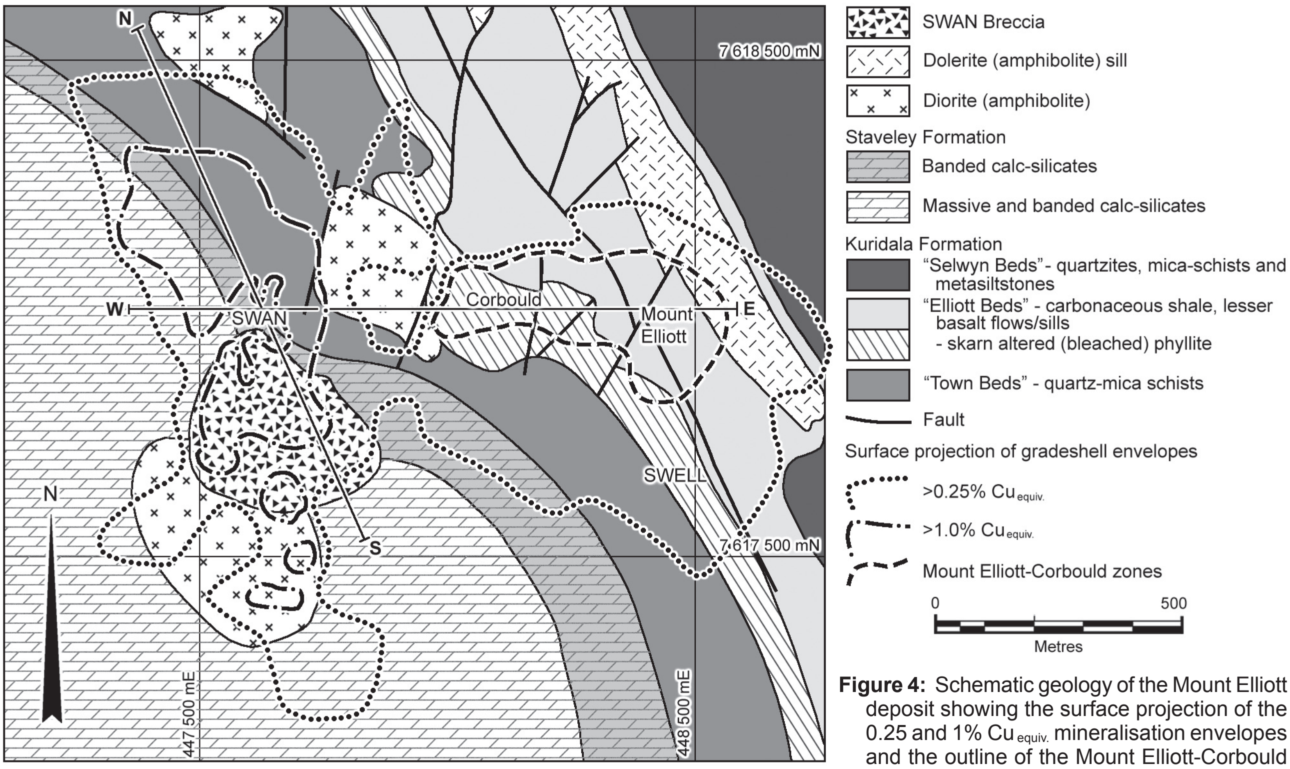

Figure 4: Schematic geology of the Mount Elliott deposit showing the surface projection of the 0.25 and 1% $Cu_{equiv.}$ mineralisation envelopes and the outline of the Mount Elliott-Corbould zones. To the west, the north-plunging SWAN zone is hosted by banded and brecciated calc-silicates of the Stavely Formation, while to the east, the Mount Elliott and Corbould zones are within the structurally overlying metasediments and metavolcanics of the Kuridala Formation. The blind SWELL zone, to the southeast, is contained within the northeast-dipping banded calsilicate unit at the structural top of the Staveley Formation (Modified from Brown, 2009; Brown and Kirwin, 2009; Brown *et al.*, 2009; Wang and Williams, 1996).

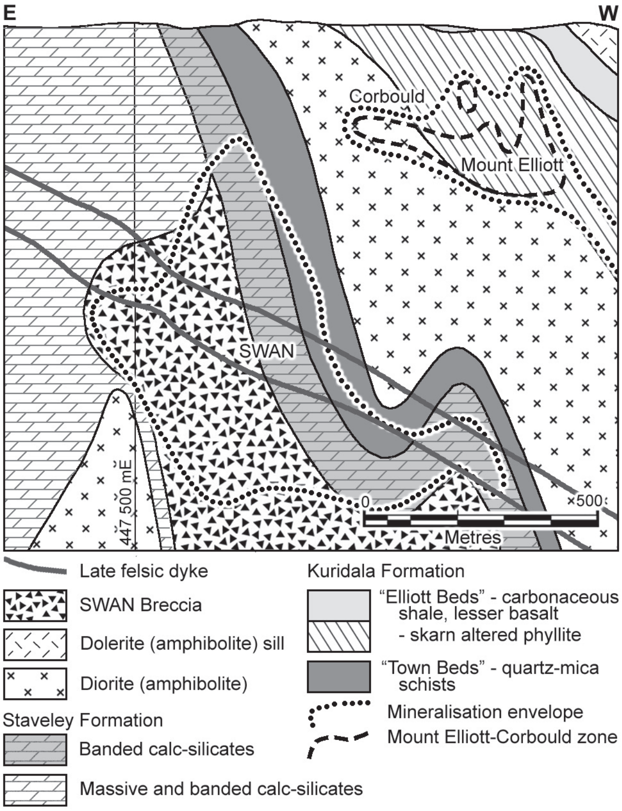

Figure 5: A schematic section through the 7 618 000 mN line of the Mount Elliott Deposit, looking north, showing the SWAN, Corbould and Mount Elliott zones and the generalised outline of the lower grade mineralised envelope encompassing the individual zones on that section. See Fig. 4 for line location (Modified from Brown, 2009, Brown and Kirwin, 2009; Brown *et al.*, 2009).

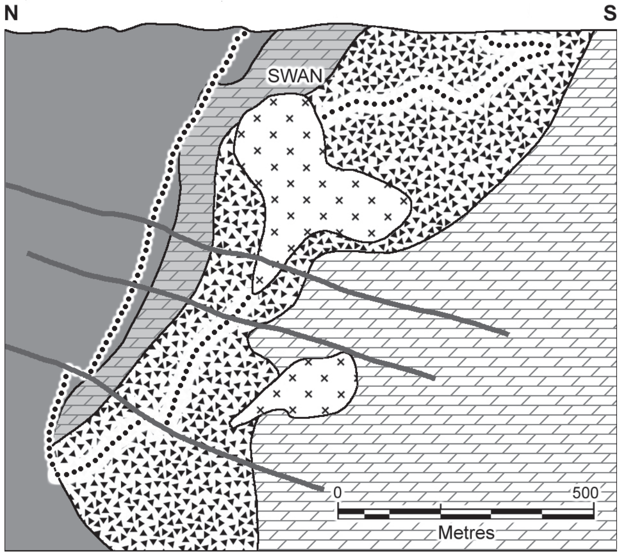

Figure 6: A schematic, approximately north-south section through the SWAN zone of the Mount Elliott Deposit. This figure shows how the near surface mineralisation at SWAN occurs as an ~200 m thick, flat lying blanket, with a steeply plunging extension to the north and northwest which forms a steeply dipping tongue. Mineralisation occurs both within the structurally upper section of the SWAN Breccia and as replacement of the overlying banded calc-silicates. A series of trachyandesite dykes cross cut the mineralisation, one of which appears to offset mineralisation at depth. See Fig. 4 for location and Fig. 5 for geological legend (Modified from Brown and Kirwin, 2009).

with the stratigraphically intervening Answer Slate absent. The bulk of the SWAN and SWELL zone mineralisation is hosted by the Staveley Formation, while the Mount Elliott and Corbould zones are within the Kuridala Formation (Brown *et al.*, 2009).

Isolated patches of mesa forming Mesozoic sedimentary rocks locally obscure the Palaeoproterozoic sequences (Wang and Williams, 2001).

The Mount Elliott zone is hosted within a package of intensely skarn-altered (clinopyroxene ±actinolite, magnetite, scapolite and apatite) phyllites, metabasalts and schists of the Kuridala Formation, intruded by metamafic rocks. This sequence, which dips steeply to the northeast has been informally subdivided into (e.g., Fortowski and McCracken, 1998; Wang and Williams, 1996; Wang and Williams, 2001; Brown and Kirwin, 2009) the:

(1) "Town Beds", that comprise the structural footwall, and are composed of quartz-mica schist (Fig. 7F) which may be locally significantly garnet altered and replaced by sub-ore grade mineralisation. In thin section, these schists are medium- to coarse-grained, made up of varying proportions of quartz, plagioclase, biotite and muscovite, and locally altered to almandine, staurolite and andalusite.

(2) "Elliott Beds" that constitute the immediate host and hanging wall sequence, and where unaltered, are composed of fine grained carbonaceous phyllite and schist, which are progressively altered to a coarse-grained skarn towards the footwall. In the hanging wall, these rocks comprise phyllites and fine-grained schists composed predominantly of quartz, muscovite, biotite and typically ~1% fine-grained graphite, with local andalusite. Pyrite and pyrrhotite are commonly concentrated in laminae parallel to the main tectonic cleavage. Massive to vesicular flows of basalt occur in places within the sequence (Fig. 7D), separated by calcareous sediments, with possible pillows having been observed, characterised by lobes with fine grained chilled margins, trapped layers of vesicles and cores of coarser grained material.

(3) "Selwyn Beds" quartzites, schists and metasiltstones which are unmineralised and are found in the structural hanging wall of the ore zone, to the northeast of the deposit area.

Small scale bedding is rarely observed, and where present is parallel to the dominant fabric, a strong foliation, striking northwest to northnorthwest and dipping at 50 to 80° northeast (Wang and Williams, 2001).

Coarse (mega-)breccias are developed within metapelites of the Kuridala Formation, in association with mineralisation which occurs as open-space infill of sulphides and gangue minerals (Fig. 7I). Breccia fragments are usually angular and may be from 0.1 to as much as 20 m across. The matrix voids can be of a similar size and are commonly characterised by very coarse grained sulphides, magnetite and pyroxene (Brown and Kirwin, 2009). These breccias are related to brittle fracture, brecciation, replacement and open space fill by mineralisation and gangue minerals (Wang and Williams, 2001; Brown, 2009; Bown *et al.*, 2009; Brown and Kirwin, 2009)

The SWAN zone is largely hosted by (1) a breccia that has been developed within a package of banded and massive calc-silicates and sheared and altered metasediments that are interpreted to constitute the Staveley Formation (Wang and Williams, 2001; Fortowski and McCracken, 1998; Brown *et al.*, 2009), and (2) structurally overlying banded calcilicates. The protoliths of the calcsilicate package comprised interbedded marble, calcareous sandstone and lesser siltstone. The massive calcsilicates are composed of coarse-grained calcite, tremolite-actinolite, albite, scapolite,

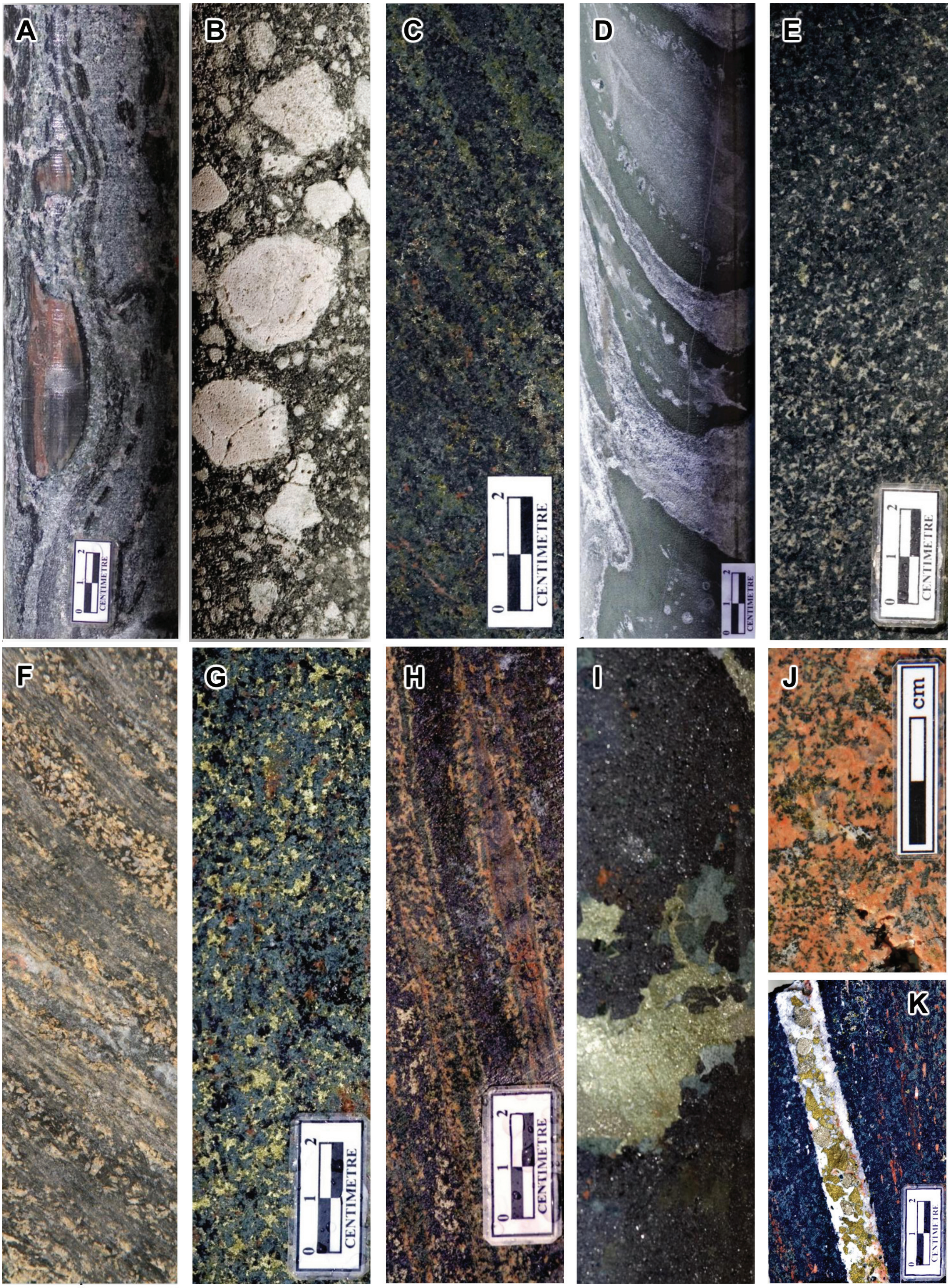

Figure 7: Key lithologies, alteration and mineralisation styles from the Mount Elliott IOCG system. **A** - Layered fine- and coarse-grained calc-silicates from the footwall of the SWAN zone; **B** - SWAN Breccia, polymictic, fragment to matrix supported breccia, host to the majority of the SWAN zone mineralisation; **C** - Banded calc-silicate from the eastern margin of the calc-silicate unit; **D** - Banded, vesicular basalt from the Kuridala Formation; **E** - SWAN diorite, from adjacent to the SWAN breccia; **F** - Altered, muscovite-chlorite schist of the "Town Beds" immediately above the contact between the Kuridala and Staveley Formations; **G** - High-grade mineralisation hosted by the SWAN breccia; **H** - Mineralisation hosted by banded calc-silicates; **I** - Coarse-grained pyroxene-chalcopyrite-magnetite-calcite and anhydrite from Mount Elliott; **J** - Late felsic dyke; **K** - Late stage, coarse-grained, carbonate-chalcopyrite-pyrite and molybdenite veining from SWAN.

muscovite and chlorite. Intercalated banded calc-silicates comprise 0.5 to 10 cm thick bands of very fine grained, commonly hematite-stained and albitic-siliceous material, interlayered with a coarse-grained assemblage as detailed for the massive calc-silicates (Fig. 7A). Individual bands are frequently boudinaged, displaced and rotated, although the gross layering is typically preserved. Where found on the margin of the breccia pipe, banded calc-silicates are commonly mineralised. A 30 to 200 m thick band of layered calc-silicate structurally overlies the main calcsilicate package, adjacent to the contact with the Kuridala Formation, also corresponding in part to the margin of the main breccia-pipe. This particular unit comprises regular, 0.5 to 3 cm bands of hematite-stained albite, magnetite, clinopyroxene, actinolite, epidote and calcite (Fig. 7C; Brown *et al.*, 2009). The metasedimentary rocks of the Staveley Formation differ from those of the Kuridala Formation in that they are thinly bedded and non-carbonaceous. The individual compositional layers are 0.5 to 10 cm thick and include calc-silicate bands composed of calcite, scapolite, diopside and actinolite, and pelitic to psammopelitic quartz-mica schist bands, the latter extensively albitised. To the east, the structural hanging wall of the uppermost banded calc-cilicate unit grades imperceptibly over an interval of 10 to 30 m into the quartz-muscovite-chlorite schist of the "Town Beds" at the contact with the Kuridala Formation (Wang and Williams, 2001).

The SWAN breccia, which varies from crackle to matrix-supported, hosts the majority of the mineralisation and is up to more than 400 m in diameter. It is composed of angular to rounded, strongly albite-altered calcsilicate and metadolerite clasts set in a fine- to coarse-grained matrix of hematite-stained albite, clinopyroxene, actinolite, magnetite, calcite, pyrite and chalcopyrite (Fig. 7B). The individual clasts vary from centimetres to metres in diameter. The intensity of the hematite-albite alteration frequently precludes the identification of the protolith of the majority of fragments (Brown *et al.*, 2009).

An up to 200 m thick metadolerite sill occurs near the contact between the Elliott and Selwyn beds in the hanging wall of the Mount Elliott zone, and forms the southern extremity of a zone of magnetic metadolerite that can be traced for 20 km to the north (Fig. 2). Discontinuous exposures of rocks originally mapped as 'metabasalt' ('diorites' on Figs. 4, 5 and 6) occur in the western part of the Mount Elliott zone, plunging steeply to the east in the footwall of the Elliott Beds. These metabasic rocks, which are overall concordant with the Elliott Beds, exhibit relationships to the host sequence indicating that they are intrusive. They range from fine-grained and massive, to medium-grained varieties that have relict ophitic to sub-ophitic textures, are composed mainly of hornblende and intermediate plagioclase, and have a dioritic composition. Overall, they have a much weaker metamorphic fabric than do the host metasediments.

A 200 to 400 m diameter body of metadiorite or metagabbro, the SWAN Diorite, intrudes the Staveley Formation to the immediate southwest of the SWAN breccia (Fig. 4). It is composed of medium- to fine-grained actinolite, plagioclase, biotite, quartz, tremolite, magnetite, epidote and calcite (Fig. 7E). The margin adjacent to the SWAN breccia is strongly hematite-stained, albitised and brecciated, although the core is relatively unaltered.

Fine- to medium-grained unmetamorphosed dykes, from a few, to several tens of metres in thickness, intrude the hanging wall metasediments of the Kuridala Formation, both at depth and in outcrop to the west. From geochemical data, they appear to be trachyandesitic in composition, although described as microdiorites by Fortowski and McCracken (1998). According to Wang and Williams (2000), thin sections show these dykes are largely pervasively albitised and carbonate altered, although some fresh cores contain large primary K feldspars, while some biotite has been described where they occur in the Corbould zone. However, they are mostly fine- to medium-grained aphyric to weakly porphyryitic rocks composed of albite ±K feldspar with lesser quartz, titanite, calcite, magnetite, pyrite and chalcopyrite. The absence of diopside veining, presence of carbonate alteration and weak pyrite-chalcopyrite suggest these dykes were emplaced towards the end of the mineralising process (Wang and Williams, 2001).

Several, narrow, late-stage, pink to grey felsic dykes crosscut the SWAN zone (Fig. 7J). These dykes, which dip shallowly (~30º) towards the east-southeast (Figs. 5 and 6), and range between 1 and 30 m in thickness, exhibit classic chilled margins. They are composed of plagioclase, K feldspar, quartz, chlorite (after biotite), titanite, magnetite, pyrite and chalcopyrite, and crosscut the mineralised breccias, but pre-date late-stage mineralised veins. Miarolitic cavities, which are common, contain chalcopyrite, pyrite and calcite, and in conjunction with the sulphide-magnetite assemblage, suggest the presence of volatile-rich and copper-gold-iron bearing melts during the waning phase of mineralisation in the SWAN region.

Geophysical Expression

Ground magnetic data, which was initially collected on 50 m lines in 2006, with a subsequent 25 m infill program over the Mount Elliott and SWAN zones in 2007, has been reduced to pole and compiled into a detailed data image (Fig. 8). To the northeast, these data show a linear 800 × 50 m feature which reflects an early dolerite sill hosted by carbonaceous metapelites and phyllitic units of the Kuridala Formation. The magnetic signature over, and immediately to the southwest of, the historic Mount Elliott mine is confused by magnetic disturbance from large slag and sulphide/magnetite bearing waste dumps as well as remaining early infrastructure. In addition, much of the high grade mineralisation had been extracted at the time of data collection. In the southwest of the mineralised system, the dominant feature is the ~400 × 200 m "bullseye" magnetic anomaly of the SWAN zone. This latter feature, in conjunction with a strong geochemical anomaly, provided the impetus for the original testing of the SWAN prospect by Union Miniere in the early to mid 1970s. It reflects both the strong magnetite accompanying the SWAN mineralisation and the immediately adjacent magnetic SWAN Diorite (Fig. 4).

A second strong magnetic anomaly, 500 m to the northnortheast of the SWAN zone, is directly associated with a fine-grained diorite (North SWAN Diorite) that contains disseminated magnetite and sulphides. The circular anomaly 500 m to the southwest of Mount Elliott has not been adequately explained and may represent a near surface section of the SWELL anomaly, although drilling in that area has failed to intersect magnetic material that could generate the measured response.

Ground gravity data was collected over the Mount Elliott region during 2007 at 100 m interval stations on

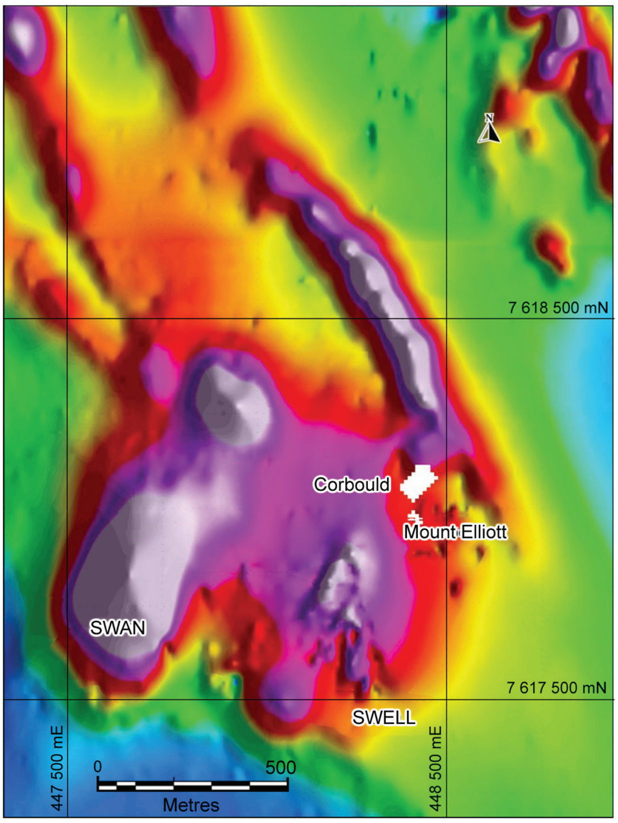

Figure 8: Detailed ground magnetic image of the SWAN, SWELL, Mount Elliott and Corbould zones of the Mount Elliott deposit, from 25 m line spaced reduced to pole magnetic data. The magnetic response to the Mount Elliott, Corbould and SWELL zones are disguised by surface magnetic interference from slag heaps, waste dumps and surface infrastructure. Compare with the geology illustrated on Fig. 4 (Brown and Kirwin, 2009).

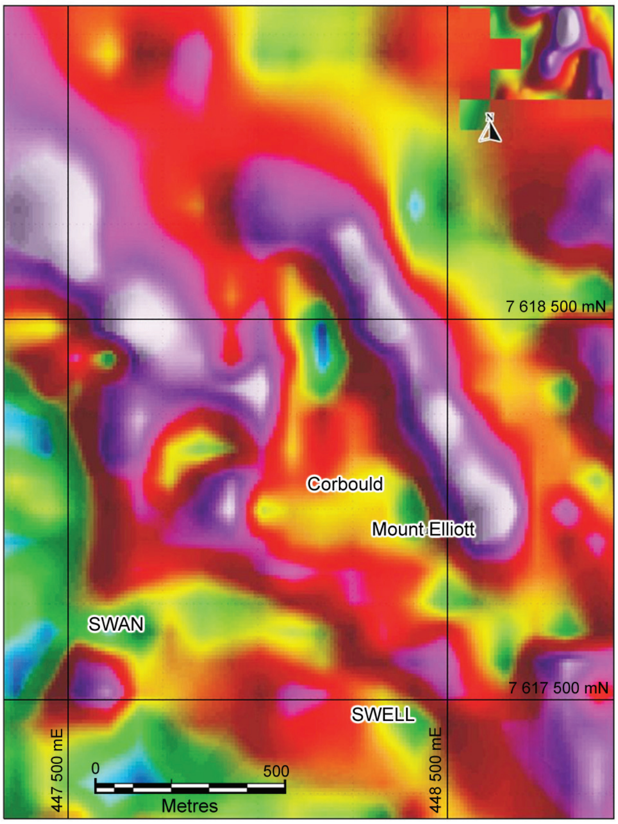

Figure 9: Detailed ground gravity image, showing the first vertical derivative of bouguer gravity over the SWAN, SWELL, Mount Elliott and Corbould zones of the Mount Elliott deposit. The image highlights the denser mafic rocks, showing the SWAN diorite in the southwest, the dolerite sill in the northeast and the diorite intrusions and basalts to the northwest. Compare with the geology illustrated on Fig. 4 (Brown and Kirwin, 2009).

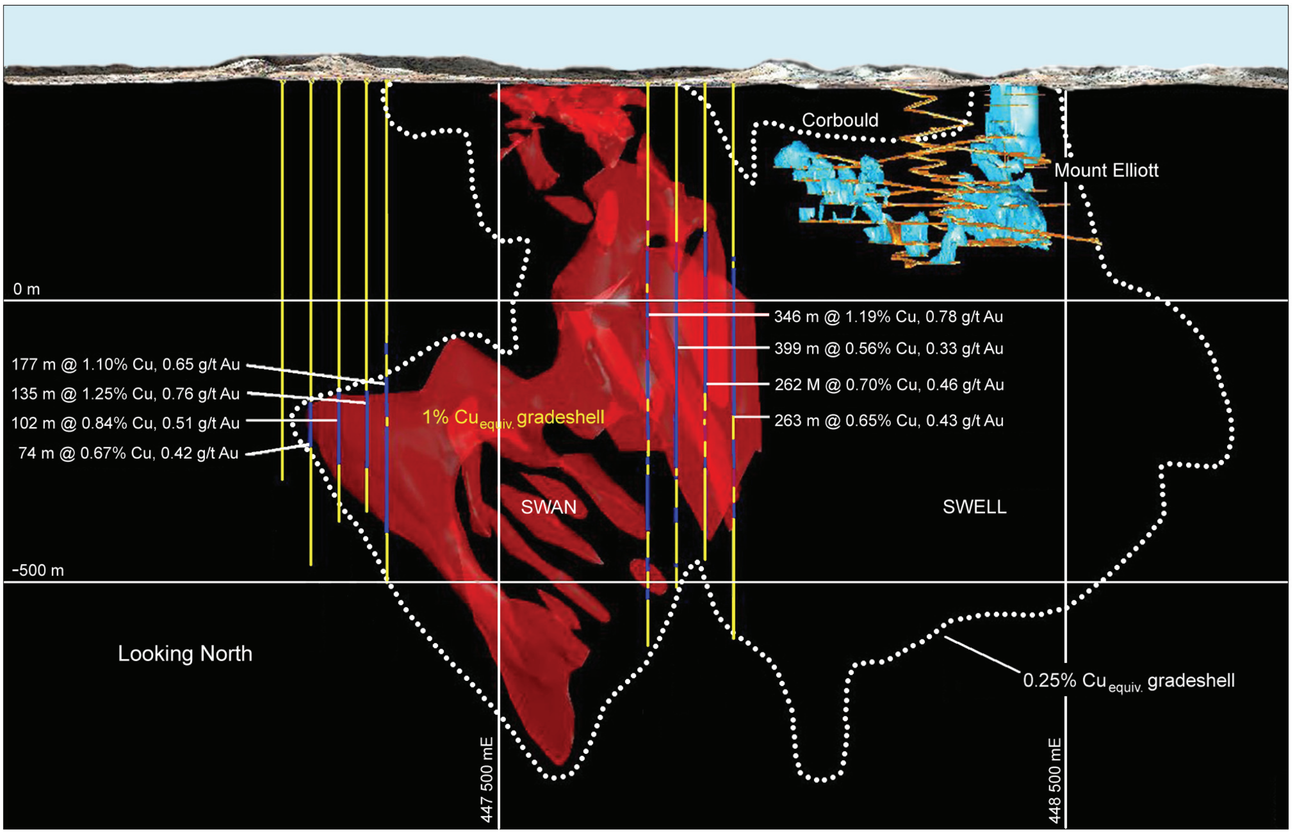

Figure 10: Section through the Mount Elliott IOCG system showing the 1% Cu $_{equiv.}$ grade shell of the SWAN zone, the Mount Elliott and Corbould zone mineralisation and the location of the SWELL zone, as well as the projected outline of the 0.25% Cu $_{equiv.}$ envelope that encompasses all four zones. In addition, a group of representative drill holes through the SWAN zone are shown with intersections illustrating the distribution and quantum of grade (Brown and Kirwin, 2009).

400 m spaced lines, subsequently infilled to 100 × 100 and 50 × 50 m centres over the Mount Elliott deposit. The resultant high resolution data are imaged as the first vertical derivative of bouger gravity on Fig. 9. As with the magnetic survey, the gravity data appears to reflect the dolerite sill in the northeast of the deposit area, as well as isolating both the SWAN and North SWAN diorites, differentiating them from the mineralisation, which combined with the intrusives to produce the more extensive magnetic anomaly at SWAN. The SWAN zone mineralisation appears to only have a moderate gravity response to the northeast of and separated from the SWAN Diorite (compare the grade shells and gravity response on Figs. 4 and 9 respectively). The large northwest aligned gravity high to the northwest appears to represent a significant mass of basalt and mafic intrusive rocks hosted within less dense siliciclastic rocks of the Kuridala Formation.

Alteration and Mineralisation

Four main styles of mineralisation are recognised within the Mount Elliott IOCG system, namely: (1) the Mount Elliott Breccia; (2) the SWAN Breccia; (3) banded replacement; and (4) late veins.

The *Mount Elliot Breccia* hosts the bulk of mineralisation in the Mount Elliott zone. It occurs as a megabreccia, dominated by usually angular clasts that are 0.1 to 20 m across, and was developed within skarn-altered metapelites. Mineralisation occurs as open-space infill of chalcopyrite-pyrite-pyrrhotite-magnetite-pyroxene (diopside-hedenbergite) ±calcite, anhydrite, apatite, gypsum and amethyst within inter-clast spaces of similar dimensions. It is commonly characterised by very coarse grained (as much as tens of centimetres across) sulphides, magnetite and pyroxene (Fig. 7I; Wang and Williams, 2001).

Fortowski and McCracken (1998), after Garrett (1992) and McLean and Benjamin (1993) described the zonation of skarn alteration, inwards and downwards, from an outer zone of bleaching due to the destruction of biotite and graphite and development of quartz-albite-sericite-calcite ±pyrite, pyrrhotite and rare fluorite. Bleaching becomes progressively more pronounced with the increase of hematite-dusted albite and minor K feldspar appears on fractures and foliations. With a further intensification of alteration, a greenish tinge appears, reflecting the addition of clinopyroxene (diopside-hedenbergite) or amphibole (actinolite-tremolite). The phyllitic texture of the host is progressively destroyed with expanded fracturing and brecciation, and the deposition of massive, crystalline hematite-dusted albite-clinopyroxene veins up to 2 m wide. Massive skarn formed with K feldspar, calcite and clinopyroxene developing within the interstices of hematite-dusted albite and eventually replacing it. Rare, mainly andradite garnet occurs at depth. This assemblage is interpreted to represent prograde, anhydrous alteration, which was overprinted and replaced in part by coarse-grained clinopyroxene-scapolite-calcite-magnetite, with chlorite, epidote, calcite, sulphides and magnetite being the result of late retrograde alteration, as is the interstitial chalcopyrite and pyrite in the massive skarn.

The main alteration paragenesis (after Wang and Williams, 2001) producing this zonation commenced with the development of a pronounced, generally pervasive, fracture- and fabric-controlled sodic alteration of the host rocks to produce white to pink (hematite-stained) albite, minor scapolite and recrystallised quartz. This assemblage replaces and obliterates the textures of all the protoliths by destroying metamorphic micas, ferromagnesian silicates and graphite. At least two subsequent phases of predominantly open-space skarn development have been recognised, separated by fracturing and brecciation, each characterised by early diopside-scapolite, and followed by the deposition of actinolite. The second, associated with extensive brecciation, was the most widespread and the dominant ore-forming event, including the deposition of chalcopyrite, actinolite, scapolite ±andradite ±tourmaline ±allanite ±apatite ±magnetite ±pyrite ±pyrrhotite and very abundant calcite, as well as minor biotite, chlorite and K feldspar. Amphiboles are sodium- and potassium-rich and scapolite is marialitic (Na- and Cl-rich). The Ca-Fe-Mg(-Na)-rich chemistry was imposed from the fluid phase, in the absence of carbonate-rich protoliths. Immobile trace element (Ti, Zr, Nb) chemistry shows the skarn developed from both metasedimentary and mafic metavolcanic host rocks, with the former being dominant. This is contrary to earlier interpretations in which it was assumed that basalt/amphibolite were the principal protolith to the skarns. Stable isotope data are also consistent with dominantly magmatic fluids during mineralisation, possibly modified by interaction with metamorphic rocks or mixed with a metamorphic fluid component. ^{40}Ar-^{39}Ar dating of sodium- and potassium-rich actinolite from the mineralised skarn yielded an age of 1510±3 Ma, believed to most likely reflect the age of the skarn and mineralisation, and close to that of the nearby batholithic granitoids (Wang and Williams, 2001).

The *SWAN Breccia* hosts the bulk of mineralisation in the SWAN zone. In contrast to the Mount Elliott Breccia, it appears to predate the introduction of mineralisation, providing a large, porous and chemically suitable trap for the introduction and deposition of ore. In addition, the clasts are considerably smaller and angular to rounded with diameters generally ranging from a few centimetres up to several metres (Fig. 7B). The individual clasts are composed of strongly albite-altered calc-silicate and metadolerite, although the intensity of that alteration frequently obscures the clast protolith lithology. Prograde alteration is represented by fine grained clinopyroxene, lacking the coarse grained hedenbergite observed at Mount Elliott. The mineralisation is dominantly within the matrix to the breccia, occurring as coarse-grained hematite-stained albite, clinopyroxene, actinolite-tremolite, magnetite, calcite, anhydrite, pyrite and chalcopyrite (Fig. 7G; Brown *et al.*, 2009; Brown and Kirwin, 2009; Wang and Williams, 1996).

Banded mineralisation comprises replacement of banded calc-silicates with centimetre scale layers of hematite-stained albite, magnetite, pyroxene, actinolite, chalcopyrite, pyrite ±calcite and anhydrite (Fig. 7H), particularly on the eastern margin of the SWAN breccia, where mineralising fluids channelled through the breccia pipe have permeated and altered the adjacent banded calc-silicate unit (Figs. 5 and 6). The SWELL zone similarly consists of a broad, southeast trending sheet like body of banded mineralisation that dips approximately 75° northeast.

The fourth, *late crosscutting vein style* of mineralisation is volumetrically much less significant, comprising coarse-grained calcite-chalcopyrite-pyrite-molybdenite veins which range from 1 cm to 2 m in thickness (Fig. 7K).

Drilling across the four main zones of the Mount Elliott area, namely SWAN, Mount Elliott, Corbould and SWELL have indicated that all four fall within a single large, low grade envelope, as defined by the 0.25% $Cu_{equiv.}$ cut-off (Figs. 4 and 10). This common envelope is interpreted to indicate that all four zones belong to a single large IOCG system, which would appear to have been subjected to a number of separate and overlapping pulses of brecciation, alteration and mineralisation. These included an early, pre-brecciation, pervasive, fault-, fracture- and fabric-controlled sodic phase to produce white to pink (hematite-stained) albite rich rock that has affected significant volumes of the Staveley Formation to form calc-silicates, and at least the structurally lower sections of the Kuridala Formation, specifically the "Town and Elliott Beds". Following this initial pervasive phase, there would have been a continued build up of overpressure from dominantly magmatic sourced fluids, channelled through the nearby Mount Dore Fault high strain corridor, and eventual explosive release up plunge of the SWAN zone, above the current surface, to produce the SWAN Breccia. Fluid flow and precipitation of calc-silicate assemblages would have sealed the upper, cooler sections of the breccia zone, allowing overpressuring to rebuild, and the attendant deposition of mineralisation in the porous SWAN Breccia, accompanied by diffusion and replacement in the structurally overlying banded calc-silicates of the SWAN and SWELL zones, before being released through failure in the Mount Elliott-Corbould zones to produce breccias and subsequent mineralisation in the latter zones. More than one pulse of overpressuring, mineralisation and brecciation are indicated. Variations in host rock rheology and chemistry (such as altered graphitic phyllite, basalts/amphibolites and calc-silicates) have resulted in differences in mineralisation style and mineral assemblages between the individual zones.

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