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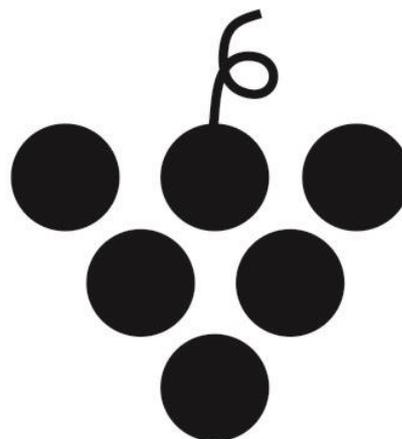
Mines&Wines

2013

Mineral Exploration in the Tasmanides

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The Organising Committee sought to obtain a broad coverage of this topic. Every effort was made to minimise amendments in content of the resultant papers. The opinions and statements within the individual papers comprising this Bulletin reflect solely the viewpoint of their authors, and are not necessarily shared by the Organising Committee or the Australian Institute of Geoscientists.

Preface

Mines and Wines 2013 is the fourth instalment of what has become an important regional conference series that has grown from a NSW focus to encompass exploration and mine geology along the length of the Tasmanides. Its growth demonstrates the important niche Mines and Wines has carved for itself between the more scientific and promotional ends of the conference market. Previous Mines and Wines conferences in 2006, 2007 and 2010 have left an important record of information on deposits and geology and our fourth outing is no exception, with an excellent set of presentations, and volume of extended abstracts.

The organising committee for this conference comprises predominantly SMEDG and AIG members who have given up their time (i.e. "billable hours") to help organise and promote this important event. This year, we welcome the increased organisation and logistical support of the AIG as Mines and Wines takes on an increasingly interstate flavour. NSW Trade & Investment, through the Geological Survey of NSW is proud to continue to be a strong supporter of Mines and Wines and I thank the efforts of our staff in assisting to ensure the conference's success. As always the support from our sponsors and exhibitors has been critical in being able to keep conference registration costs low and within reach of all, particularly in the current trying time.

The industry has seen great changes since Mines and Wines 2010. An exploration and development boom across an unprecedented range of commodities has rapidly deflated during the course of 2013. Of most concern, funding for exploration among the juniors has become extremely difficult to obtain despite many exciting opportunities for discovery and the quality of many exploration programs. Despite this, NSW has seen several projects advance to prefeasibility or mining status over the last two years, in addition to many significant exploration successes. While undercover regions inevitably beckon, the exploration case studies and successes reported in this conference challenge the oft repeated mantra that exposed terranes, or even well known mining camps, have been fully explored. The Tasmanides remains a fertile terrane made rich in opportunities through new geological and exploration models, new research and exploration data and techniques, and the courage and skills of our explorers.

Our conference provides an excellent opportunity for people form across the profession to interact and exchange information in a relaxed and convivial setting. I am sure that it will be an enjoyable and rewarding experience for all.

Phillip Blevin
Chairman, Organising Committee

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MINERAL EXPLORATION IN THE TASMANIDES

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THE TIN SYSTEMS OF NSW REVISITED - NEW APPROACHES, DATA, IDEAS AND SOME UNEXPECTED OUTCOMES.

Phillip L Blevin

Geological Survey of New South Wales, PO Box 344, Hunter Region Mail Centre NSW 2310

Primary tin deposits occur almost exclusively associated with the apical portions of high level, felsic and fractionated granites. These granites are typically silica-rich, peraluminous, metaluminous or less commonly alkaline and are located dominantly in Phanerozoic orogenic belts within continental interiors or margins. The granites themselves represent recycled older crustal materials although some provinces are characterized by juvenile, isotopically unevolved crust (e.g. New England Orogen, Australia; Blevin et al., 1996). Key deposits types include greisens and disseminations, as well as veins and pipes which can occur inside and outside the granite, and as replacement deposits in the wallrocks (skarns and carbonate replacements). Associated metals can include W, Ag, Bi, Mo, Pb, Zn, Cu and As. REE+Y, Th and U can be of interest and light elements (F, Li, Be, B) are often important in controlling the type and style of mineralisation and alteration. The resistate nature of cassiterite means that secondary accumulations are also an important source of Sn. Such deposits comprise the most important source of tin in onshore eastern Australia. Primary Sn mineralisation in onshore eastern Australia tends to be low grade in many provinces (Blevin, 1998).

The first discovery and possible production of Sn in NSW was from the Bungonia area and the Shoalhaven coast - part of the "lost tinfield" of NSW. Tin in NSW is located in distinct provinces, and is mostly associated with compositionally fertile granites in predictable metallogenic associations. However the old rule in finding new tin deposits, viz. "tin is where tin lives", has some noticeable exceptions in NSW as demonstrated by the large Doradilla deposit (a metallogenic "shag on a rock"), but also includes some other exceptions as well, for example on the south coast and adjacent hinterland.

Ardlethan and the Wagga Tin Belt

Significant tin mineralisation is associated with hydrothermal breccia pipes adjacent the Ardlethan Granite (Ren et al., 1995). The mineralisation is relatively W poor, in contrast to others systems of the Wagga Belt. Studies at the deposit by the Geological Survey has demonstrated that the rocks previously mapped as the carapace phase of the granite are equivalents of the regionally extensive Gurragong Volcanics, and that several discrete magmatic events can be recognised on the basis of composition and SHRIMP age data. More detailed timing of cassiterite precipitation in relation to these magmatic events is currently being undertaken by an honours student at the University of Newcastle. Importantly, the late mine porphyries at Ardlethan which are spatially and temporally associated with the main ore pipes are isotopically less evolved than, and quite distinct from, the rest of the volcanic and intrusive suite. The Ardlethan Granite is itself isotopically and temporally closely associated with the just unroofed Burrandana Granite, south of Wagga. Elsewhere in the Wagga Tin Belt Sn is associated with S-type granites at Mount Paynter, Taleeban and the extensive Gibsonvale-Kikoira alluvials. To the north Sn-W mineralisation at Tallebung represents the northerly limit of the belt, there being no Sn mineralisation associated with the Erimeran Granite. Doradilla, near Bourke represents a highly fractionated I-type isotopically and compositionally more similar to the I-type Sn granites of the New England Orogen (Blevin, 2011).

New England Orogen.

Most of NSW's tin production has been sourced from New England, and most of that has been via alluvial production sourced from the I-type Mole, Gilgai and Ruby Creek Granites (Blevin and Chappell, 1993; most of east Australia's tin production has been from I-types rather than S-types). Minor production has also been sourced from the Watsons Creek, Dumboy Gragin and Gundle areas. The orogen retains potential for buried hard rock resources, as exemplified by the large Taronga stockwork system NW of Emmaville. Where the mineralised leucogranites of New England were originally assumed to be Triassic in age and distinctly younger than the less evolved granites of the Moonbi and Uralla Supersuite, SHRIMP dating by GA has demonstrated that many of the Mo-Sn-W mineralised plutons are Permian, and indistinguishable in age not only

from the main supersuites, but also from the Wandsworth Volcanic Group (Cross and Blevin, 2010). Curiously, Sn mineralisation in the Tingha-Gilgai region appears associated with an oxidised I-type (Gilgai granite), a genetic anomaly that requires further investigation. Mole, Dumboy Gragin and Ruby Creek remain Triassic in age, while tin mineralisation associated with the Bundarra Supersuite is early Permian. Tin mineralisation in New England has thus occurred over a range of ages. While a loose metallogenic zonation from Sn to Mo to Au seems to occur from west to east across the southern NEO, the general metallogenic character of the orogen in NSW is in stark contrast to the Cu and Au dominated northern NEO in Queensland.

Other occurrences of note in NSW

Tin ± W also occurs associated with the fractionated S-types of the Wyangala Batholith, with A-types in the Temora area, and with I-type granites in the east of the Lachlan Orogen around Bungonia, Ettrema/Tolwong and Wandandian. Here, Sn systems originally exposed at the surface were buried during the filling of the Sydney Basin but are currently being exhumed once again. Other polymetallic vein occurrences in the region may indicate the presence of a zoned mineral field and suggests that highly fractionated (and thus K-, Th- and U-enriched) granites may extend north under the Sydney Basin. In the Broken Hill region pegmatites contain Sn and W in addition to a range of strategic and industrial minerals.

Studies in NSW tin systems

Major studies culminated in the mid to late 1980s to early 1990s with a PhD at Ardlethan (Ren et al., 1995); mapping, dating and petrological work around the Mole (e.g. Kleeman et al., 1997); fluid inclusion and stable isotope studies (e.g. Sun and Eadington, 1987), and work on the unusual Doradilla system evolving out of a major exploration campaign (Plimer, 1984). Exploration was also conducted at Taronga, Sundown (in Qld, prior to its inclusion into a national park) and Kikoira. More recently studies have been more sporadic. Work on fluid inclusions in the Mole granite lead to the conclusion that Cu was transported in the vapour phase in such systems (Heinrich et al., 1992), influencing international fluid inclusion research for many years and even leading to the suggestion by others that porphyry Sn deposits would be found by drilling under porphyry Cu deposits!

Granite geochemical studies were also undertaken by Bruce Chappell and his coworkers who argued that "tin granites" were simply highly fractionated melts of I-, S- or A-type lineage, and did not necessarily represent specialised melts, or require specialised sources. Lehmann (1990), and Blevin and Chappell (1992) argued for Sn enrichment via extended fractional crystallization of reduced magmas originally endowed with typical crustal Sn concentrations. More recently, high precision dating of hydrothermal and magmatic minerals in the Mole Granite have been undertaken by Schaltegger et al (2005). The advent of direct U-Pb dating of cassiterite by LA-ICPMS and SHRIMP has allowed the possibility of dating and geochemical fingerprinting of cassiterites as a provenance indicator (Blevin and Norman, 2010).

The Geological Survey of New South Wales is undertaking a range of studies to better characterise these systems. Collaborative institutions include James Cook University, the universities of New England and Newcastle, and the Australian National University. Geochronological support (SHRIMP) is provided by Geoscience Australia. Most research on tin systems in NSW however is now 20-30 years old, and a generational change in geologists during that time also means that much of the collective wisdom garnered during the exploration and mining heydays up to the 1980s has been lost. Undertaking studies brings these systems to the attention of a new generation of geologists and also enables them to be reassessed in terms of their potential for other commodities including REE-Y, U and Th. Better placement of these deposits in their respective regional settings is also important in order to develop better exploration models.

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THE MALLEE BULL DISCOVERY AND EXPLORATION IN THE CENTRAL COBAR BASIN

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Keywords. Copper, Silver, Gold, Mallee Bull, Cobar, DHEM, four mile, superbasin

Abstract
The Mallee Bull copper-silver-gold base metal discovery is located within the historic "Four Mile gold field" 110km south of Cobar NSW in the central region of the Siluro-Devonian Cobar Superbasin. Based on information at hand at the time of writing this document Mallee Bull is being interpreted as an example of epigenetic mineralisation related to hydrothermal activity associated with extensional tectonism and later compressional tectonics. Geological and structural logging of drill core, petrographic studies and detailed prospect-scale mapping demonstrates that Mallee Bull is most appropriately classified as a "Cobar-style" deposit.
Mallee Bull lies on the western limb of a regional-scale anticlinorium plunging at about 30 degrees to the south. Structural modelling to date has identified a main north to north-northwest striking, west-dipping hanging wall fault close to mineralisation which forms a distinct structural domain boundary. Larger local folds are clustered along this fault. The structural domain west of the fault is dominated by a suite of small NE trending, shallow NW dipping faults whereas to the east of the fault structures associated with mineralisation are dominated by NNE trending, steeper WNW dipping faults (Holcombe 2013). A major NNE trending fault identified in geological mapping and recently intercepted in diamond drilling shows evidence of reactivation and fluid passage and possibly represents a reactivated and structurally modified pre-existing basin fault. Mineralisation occurs stratigraphically within and below a mass flow package of volcaniclastics, bioclastic limestone, and basin sediments with variable local thicknesses which are interpreted to represent deposition near a basin margin structure or within and adjacent to lobate distributory fans.
Regional mapping and structural modelling has identified a steep axial plane cleavage and fold axes associated with regional scale upright and symmetrical folding. This folding event is most probably associated with basin inversion and was most likely accompanied by the main mineralising event, with fluids focussed along dilational structures formed during the folding as well as ponding within the mass flow units.
The geometry of the ore body is a steeply (60-70 degrees) west-dipping, tabular mass which is rectangular in plan. The mineralisation is parallel to sub-parallel to bedding, extends down plunge for over 700m, is more than 120m wide and thickens northward. Mineralisation is currently open to the north, south and at depth.

Geological Setting
The Mallee Bull mineralisation is hosted by rocks of the Upper and Lower Amphitheatre Groups (Figure 1). The Upper Amphitheatre Group strata have not been formally subdivided in the subject area and are locally informally referred to as the *Mallee Bull formation*. The top of the Lower Amphitheatre Group is represented by the Shume Formation. A thin interval of allochthonous strata straddle the boundary between the two Groups and are informally referred to as the *Mallee Bull Formation allochthonous facies* and the *Shume Formation allochthonous facies*. A distinctive, supermature quartz arenite marks the stratigraphic top of the Shume Formation and is informally referred to as the *Keep It Dark sandstone member*.
The overall succession is essentially a turbiditic sequence of well-bedded, graded, fine to medium-grained sandstones to mudstones. Individual graded beds are generally less than 0.5m thick, with local thick beds to 2m maximum. Dewatering structures are common throughout, ranging from flammate sandstone bases to narrow sandstone and mudstone dykes, and intervals of disrupted and rotated sandstone beds in massive to streaming-laminated mudstones. A single, well-developed cleavage is present throughout all but the most strongly silicified intervals. Preliminary data suggest that there are limited differences in the detrital compositions of the Shume and Mallee Bull formations, although the Shume Formation sandstones are apparently more quartz-rich (Chapman 2012).
The allochthonous strata comprise beds of felsic volcaniclastic sandstone, pebbly sandstone and diamictite with subordinate bioclastic

MALLEE BULL AREA STRATIGRAPHY AND MINERALISATION

Figure legend:
- Disseminated and joint-fill pyrite
- Disseminated pyrrhotite
- Disseminated sphalerite-galena-pyrrhotite-(chalcopyrite)
- Stringer chalcopyrite-pyrrhotite-(cassiterite-arsenopyrite)
- Massive pyrite-pyrrhotite (-chalcopyrite)
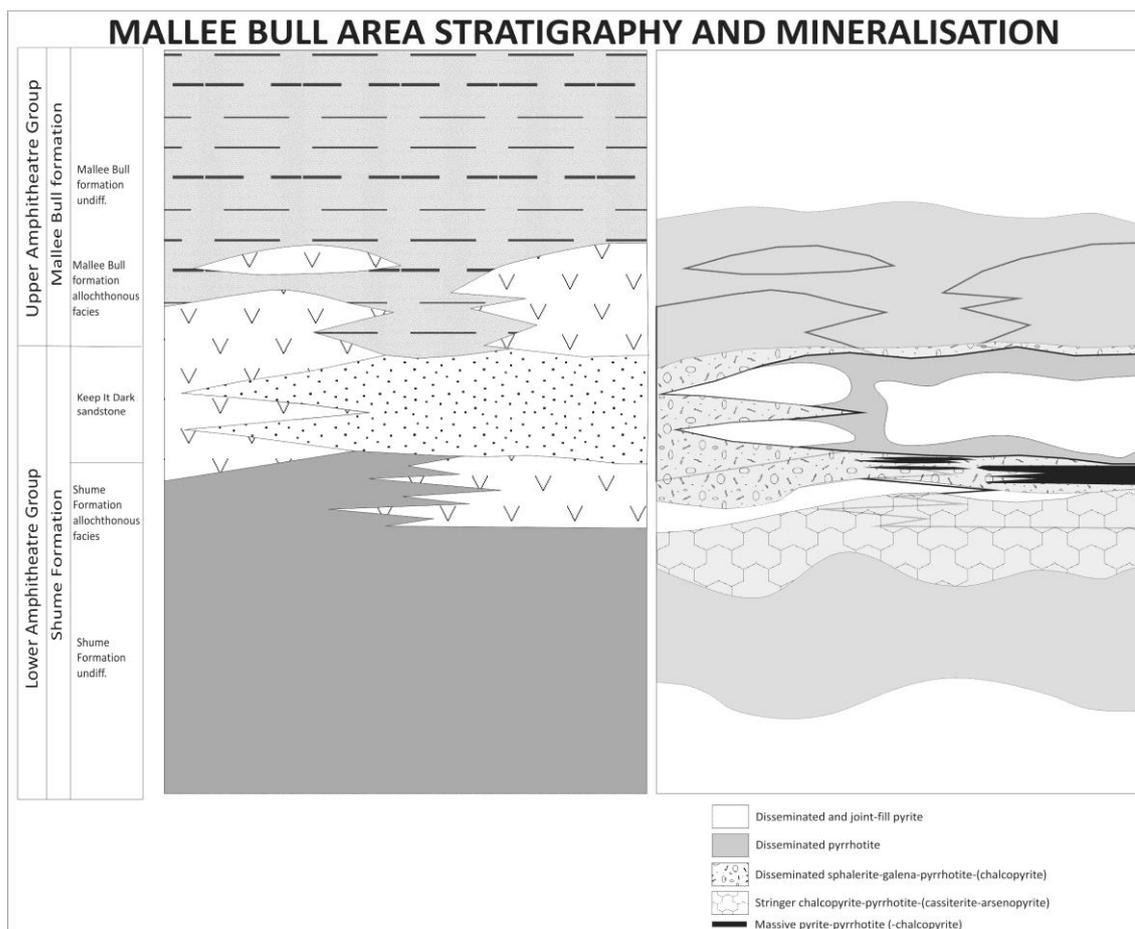
Figure 1. Stratigraphy and mineralisation model for the Mallee Bull prospect.

(with abundant, coarse crinoids and rugose and tabulate corals) and lesser micritic limestone-rich diamictite. These beds range in thickness from millimetre-scale to more than 10 metres. They are unsorted and massive, with a weak to moderate cleavage. They are considered to be of mass flow origin. The allochthonous strata are locally absent, and in places may only be present in either the Shume Formation or Mallee Bull formation.

The Keep It Dark sandstone member is distinctive in outcrop and drill holes. It is generally a fine-grained, very well sorted, massive quartz arenite which locally hosts massive white quartz-calcite veins. The sandstone ranges in thickness from several centimetres to more than 10 metres, and is locally absent. In places it forms thin, laminated and rarely cross-laminated beds with minor volcaniclastic detritus and rare pebbles. The unit is interpreted to represent a mass flow deposit sourced from a different provenance to that otherwise supplying sediment to the basin. The laminated variant probably represents the extreme margins of mass flow lobes.

Mineralisation

The Mallee Bull mineralisation comprises five distinctive variants (Figure 1), most of which exhibit close to general parallelism to stratigraphy.

1. Disseminated and joint-fill pyrite is ubiquitous throughout the stratigraphy. Disseminations occur as sub-millimetre to 5 millimetre diameter fine-grained aggregates, commonly with framboidal geometry. They are interpreted to be diagenetic. Joint fills of fine to medium-grained, cubic and massive pyrite aggregates occur throughout the sequence. These are interpreted to be of burial or regional metamorphic origin.

2. Disseminated pyrrhotite occurs as an envelope to the complex sulphide bodies. It grades inward from very fine-grained, sparse to abundant disseminations, to millimetre-size flattened spherical aggregates which have either been deformed by cleavage development, or have preferentially grown along cleavage planes.   This form of

mineralisation largely comprises magnetic, pale yellow-pink pyrrhotite with magnetic susceptibilities of 90-350 x 10^{-5} SI units. Non-magnetic pyrrhotite is present locally. The disseminated pyrrhotite commonly is present from near the top of the Mallee Bull allochthonous facies to below the lower surface of the cupriferous stringer zone. It is locally absent in the Keep It Dark Sandstone and in an interval of intense silicification beneath the massive sulphide lenses.

3. Massive to semi-massive sulphide lenses comprising massive and replacement-textured pyrite-pyrrhotite occur stratigraphically beneath the Keep It Dark sandstone. The lenses occur singly, as multiple stacked lenses (up to 4 lenses), or may be absent. Individual lenses range in thickness from several centimetres to more than 10 metres. The dominant mineral present is generally pyrite, with minor to abundant magnetic pyrrhotite and minor to trace chalcopyrite locally. Trace sphalerite, galena, gold, electrum, tetrahedrite, euhedral arsenopyrite and distinctive acicular cassiterite are also present. Pyrrhotite is dominant in some of the deepest occurrences of these lenses. The lenses are in sharp contact with adjacent altered host rocks, or grade into zones of disseminated mineralisation through semi-massive variants.
    Textural variants include:
    a). common, fine to medium-grained, massive;
    b). common, variable grainsize and morphology pyrite comprising fine to medium-grained aggregates intermixed with contrasting, medium to coarse-grained aggregates with a complex, anastomosing fabric suggesting cataclasis and remobilisation. Pyrite morphologies indicate multiple generations of this species.
    c). replacement textured pyrite exhibiting relict clast and bedding shapes, and commonly associated with massive, featureless pyrite.
    Scattered, minor to abundant clasts of apparent volcanogenic detrital quartz occur locally throughout the massive sulphide lenses. Each of the above 3 variants of massive to semi-massive sulphides may be present locally.
    The massive to semi-massive sulphides lenses report anomalous Cu, Pb, Zn, Ag, As, Co, Sn, Au

4. Disseminated mixed sulphides comprise bedding- and clast-replacement-textured aggregates of sphalerite, galena and pyrrhotite with minor chalcopyrite and trace euhedral arsenopyrite, pyrite and acicular cassiterite. This style of mineralisation occurs mainly within the Shume Formation allochthonous facies, is laterally equivalent to, and associated with, massive sulphide lenses, and locally is weakly present above the Keep It Dark sandstone. Partial to total replacement of diamictite clasts are ubiquitous, and sulphides commonly rim clasts and selectively replace bedding laminae. Apparent pressure shadows of sulphides are developed on the ends of some elongate clasts. Local semi-massive aggregates of coarse, intermixed sphalerite and galena occur locally. The disseminated mixed sulphide bodies report anomalous Zn and Pb, with lesser Cu, As and Ag.

5. The cupriferous stringer zone is present throughout the deposit as the lower-most mineralised interval. It occurs both within the Shume Formation allochthonous facies and undifferentiated Shume Formation. This mineralisation is commonly separated from overlying mineralisation by a barren zone of altered sediments ranging in thickness from about 1 metre to tens of metres. The stringer zone grades upward and downward into unmineralised rocks by a decrease in abundance and thickness of mineralised veins. The stringer zone comprises a stockwork-like mass of variable width, largely randomly oriented veins. The veins include various combinations of quartz, albite, calcite, ankerite, chalcopyrite and pyrrhotite with minor to rare acicular cassiterite, arsenopyrite, galena, sphalerite, boulangerite, tetrahedrite and stibnite. Local vein amalgamations form quartz-healed jigsaw breccia zones. Massive and semi-massive chalcopyrite-pyrrhotite aggregates are present in places, commonly exhibiting sinuous flow laminae resulting from deformation and remobilisation.
    The stringer zone reports anomalous Cu, with subordinate Zn, Pb, As, Ag, Sb and Au.

In addition to the common mineralisation styles, massive and laminated quartz-calcite and quartz-albite veins are present throughout the area beyond and within the mineralised zone. These veins rarely host minor pyrite or pyrrhotite, and a single occurrence of visible gold was noted in

one drill hole. These veins are equated with those exploited by artisan miners in the Four Mile gold field.

Alteration
The Mallee Bull mineralisation is accompanied by significant alteration. The allochthonous volcaniclastic rock packages display abundant green sericitic alteration of feldspars and matrix material, and ferromagnesian minerals are altered to black chlorite. Pseudomorphous replacement of the volcaniclastics by sulphides is present in the massive to semi-massive sulphide lenses and the disseminated mixed sulphide bodies.

Pale green (low-Fe) chlorite is associated with the cupriferous stringer zone. Chloritic alteration of the host rocks grades outward from the most intensely mineralised intervals, and is present in places for tens of metres beneath the stringer zone. Black chlorite is also present within some associated quartz veins. Pale green chlorite also accompanies many barren white quartz veins located above the mineralised intervals.

Silicification is ubiquitous throughout the mineralised zone. Intense siliceous alteration of siltstone and mudstone clasts and beds beneath the Keep It Dark sandstone has produced white, chert-like lithologies similar to those referred to in the Cobar mineral field as *elvan*. Possible weak silicification of the outcropping Shume Formation up dip of the Mallee Bull mineralisation has resulted in a low topographic rise and prominently exposed strata. The Keep It Dark sandstone is generally strongly silicified, imparting a quartzite-like appearance. Variable pyrrhotite replacement is present throughout the polymetallic mineralised zone and beyond, forming a halo of anomalously magnetic rocks.

Exploration History
The historic Four Mile gold field, within which Mallee Bull occurs, was discovered shortly after the nearby Gilgunnia Goldfield in 1895. Production records are either poor or non-existent with only about 660g of gold being reported (Supple 1993). Historic workings in the Four Mile gold field include 76 shallow exploration pits and trenches and 30 shafts exist up to 30m deep. Visual inspection of workings found isolated quartz stockpiles, which assayed up to 6 ppm Au. Portable XRF testing of mullock spoils revealed local weak lead and arsenic anomalism. The auriferous reefs generally strike at 020°, 120° or 150° magnetic and vary in width from a few centimetres to 1m. Two types of quartz vein are recorded:
1. White bucky supergene quartz which can be enriched in gold and poor in base metals and
2. Laminated and commonly folded epigenetic quartz, emplaced along well-defined structures and hosting sparse gold and minor galena, sphalerite, and chalcopyrite (Tippet 1974).

Modern exploration began in the area in 1970 when the first title was granted to Milstern Exploration. In joint venture with Mt Hope Minerals NL, they explored for copper lead and zinc within the vicinity of the historic gold workings at Gilgunnia and the copper, lead and silver rich workings at Mayday (Brian 1971). Work conducted included airborne and ground magnetic surveys, surface mise-a-la-masse and drill hole induced polarization surveys, geological mapping, geochemical sampling and diamond drilling focused around the Mayday workings and the Mount Hope Volcanics.

During 1971 to 1974 Penzoil of Australia conducted extensive sampling of the Four Mile gold field workings for gold, silver, copper and lead. Initial sampling was undertaken on host rocks and quartz vein material. Results confirmed that gold distribution was erratic, low grade, and confined to vein quartz (Tippett 1974). Tippett (1974), confirmed that the orientation of gold-quartz stockworks in the Four Mile area are apparently controlled by the orientation of fold axes.

During 1976-1978 detailed geological mapping and palaeontology by Union Corporation considered a mappable horizon of acid volcanics and cherts adjacent the Four Mile gold field, which were weakly mineralised and magnetic to be prospective for volcanogenic sulphide deposits (Taylor 1977). Furthermore the rocks were interpreted to be of the same age as rocks hosting mineralisation around Cobar and confirmed a similar stratigraphic position to those rock hosting the Shuttleton mineralisation. An airborne magnetic survey initially flown north south and latter re-flown east-west with a 300m line spacing and 70m elevation identified a number of magnetic anomalies in the vicinity of the Four Mile workings. Their *Anomaly 1*, which is coincident with Mallee Bull, was followed up with a ground magnetic survey, the results of which were described as an easterly dipping 40 gamma bedrock anomaly with a strike broadly parallel to the local cleavage (Taylor 1977). Shallow auger drilling across the anomaly identified anomalous As

475ppm, Zn 290ppm, Pb 140ppm and 80 ppm Cu from one sample but failed to generate any further interest. The modelled depth to source was around 180m and an explanation for the magnetic anomalism was not resolved.

During 1981 to 1982 the Shell Company of Australia reviewed previous work by Union corporation and also considered the stratigraphy which hosts Mallee Bull to be prospective for Cobar style mineralisation (Betts 1982). A series of 25m spaced RAB lines were drilled at 500m intervals along the strike of the Mallee Bull host strata. A few weakly anomalous base metal values were returned but were not considered prospective and budgetary restrictions lead to the relinquishment of all leases.

Newmont Holdings acquired tenure over the Four Mile gold field in 1984 on the basis of its proximity to the north-north-easterly trending Mt Hope – Gilgunnia – Nymagee Gravity Lineament (MGNL) (Teluk 1986) or as it is more recently referred to, the Wagga Tank to Nymagee Lineament (David 2005). This lineament partitions the Cobar Superbasin and appears to truncate a major north-south trending gravity feature known as the Cobar Gravity Lineament (CGL) which in the north follows the eastern margin of the basin with the majority of deposits in the Cobar Basin either along this gravity feature or proximal to it (Figure 2). The lease was relinquished by early 1986 as no prospective targets were identified.
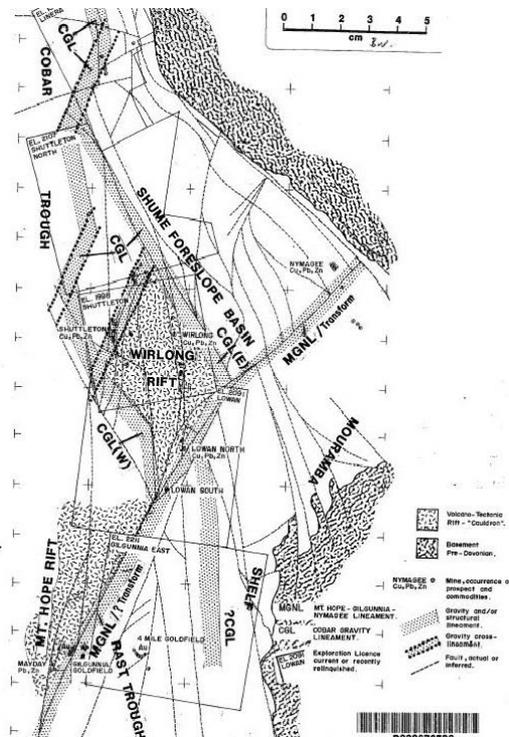
Figure 2 Newmont Gravity Interpretation with Mayday, Four Mile and Gilgunnia gold fields bottom left

Epoch mining during 1988 unsuccessfully tested the gold potential at the Four Mile gold field. A series of 7 lines with 10m spaced RAB holes dipping at 60 degrees towards 056 magnetic north were completed to 14m depth with 2m composites assayed for gold (Duncan 1988). Virtually all samples were below the limit of detection with no further work planned.

In the period 1993- 1996 Renison Ltd (RGC) recorded the depths and style of mine workings, host rock lithology and alteration, bedding and quartz vein orientations and assayed rock samples from the workings in the Four Mile gold field. Trenching was carried out in order to elucidate the extent and structure of the mineralised quartz veins mined at Four Mile. Quartz was observed to vary from clean white quartz to ferruginous, chloritic, strongly foliated and locally folded quartz. The quartz veins were considered too sparse and the host rocks only weakly altered with no further work warranted (Mroczek 1993).

Pasminco during 2002-2003 remodelled the fixed wing aeromagnetic survey flown by RGC in 1992 in pursuit of Elura style magnetic anomalism. Anomaly G5 was identified as a discrete 20 nT

magnetic high which corresponds to Peel Mining's Butchers Dog anomaly. The anomaly was considered a low amplitude, deep and wide basement source and not considered analogous to Elura and was rated a low priority (Randell 2003).

In early September 2009 Peel Mining Limited acquired ELA 3776 covering 84km2 surrounding the May Day deposit and historic Gilgunnia and Four Mile gold fields. ELA 3776 was granted to Peel as EL7461 in March 2010. In December 2010 a 200m line spaced, 62 line kilometre, East West airborne Versa tile Transient Electromagnetic (VTEM) survey was undertaken to test the area of the historic magnetic anomaly G5, a regional anticline with prospective stratigraphy and the historic Four Mile gold field. This survey identified a discrete late time Electro Magnetic (EM) conductor with a coincident magnetic anomaly over what is now known as Mallee Bull (Figure 3).

Figure 3. Airborne electromagnetic and magnetic survey over Four Mile goldfield
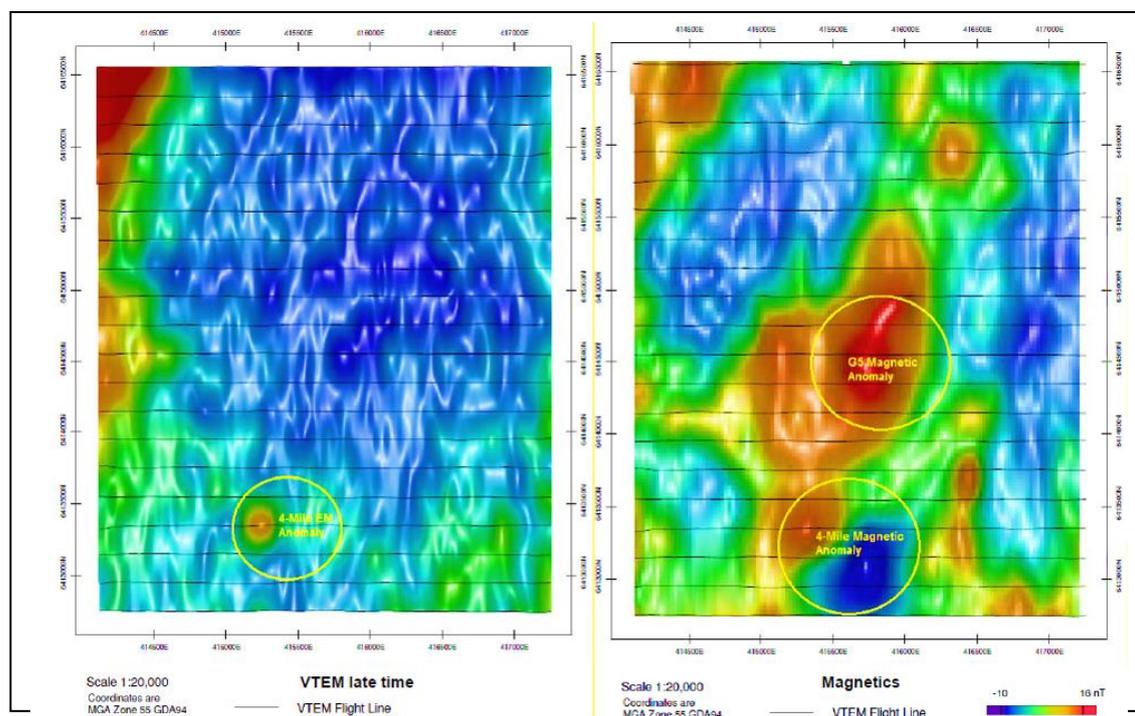
There is no obvious surface expression for the mineralisation and an early line of shallow rotary air blast (RAB) drilling over the top of the VTEM anomaly failed to identify anomalous geochemistry. Deeper early stage reverse circulation (RC) drilling to a maximum depth of 270m intersected alteration and Cu-Ag-Au-Pb-Zn mineralisation and provided a platform for subsequent down hole electromagnetic surveys (DHEM). An initial DHEM survey on hole 4MRC004 from 10-250m down hole using a Crone Bore-Hole system identified a 40 ms off hole conductor in late time channels. Further DHEM on 4MRC002 and a 200m x 200m fixed loop electro magnetic (FLEM) survey was conducted to test the up plunge potential of the conductor and further refined the target location. Down hole gyroscopic surveys of the RC holes further refined the target identifying significant lift and drift of drill hole trajectories (figure 4). Geophysical modelling then lead to the extension of RC hole 4MRC006 with a diamond tail which intersected a 60m wide zone of alteration and shearing from 250m down hole containing multiple massive sulphide and stringer mineralised zones.Better assays from hole 4MRCDD006 include; *10m @ 0.14% Cu, 41 g/t Ag, 0.77 g/t Au. 9.01% Pb, 11.00% Zn from 252m and 6.65m @ 3.10% Cu, 34 g/t Au, 0.93 g/t Au, 0.65% Pb, 0.13% Zn from 267.35m.*
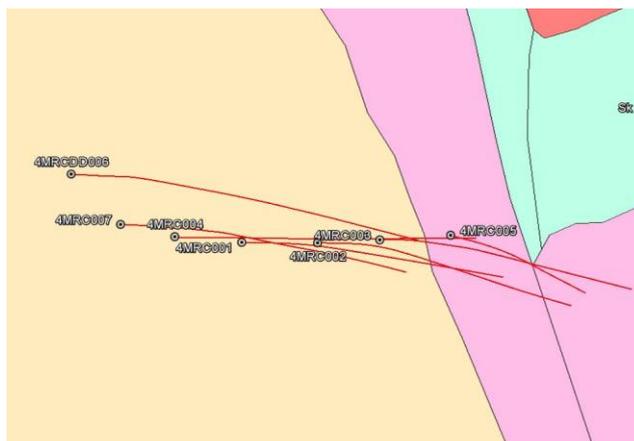
Figure 4. Discovery holes at Mallee Bull showing significant drift in drill hole trajectories

Ground gravity measurements taken at 100m centres as part of a 1500m x 2000m grid centred around Mallee Bull identified a weak gravity anomaly directly above the ore body and a discrete gravity high proximal to the surface expression of Mallee Bull which is believed to be associated with the silica altered host rocks.

The surface expression of Mallee Bull is reasonably unremarkable with no obvious supergene enrichment or gossan development. The lower detection limits of modern portable X-ray fluorescence (XRF) devices have proven to be a cost effective way of locating the surface expression of Mallee Bull. A regional 10 km^2 soil XRF (Niton xl3t) grid with an initial sample density of 50 x 100m was completed over Mallee Bull and generated a weakly anomalous "bulls-eye" target area of 250m x 200m for both zinc and arsenic.

Acknowledgements

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GEOLOGY AND RESOURCES OF THE HEEMSKIRK TIN PROJECT – ZEEHAN TASMANIA

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Key Words: tin, silver-lead, Zeehan, Heemskirk, granite

Introduction

The Heemskirk Tin Project is held by Stellar Resources Ltd under Retention Licence 5/1997. The RL covers the western side of the Zeehan Township on the West Coast of Tasmania (Figure 1). Zeehan is a historic mining town established in the 1880's.

The immediate area surrounding the project was subject to intensive mining of silver-lead mineralisation via numerous shafts, adits, small pits and costeans developed between 1883 and 1963. The majority of the production from the field took place between 1883 and 1914 with over 260,000t of silver-lead ore produced. Minor tribute mining continued until 1963 with a small spike in activity post World War 2. Tin mineralisation was identified on the field however the only historic production was from the Stannite Lode at the Oonah Mine between 1897 and 1910. 15-20,000 tonnes was mined to produce a tin-copper matte (King, 1961). Minor cassiterite was noted at Queen Hill in 1937.

Modern exploration commenced in the mid 1960's when Placer Prospecting drilled a series of holes at various prospects in the area, including at Queen Hill. In 1971 Gippsland Minerals drilled 10 holes at Queen Hill and discovered the Queen Hill cassiterite lodes adjacent to the old silver-lead stopes. Gippsland entered into a JV with Aberfoyle Resources in 1972 and extensive exploration drilling then continued up to 1990. In 1976 Aberfoyle discovered the large, blind Severn Deposit about 300m east of the Queen Hill Deposit. Collapse of the tin price in the late 1980's saw activity cease and the project retained under an RL in 1997. Stellar Resources acquired the RL in 2008 and recommenced exploration drilling and metallurgy test work in 2010. A scoping study was completed in 2011 followed by a Pre-Feasibility Study in 2013.

The PFS is based on a 600,000 tonnes per annum underground mining operation. An Inferred and Indicated Resource of 6.28Mt @ 1.14% Sn at a 0.6% Sn cutoff forms the basis of the Mining Inventory[1] of 3.95Mt @ 1.06% Sn. A conventional gravity and flotation concentrator is proposed producing an average of 4,327 tonnes per annum of tin in concentrate over 7 years. Average concentrate grade is expected to be approximately 48% tin.

The resource estimation is based on historic diamond drill results and on the systematic resource extension drilling completed by Stellar Resources since 2010. Exploration and infill drilling is ongoing and future resource additions are anticipated.

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1 The Mining Inventory is based on 75% Inferred Resources. Further drilling and estimation may result in changes to the economically minable portion of these resources.

Regional Geology

The Zeehan district has seen complex deformation, igneous activity and sedimentation from the Late Proterozoic to the present. Basement rocks in Tasmania are dominated by the Late Precambrian Tyennan Element in the east and the Rocky Cape Association of similar age in the

northwest. The Zeehan Basin on the eastern margin of the Dundas Trough was a major control on the pre-Carboniferous geology of the Zeehan District.

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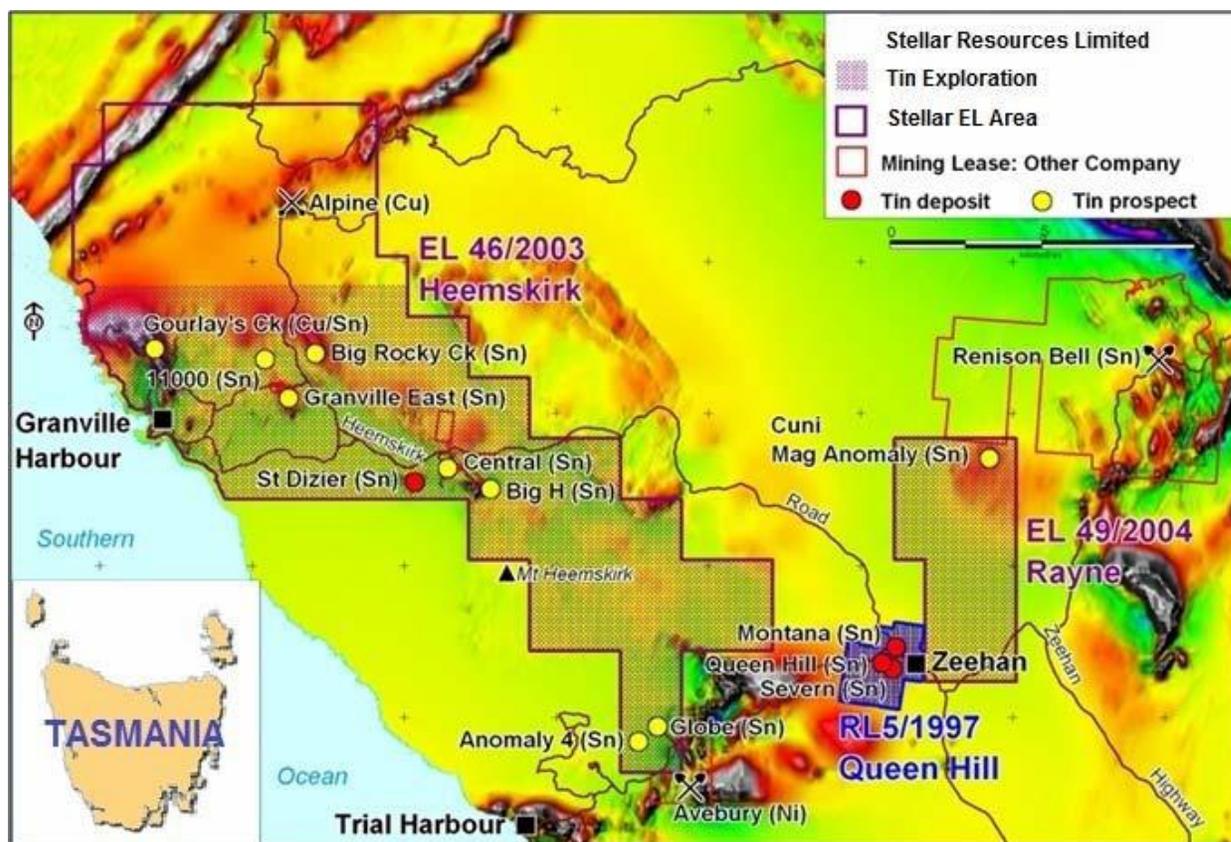
Figure 1. Location of RL 5/1997 and EL's 46/2003 and 49/2004.

Around 700Ma a shallow rift basin developed between the northwest and eastern basement blocks. Siliciclastic sediments of the Forest Conglomerate, Donaldson Formation, Timbs Group and Oonah Formation were deposited in the deepening basin. Sag phase siliciclastic sedimentation and carbonate deposition followed and are represented by the Black River Dolomite, Savage Dolomite, Success Creek Group and upper Timbs Group. The Success Creek Group unconformably onlaps the Oonah Formation in the Zeehan district and is marked by a structural and low grade metamorphic contrast between the two groups (Corbett, 1989). The hiatus in deposition and increased complexity of the Oonah formation is a result of the late Precambrian Penguin Orogeny.

Continued rifting in the early Cambrian (580-550Ma) resulted in the deposition of a thick pile (>5km) of tholeiitic volcanics and associated sediments, carbonate and chert of the Crimson Creek Formation. The Crimson Creek tholeiites have a within plate geochemical signature (Brown and Jenner, 1989). Correlates of the Crimson Creek Formation occur elsewhere in NW Tasmania outside of the Dundas Trough (Brown, 1986, Brown and Jenner, 1989).

During the Middle Cambrian (515-510Ma) a sequence of mafic-ultramafic complexes were emplaced on the western margin of the Dundas Trough. Ultramafic detritus in clastic rocks suggests they were emplaced high into or above the Crimson Creek Formation and were subject to Middle Cambrian Erosion (Corbett, 1989).

Post collision extensional tectonics produced troughs into which the Cambrian Dundas Group and Mt Read Volcanics were deposited.
The Late Cambrian Delamarian Orogeny resulted in localised uplift and erosion of the Tyennan Block and subsidence of the Dundas Trough. The Ordovician to Devonian Wurawina Supergroup unconformably fills structural and erosional basins (Banks and Baillie, 1989).

The Middle Devonian Tabberabberan Orogeny has resulted in polyphasal deformation with intersecting fold trends forming dome and basin structures and overprinting relationships (Williams, 1978). Folds are generally upright to steeply inclined with plunging hinge lines. Many faults are steep thrusts and reactivation of Cambrian structures is common. Folding within the Zeehan Basin produced dominantly NNW trending fold hinges. Localised WNW trending folding is located in the Zeehan-Linda zone, possibly associated with the large Firewood Siding and Tenth Legion thrust faults (Williams, 1978).

Several small to medium sized post tectonic I and S type granitoids intrude the early lithologies. Granitoids were emplaced at shallow levels and are dominantly granite or biotite adamellite. Geophysical modeling has indicated the presence of a large ENE-trending ridge of granite linking the Heemskirk and Granite Tor plutons (Leaman and Richardson, 2003).

A number of styles of mineralization are associated with the Devonian granitoids including tin-tungsten and lead-zinc-silver (Collins et al, 1989) and the recently discovered Avebury Nickel Skarn (Callaghan and Green, in press).

Cassiterite mineralization is associated with stratabound massive sulphide bodies replacing carbonates of the Oonah Formation (Mt Bischoff, Queen Hill), Success Creek and Crimson Creek Groups (Renison, Severn, Montana). Stockwork and fault related cassiterite-sulphide mineralisation is associated with the Renison, Severn, Queen Hill and Montana deposits. Disseminated cassiterite is associated with greisenised granite in the southern part of the Heemskirk Granite.

Skarn tin-tungsten and tungsten-magnetite deposits occur adjacent to granite bodies in direct contact with calcareous sediments (Tenth Legion, St Dizier, Kara, Dolphin, Mt Lindsay).

Lead-zinc-silver vein mineralization occurs in haloes around granite bodies. These deposits are typically small such as the numerous deposits of the Zeehan-Dundas field. The Magnet Mine is the largest known deposit of this type with 630,000t @ 7.3%Pb, 7.3% Zn and 427g/t Ag produced.

Post deformation sedimentation resumed in the Permian with thick, essentially flat lying sequences of mudstone, sandstone and minor carbonates of the Parmeener Supergroup. Minor Jurassic Dolerite sills are present in the Dundas Trough.

Tertiary faulting, basin formation and alkali-olivine basalt extrusion formed the large Macquarie Harbour Graben west of Strahan and basalt flows north of Mt Heemskirk. Surficial Quaternary deposits are widespread and erosion and deposition continues to modify the landscape.

Local Geology

The oldest rocks in the Zeehan locality are the siliciclastic sediments of the Oonah Formation comprising quartzite, black shales and siltstones. The Oonah Formation in the Queen Hill-Severn area is characterized by two distinct lithologies, a thinly bedded interlayered sequence of black

shales and thin quartzite known as the QS sequence (Aberfoyle nomenclature) and a prominent grey quartzite known as the QST sequence.

Coeval with the Upper Oonah Formation is a localised basaltic sequence of tholeiitic lavas and proximal volcaniclastic breccias known as the Montana Volcanics. These are located on the western side of Queen Hill and form the western margin of the tin mineralisation. The volcanics are associated with localised carbonates and siltstones.

A localised sequence of grey siltstone and dolomite locally known as the Montana Beds separates the Oonah Formation from the Crimson Creek Formation on the eastern side of Queen Hill. The Montana beds are discontinuous, varying in thickness and composition, probably having formed in localised palaeo basins.

The Crimson Creek Formation forms a thick sequence of graded basaltic volcaniclastic turbidites with interbedded black shales. Rare vesicular basaltic lavas and proximal volcaniclastic breccias are present in some drill holes. Carbonate beds are more common towards the base of the formation.

The deposits are located in a northeast-southwest trending flexure in the dominantly east-west trending geology (Figure 2). Locally the foliation and bedding generally dip steeply east at about 70-80 degrees. The stratigraphy is east facing and recent petrography and immobile element studies by Ralph Bottrill (2012) support an east facing sequence.

The Zeehan Tin Deposits are typical of Devonian Granite related tin mineralisation. Granite outcrops at Mt Heemskirk to the west of Zeehan and at Pine Hill and Granite Tor east of Zeehan. Gravity modeling (Leaman and Richardson, 1989) and the metal zonation of the Zeehan Dundas field strongly suggest the presence of a granite body extending east from Mt Heemskirk. Several deep drill holes at Renison have intersected the granite at depth.

Base metal mineralisation is considered by many workers (Anderson, 1990, Kitto, 1996) to be the distal expression of a zoned hydrothermal system with the tin deposits located proximal to the granitic source rocks. Base metal mineralisation at Queen Hill strongly supports this hypothesis with base metal concentrations increasing significantly in the upper part of the tin mineralisation. This same zonation is reflected on a district scale by the zonation of historic base metal-silver workings around the tin deposits (Figure 1).

The Queen Hill deposit is essentially stratabound on the Montana Volcanics-Oonah Formation boundary with mineralisation occurring in both sequences. Mineralisation strikes northeast-southwest, dips steeply east and plunges northeast, remaining open down plunge. The deposit has a strike length of over 200m extends from surface to 250m, varying in thickness from 2-25m (Figure 4). The deposit comprises two main lenses with several small associated lodes. Some of the dolomite beds associated with the volcanics have been replaced forming semi-massive sulphide bodies. Mineralisation occurs as pyrite-siderite veining and replacements with accessory cassiterite, stannite, galena and sphalerite. The deposit is strongly zoned with galena-sphalerite disseminations and veining more common towards the top and periphery of the cassiterite-iron sulphide mineralisation. Base metal silver veins form lode style deposits on the periphery of the deposit.

The Severn mineralisation is essentially of stratabound stockwork and replacement style, located on the Oonah Formation - Crimson Creek Formation boundary with mineralisation occurring in both sequences but principally in the Montana Beds and Lower Crimson Creek Formation. Mineralisation strikes northeast-southwest, dips steeply east and plunges northeast, remaining open down dip and down plunge. Mineralisation occurs principally as pyrite-pyrrhotite-siderite stockwork veining with accessory cassiterite, chalcopyrite and rare arsenopyrite, stannite, galena and sphalerite. Vein widths vary between a few millimeters to 0.5m. Vein orientations are variable. Some of the dolomite beds associated with the Montana Beds have been replaced

forming semi-massive sulphide bodies.   The mineralised zone is broad, extending over 400m in strike length and 50m in width, extending from 70m below surface to 500m from surface (Figure 4). A high grade core and several smaller sub parallel zones are located towards the base of the broad low grade stockwork style mineralisation. These form the basis of the Severn Mineral Resource Estimation.

The Montana deposit is interpreted to be an essentially vertical body striking east northeast. The deposit extends over 100m in strike length and extends from 50m below surface to nearly 400m below surface. Mineralisation is relatively thin extending between 2-8m in width. The mineralisation, occurs as massive pyrite-siderite with accessory cassiterite-galena, sphalerite and stannite, is mostly hosted in the Montana Beds but the western margin is hosted in the Oonah Formation. The tin mineralisation is located below and adjacent to galena-silver-sphalerite lodes that were historically mined to a depth of approximately 70m from surface in the Historic Montana No 2 Mine. Two galena silver lodes were developed, one trending northwest, the other east-northeast. Stanniferous pyrite mineralisation occurs between the two lodes extending down dip sub parallel to the east-northeast galena-silver lode.

Resource Estimation

The Heemskirk Tin resource estimation is based on 100 historic diamond drillholes for 25,537.7m and 35 recent diamond drillholes for 10,428.5m.   Drill core was analysed at commercial laboratories for a range of elements by fused disc and pressed powder XRF.   Bulk Density determinations were made from a combination of pynctometer and the Archimedes method on drill core samples. Core is non-porous with minimal voids and cavities.

Geological domaining is based on a 0.4% Sn boundary on mineralisation demonstrating sectional continuity within a broader zone of low grade Sn mineralisation. The domains are considered geologically robust in the context of the classification applied to this estimate.

Block-modeled Sn, S, acid soluble Sn^2 and SG for the Severn and Queen Hill resources were estimated using an ordinary kriging algorithm. Block-modeled Sn, S, acid soluble Sn and SG for the Montana resource was estimated using an inverse distance squared algorithm.

Classification of the Heemskirk Tin Deposits takes into account data quality and distribution, spatial continuity, confidence in the geological interpretation and estimation confidence.

The estimated resource, reported above a 0.6% Sn cutoff as Inferred and Indicated Resource in accordance with the 2012 edition of JORC Code is listed in Table 1.

Table 1. Heemskirk Tin Deposit Indicated and Inferred Resource, 0.6% Sn cut off.

Classification	Deposit	Mtonnes	Sn %	Sn tonnes
Indicated Resource	Queen Hill	1.41	1.26	17,790
Total Indicated Resource		**1.41**	**1.26**	**17,790**
Inferred Resource	Queen Hill	0.19	1.63	3,090
	Severn	4.17	0.98	40,900
	Montana	0.51	1.91	9,710
Total Inferred Resource		**4.87**	**1.10**	**53,710**
Total Resource		**6.28**	**1.14**	**71,500**

Note: tonnes have been rounded to reflect the relative uncertainty in the estimate

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[2] Acid soluble Sn measures Sn sulphide mineralisation (stannite)

The resource remains open down plunge and along strike and future additions are likely with continued exploration drilling (Figure 4).

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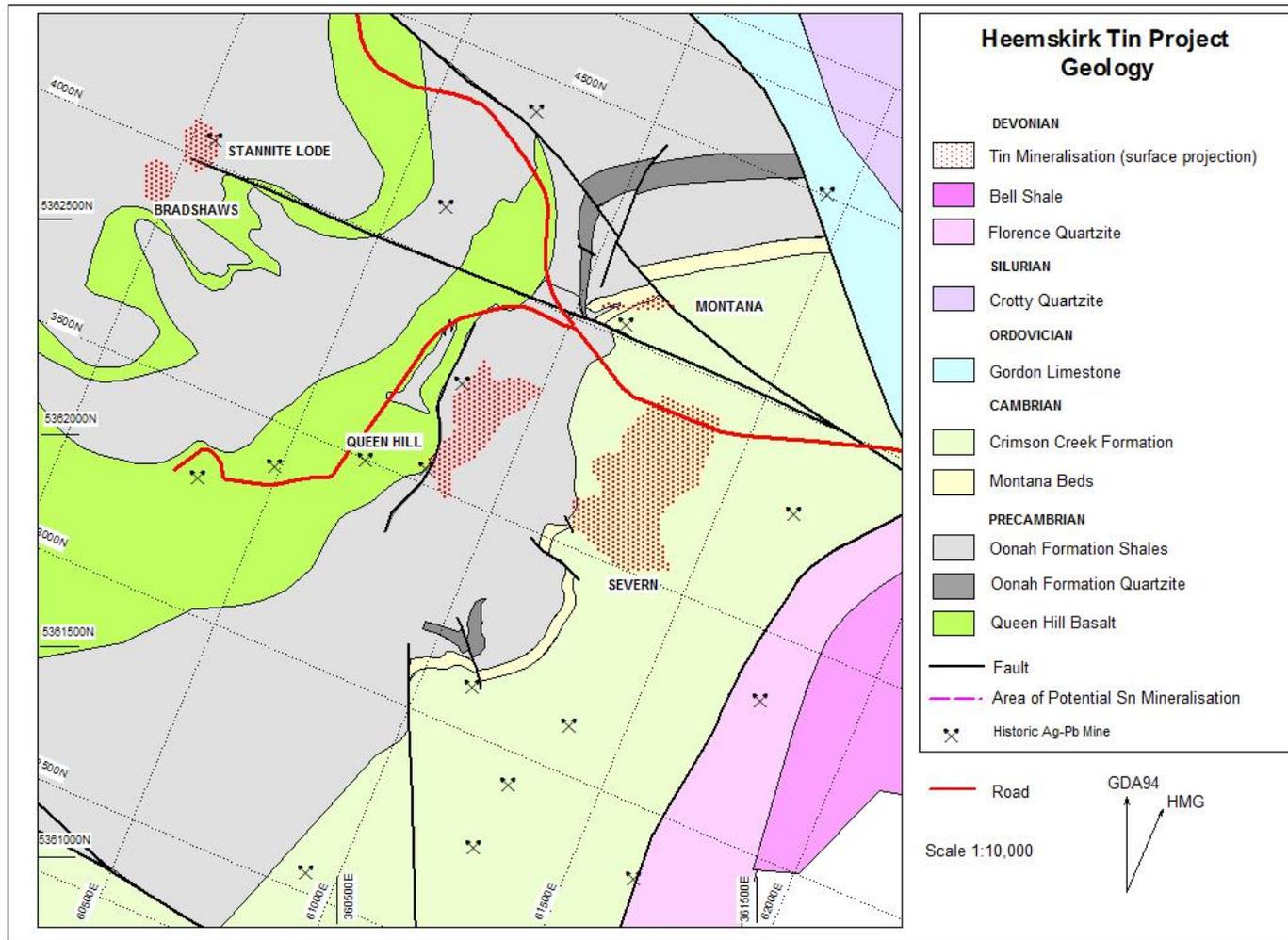
Figure 2. Heemskirk Tin Project Local Geology
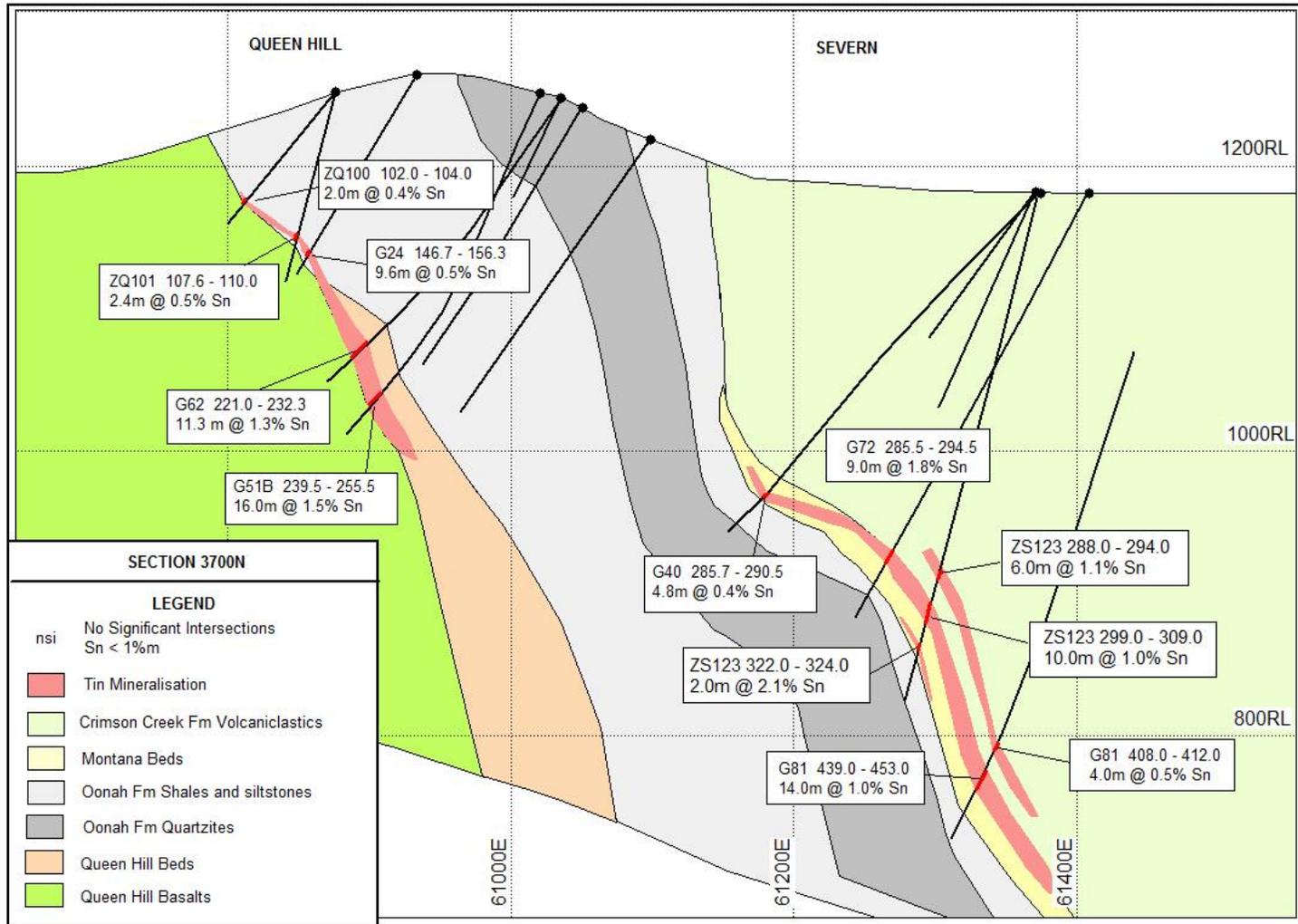
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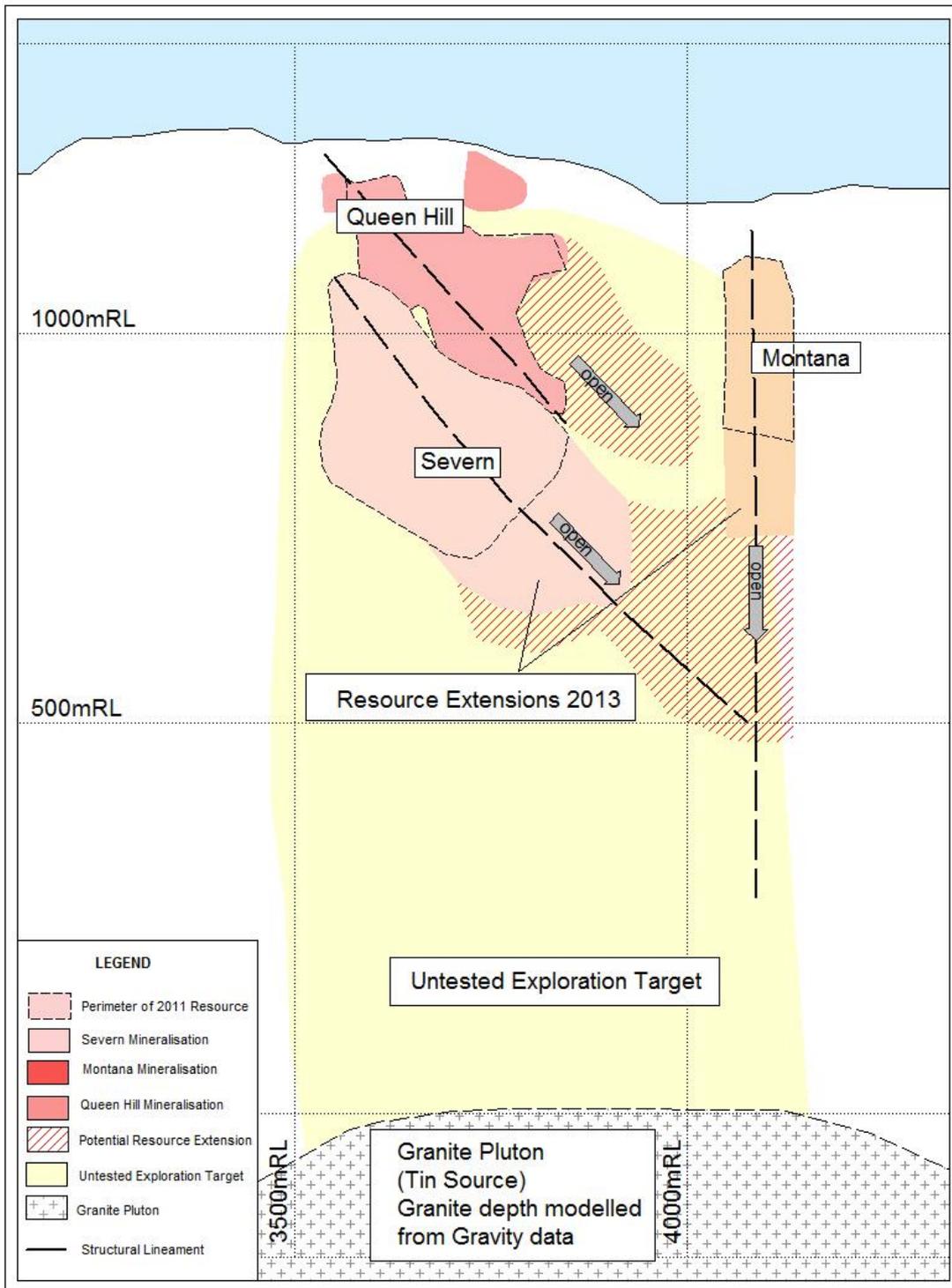
Figure 4. Heemskirk Tin Deposit Composite Long Projection.

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Competent Person Statement

The information in this report that relates to Mineral Resources was prepared in accordance with the 2012 Edition of the 'Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves' ("JORC Code") by Tim Callaghan of Resource and Exploration geology, who is a Member of The Australian Institute of Mining and Metallurgy ("AusIMM"), has a minimum of five years experience in the estimation and assessment and evaluation of Mineral Resources of this style and is the competent Person as defined in the JORC Code. This report accurately summarises and fairly reports his estimations and he has consented to the resource report in the form and context it appears.

TASMANIDES ARC-STYLE Au-Cu MINERALISATION, IN A PACIFIC RIM CONTEXT

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ABSTRACT
Prospecting in eastern Australia might be aided by comparisons between the setting and nature of Tasmanides (in the definition of Glen, 2013) arc-style Cu-Au mineralisation with the controls to varying styles of similar ore systems in younger less deformed Pacific rim arcs. Recent reconstructions of the Tasmanides suggest considerable rollback-related extension resulted in the deposition of extensive Ordovician Macquarie turbidites rather than previously considered proximal magmatic arc rocks (Glen, 2013), and so more emphasis should now be placed upon regional structures as loci for development of (island or magmatic) arc style porphyry Cu-Au and epithermal Au-Ag mineralisation. Three major structure types which localise intrusions and associated mineralisation include:

- Arc parallel faults which might also represent terrain boundaries and may have been mineralised during transient changes to oblique convergence.
- Transfer structures which accommodate changes across the arc such as the dramatic increase in width towards the southern portion of the Tasmanides.
- Conjugate fractures formed in settings of orthogonal convergence.

Porphyry Cu-Au as well as low and high sulphidation epithermal Au-Ag ore systems, formed from different ore fluids, occupy varying positions within arc and back arc environments, although linked in time and space. These linkages and zonations in mineralisation and alteration provide features which may be used to prospect for hidden ore systems. Lithocap zonations only provide vectors to porphyry mineralisation if the elements which make up an individual alteration zone are correctly understood.

INTRODUCTION
Although the science of porphyry Cu mineralisation began to evolve in the 1960's, as the development of appropriate earth moving equipment facilitated mining of bulk tonnage low metal grade ores, it is now some 30 years since a rise in Au price prompted more intensive studies of epithermal Au mineralisation. As both form in arc-back arc settings (SW Pacific island arcs floored by oceanic crust and magmatic arcs floored by continental crust in Latin America), mineral exploration has partly driven a need to better understand tectonic processes. In eastern Australia, the recent analysis of the Tasmanides tectonic setting by Glen (2013) suggests considerable rollback-related extension provided an environment for deposition of laterally extensive Ordovician turbidites in the hanging wall to a SW dipping subduction zone located in the New England region, rather than a traditional view of NS trending linear (Macquarie) magmatic arcs, as the environment for porphyry Cu and deep epithermal Au-Ag formation. Exploitation of geothermal energy has provided modern analogies to aid in the understanding of mineralisation processes, herein with an emphasis upon the work by the late Terry Leach on the Philippine island arc geothermal systems as analogies for a greater proportion of Cu-Au mineralisation styles, than the more widely published New Zealand back arc geothermal examples (Corbett 2008). Exploration might be aided by a better understanding of the controls to the varied styles of Cu-Au mineralisation derived from comparisons of the redefined (Glen, 2013) Tasmanides to younger less deformed Pacific rim ore environments and ore systems (Corbett, in prep.).

ORIGIN OF TASMANIDES ARC PORPHYRY-EPITHERMAL ORE SYSTEMS
Arc and back arc hosted Cu-Au mineralisation (with Mo and Ag where appropriate) under consideration within the Pacific rim (including the Tasmanides) displays variable relationships to intrusion source rocks which have been ultimately derived from subduction related melting. Buoyant magmas rise to elevated crustal settings and erupt as typically andesitic volcanic arcs, or cool at depth to form buried porphyry Cu-Au intrusions, interpreted to overlie deeper magmatic source rocks for metals. At higher crustal levels the interplay of evolving magmatic fluids and

circulating meteoric waters within dilatant structures, facilitates the formation of high and low sulphidation epithermal Au-Ag mineralisation derived from quite different fluids. Felsic subvolcanic intrusions and breccias display relationships to mineralisation in extensional settings. The original west Pacific exploration models (Titley, 1982; Sillitoe, 1973) that placed porphyry Cu deposits in the root zones of stratovolcanoes continue to evolve to cater for differences recognised in the SW Pacific rim such as porphyry systems emplaced into basement rocks without associated volcanic sequences (Grasberg, Indonesia; Porgera, Golpu at Wafi, Papua New Guinea). The Tasmanide Cadia Valley porphyry systems which are hosted within a turbidite sequence (Wilson et a., 2007), were derived from a distal magmatic source, considered from the alkaline character to mantle-derived (Glen and Walsh, 1999) and emplaced via deep crustal structures. Consequently, in the absence of proximal magmatic arcs for much of the Tasmanides, major structures which control the Tasmanide architecture such as the widening to the south, should be prospected as sites for the emplacement of porphyry and intrusion-related epithermal Cu-Au mineralisation.

LOCALISATION

Three classes of major structures (figure 1) which localise porphyry-epithermal ore systems are relevant to the Tasmanides:

Arc parallel structures, commonly characterised as terrain boundaries with general reverse senses of movement in orthogonal arcs (Domeyko Fault-West Fissure, Chile) or lateral movement in oblique arcs (Philippine Fault), may host ore systems within dilational segments. In conditions of oblique movement, negative flower structures host stacked dilatant sites characterised with decreased depth as: most deeply buried splay faults, fault jogs or link structures, and surficial pull-apart basins (Corbett and Leach, 1998). Splay faults localise porphyry Cu deposits at the Chuquicamata mine in the West Fault, Chile (Boric et al., 1990), and the Far South East porphyry Cu-Au in the segmented Philippine fault, Philippines (Corbett and Leach, 1998). The La Escondida porphyry Cu, Chile occurs in a link between Domeyko fault segments (Corbett, unpubl. data), and the Frieda porphyry-Nena high sulphidation epithermal system are also localised by a splay in the arc parallel Fiak-Leonard Schultz Fault, Papua New Guinea (Corbett, 1994). The West Fault-Domeyko Fault system is interpreted to have changed from reverse to regional dextral movement during the emplacement of Chuquicamata and La Escondida porphyry Cu deposits, which is also apparent at the higher crustal level El Indio and La Coipa high sulphidation Au and El Peñón low sulphidation Au-Ag epithermal deposits, Chile.

In the Tasmanides, the Gilmore suture localises Cu-Au mineralisation with many ore systems discernible as having formed under conditions of sinistral strike-slip deformation (Mt Adra, Gidginbung, West Wylong). The Gympie and Cowal deposits lie within pull-apart basins (20 km long for Gympie) in which basin forming growth faults are reactivated as vein hosts, also in conditions of sinistral movement on the roughly NS structural grain. From comparisons with other arcs, it has previously been suggested (Corbett and Leach, 1998) this orogen-wide tendency for sinistral oblique movement discernible in the kinematics of individual Tasmanide ore systems, apparently through protracted time (Browns Creek skarn, Mineral Hill, Cobar district [in Glen 1987]), results from transient changes on the nature of convergence which provide triggers for the forceful emplacement of spine-like porphyry intrusions and evolution of ore fluids to form higher crustal level epithermal deposits. However, these transient changes in convergence might only be discernible in the geological record as the divergence between the kinematics of individual ore systems and the overall arc.

Orthogonal extension on arc parallel structures also localises epithermal mineralisation in many Pacific rim epithermal districts (200% Basin and Range district of SW USA-Mexico; Bulolo Graben, Papua New Guinea), which may be apparent in the localisation of Drummond Basin low sulphidation epithermal Au deposits.

Transfer structures (termed transform by some workers) cut arcs at high angles and facilitate segmentation of the subduction-arc complex characterised by variations in strike of the arc, dip of the subducting plate or rate of subduction, commonly with protracted histories of activity. Transfer structures have long been recognised with a regular spacing across the island of New Guinea (Corbett, 1994) as deep fundamental breaks which may tap mantle-related magmas (Porgera, Papua New Guinea), or focus overprinting intrusion events (Wafi-Golpu, Papua New Guinea). The giant Yanacocha high sulphidation epithermal-porphyry district lies in such a structure which

facilitates bending of the Peruvian Andes (Teal and Benavides et a., 2010; Longo et al., 2010). The Lachlan Transverse Zone (Glen and Walshe, 1999) localises the Cadia district where analysis of mine data demonstrates the Ridgeway and Cadia East ore systems lie within pull-apart basin scenarios at the intersection of NS fractures with sinistral senses of movement, while sheeted quartz veins are aligned with the dilatant WNW fractures here and Cadia Hill. The dilatant fractures have acted as growth faults during volacanism (Wilson et al., 2997) and also splay faults to localise porphyry emplacement. While the recognition of a relationship between Lachlan Transverse Zone NW structures and Cu-Au mineralisation is not new, (Scheibner and Stevens, 1974), the pronounced thickening of the Tasmanides from Queensland to NSW (Glen, 2013) is no doubt accounted for by transfer structures which now represent high priority exploration targets, especially at the intersection of the NS structural grain.

Conjugate fractures with a regular spacing (Corbett, unpubl. data) localise ore systems in orthogonal magmatic arcs (northern Chile-Argentina; Argentine Patagonia; NE Sulawesi, Indonesia), in conditions of compression or extension, commonly at intersections with arc parallel fractures where regular changes in kinematics (above) create dilatant settings. Modest sized low sulphidation epithermal veins in Patagonia are localised by NE and NW conjugates in mostly compressional regimes. Larger high sulphidation epithermal systems are localised on conjugates during extension (Pascua-Lama, Veladero, Chile-Argentina) than those formed in compression settings (El Guanaco, Chile and Quevar, Argentina). In the Northern Tasmanides intersecting conjugates localise the Kidston breccia pipe by tapping the underlying magma source (Corbett and Leach, 1998).
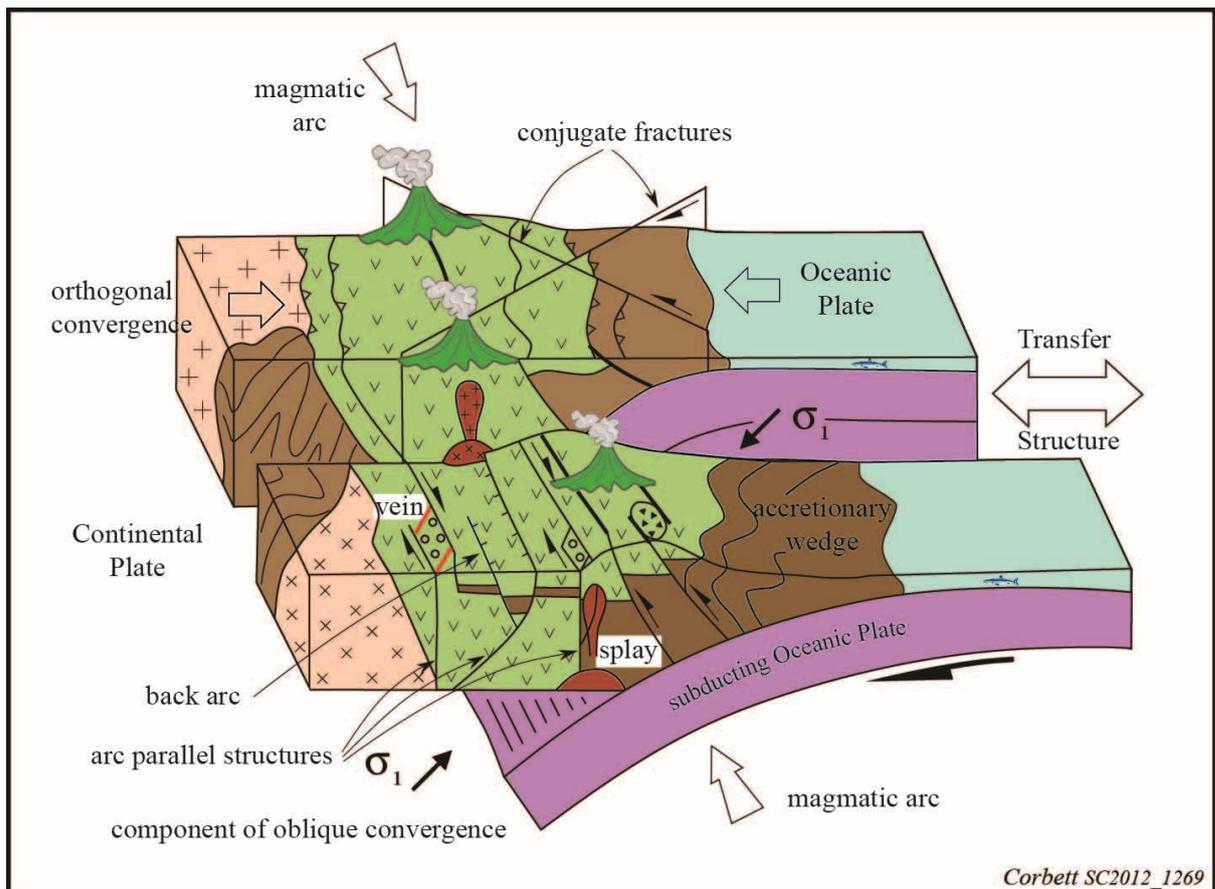
Figure 1. Conceptual magmatic arc formed at an ocean-continent collision with oblique and orthogonal convergence segments showing the three types of structures classed as arc parallel, transfer structures and conjugate fractures (from Corbett in prep., modified from Corbett and Leach, 1998 and Corbett, 1994).

MINERALISATION STYLES

The mineralisation styles (figure 2) recognised in the Tasmanides are broadly similar to those recognised in Pacific rim arcs (Corbett, 2009 and references therein; Corbett, in prep.) although typically older and more deeply eroded.

Porphyry Cu-Au intrusion rise as locally vertically attenuated spine-like forms to within a km of the palaeo surface above deeper magmatic source rocks for much of the metals and provide economic ore systems in settings of repeated intrusion emplacement and mineralisation, provided barren post-mineral intrusions do not stope-out ore. Intact buried porphyry systems (Ridgeway, Australia; Golpu, Papua New Guinea; Oyu Tolgai, Mongolia) represent attractive targets as significant metal contents lie in the overlying wall rocks. Some vectors which might aid in discovery of these hidden buried intact ore systems include:

- Structure described above as a basic targeting tool.
- Zoned prograde potassic-propylitic hydrothermal alteration (Corbett, 2008, 2009 and references therein; Corbett, in prep.) in which the presence of inner propylitic actinolite represents a good indicator of nearby porphyry systems, although epidote may provide a larger alteration footprint (see the Terry Leach zoned alteration pH vs temperature figure in Corbett and Leach, 1998). At Wafi-Golpu, the first appearance of actinolite alteration correlates with the first appearance of chalcopyrite and is coincident with the 0.1% Cu shell (Menzies et al., 2013).
- D veins (in the terminology of Gustafson and Hunt, 1975) characterised by quartz, pyrite, chalcopyrite, galena, sphalerite and carbonate form marginal to porphyry systems and zonations in mineralogy such as sphalerite composition (colour), may provide some indication of distance to the buried source intrusion (Corbett, in prep.). Consequently, broad Zn anomalies may rim porphyry systems and provide vectors to the central porphyry mineralisation (e.g., Wafi-Golpu in Menzies et al., 2013).
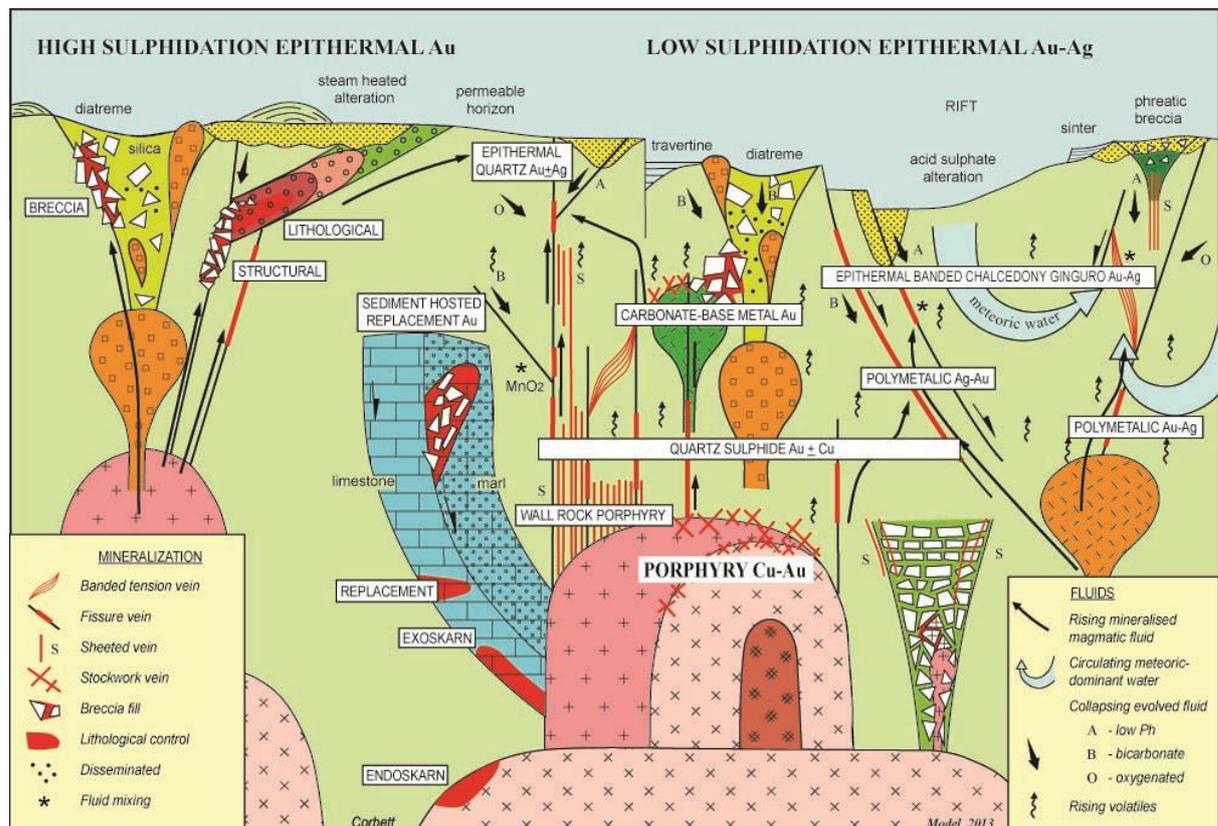
Figure 2. Conceptual model illustrating the linkages between porphyry with high and low sulpidation epithermal mineralisation (from Corbett in prep., modified from Corbett, 2009).

- Careful analysis of down hole and surface Cu-Mo geochemistry provides vectors to porphyry mineralisation (Menzies, pers. commun.). Cadia Hill is rimmed by >250ppm Cu

(Wood, 2012) and Golpu >150ppm Cu (Menzies et al., 2013) while the Gulpu advanced argillic alteration host >40ppm immobile Mo. Elsewhere, the Bajo de la Alumbrera porphyry, Argentina is rimmed by >43ppm Mo (Sillitoe, 1995) and Batu Hijau >30ppm Mo (Meldrum et al., 1994).

- Higher temperature end members of the barren shoulder continuum (Corbett, 2008), described below may vector towards source intrusions (below).
- Geophysical signatures in settings obscured by cover will include spot magnetic highs for intact prograde potassic alteration, although destroyed by later retrograde phyllic-argillic alteration. Donut shapes prevail for preserved prograde alteration at deeper erosional levels. Chargeability anomalies vary to significantly higher levels within retrograde phyllic silica-sericite-pyrite-carbonate alteration which collapses upon prograde alteration, causing magnetite destruction. Caution is urged in the use of geophysical prospecting as chargeable phyllic alteration does not equal porphyry Cu-Au mineralisation but is part of the overall porphyry system (Corbett, 2008, 2009).
- Careful attention to the style of breccias may also aid explorationists in the identification of porphyry targets (Corbett, in prep.).

Skarn deposits develop by the reaction of porphyry-related hydrothermal fluids with reactive carbonate wall rocks and may form attractive Cu-Au ore systems within porphyry districts (Browns Creek, NSW; Mungana, Queensland), and host distinctive prograde and retrograde mineralogy including magnetite, identified in regional magnetic surveys. In each of the above examples, highest grade ores overprint the skarns as porphyry-like sheeted quartz veins at Browns Creek and as Ag-rich tennantite veins at Mungana, and so the skarn in part represents a favourable host rock connected to the magmatic source. A most important aspect of Tasmanide magnetite skarns is as a vector towards nearby porphyry mineralisation (e.g., Big Cadia skarn), just as many Pacific rim porphyry systems developed from magnetite skarn discoveries (Ok Tedi & Nena, Papua New Guinea; Grasberg, Indonesia).

Wallrock porphyry systems (Cadia Hill, Tooloom, Australia; Gaby, Ecuador; Maricunga Belt, Chile) characterised by sheeted Au>Cu bearing quartz-sulphide veins represent the transition between porphyry and (deep) low sulphidation epithermal regimes (figure 2). Most display marginal metal grades, although Cadia Hill economics were assisted by the presence within a mineralised district (Ridgeway).

Epithermal Au-Ag deposits are divided between high and low sulphidation styles, most easily considered by explorationists as derived from distinctly different hydrothermal fluids which provide characteristic ore and gangue mineralogy and wall rock alteration (Corbett and Leach, 1998; Corbett, in prep.).

<u>**Low sulphidation epithermal**</u> ore systems (figure 2) are deposited from near neutral fluids characterised by varying mixes of meteoric and magmatic waters and display two fluid flow trends from deeper crustal level intrusion metal sources to near surficial settings (Corbett and Leach, 1998; Corbett, 2001, 2009; Corbett, in prep.). The controls of dilatant structures, competent host rocks and efficient mechanisms of Au deposition (Leach and Corbett, 2008) provide higher Au grades in deposits further from the intrusion source. Styles include:

Quartz-sulphide Au + Cu mineralisation comprises quartz with auriferous pyrite and varies with depth to include chalcopyrite, pyrrhotite and specular haematite and at higher crustal levels, marcasite and opal, or quenched arsenian pyrite. The modest Au grades deposited from a cooling magmatic-rich ore fluid (Hamata, Papua New Guinea) are compensated by the good metallurgy of coarser grained ores which are readily treated as heap leach operations, especially where oxidised (Round Mountain & Sleeper, Nevada, USA). However, fine grained commonly arsenian pyrite ores deposited from quenched ore fluids display refractory metallurgy (Lihir & Kerimenge, Papua New Guinea). Many systems display elevated Au grades where overprinted by epithermal quartz-Au-Ag mineralisation (Emperor, Fiji; Round Mountain, Sleeper) or in settings of improved mechanisms of Au deposition (Leach and Corbett, 2008). Ore fluids have mixed with oxygenated groundwaters at Kencana at Gosowong, Indonesia, as evidenced by hypogene haematie, and bicarbonate waters in the Link Zone at Wafi, Papua New Guinea, evidenced by rhodochrosite. Quartz-sulphide systems are common ores in deeply eroded arcs such as the Tasmanides (Nolans, Mt Wright, London-Victoria, Mineral Hill, McKinnons, Adelong, Mt Adra, Drake). Caution

is urged as quartz-sulphide mineralisation commonly displays near surface supergene Au enrichment with resultant disappointing drill results from testing attractive soil and rock chip anomalies.

Carbonate-base metal Au mineralisation coined by Leach and Corbett (1993) to describe some of the most prolific Au producers in the SW Pacific rim (Porgera, Misima, Hidden Valley in Papua New Guinea; Chatree, Thailand; Antamok, Acupan, Victoria in the Philippines; Kelian, Mt Muro, Cikotok District in Indonesia; Gold Ridge in the Solomon Islands, and others) characterised by early pyrite (of the quartz-sulphide stage) followed by sphalerite>galena and later variable but dominantly Mn carbonate. Ores typically occur as breccia fill, stockwork and lesser fissure veins and may display an association with felsic intrusions and breccias. The mixing of rising magmatic ore fluids with oxidising bicarbonate waters provides higher Au grades than the quartz-sulphide systems (Corbett and Leach, 1998; Leach and Corbett, 2008), although many deposits display highly variable internal metallurgy. These deposits exhibit pronounced vertical zonation as well as variations in time from earlier quartz-sulphide to later epithermal quartz Au $\pm$ Ag ores (below). Tasmanide examples include Cowal, Kidston, Mt Leyshon and Mt Rawdon and as parts of many other deposits such as Mineral Hill, London-Victoria and Drake (although Ag-rich). This style of mineralisation, commonly discernible in weathered exposures by the MnO stain after Mn carbonate, are highly attractive bulk low grade mining operations (Cowal, Porgera).

Epithermal quartz Au $\pm$ Ag (modified from epithermal quartz Au-Ag in Corbett and Leach 1998) mineralisation is characterised by gangue-poor, high fineness, high to locally bonanza grade, free Au, which commonly overprints quartz-sulphide (Round Mountain & Sleeper; Emperor, Fiji) or carbonate-base metal ore systems (Porgera Zone VII, Mt Kare, Edie Creek in Papua New Guinea). The addition of chalcedony-adularia from circulating meteoric waters may provide banded veins with high fineness free Au in contrast the ginguro bands described below (Sleeper; Gowowong, Indonesia). Ores of this style are recognised in the Tasmanides at Mineral Hill, Twin Hills, and Mt Boppy in the Cobar region and represent particularly attractive exploration targets if preserved from erosion. Some bonanza Au deposits such as Gympie and Tick Hill may also be intrusion-related systems ultimately of this style.

Chalcedony-ginguro banded Au-Ag low sulphidation epithermal veins typically form in Pacific rim strongly extensional settings (figure 2) where there is considerable input of meteoric ground waters (Hishikari & Sado, Japan; Waihi & Golden Cross, New Zealand; Kupol & Asacha, Eastern Russia; Midas, USA; Cerro Vanguadia & Cerro Negro, Argentine Patagonia; Tolukuma, Papua New Guinea). Many western Pacific rim examples (Waihi, Kupol) terminate downwards with lower Au and higher base metal contents, although in Latin America there is a downward progression to mineralised low sulphidation epithermal **polymetallic Ag-Au** veins (Arcata & Cayollama in Peru; Palmarejo & Fresnillo in Mexico) mines as Ag-Au resources. Most Au in chalcedony-ginguro systems occurs in the sulphidic ginguro bands deposited from magmatic fluids, rather than the chalcedony and adularia deposited from meteoric waters. The polymetallic ores are likened to Ag-rich fissure vein hosted carbonate-base metal mineralisation. In the Tasmanites banded chalcedony-ginguro veins are well developed in the Drummond Basin (Vera Nancy-Pajingo) extensional environment, although individual examples display greater magmatic components (Twin Hills). Tasmanide polymetallic Ag-Au veins (Hadleigh Castle & Mungana Queensland; Conrad, NSW) are deposited from magmatic-dominated fluids.

High sulphidation epithermal Au $\pm$ Ag ore systems are deposited from a magmatic fluid which develops a hot acidic character during evolution from porphyry to epithermal crustal levels, and so there is an important physical separation between the epithermal ore system and its intrusion source (Lepanto-Far South East, Philippines in Corbett and Leach, 1998). Controls to fluid flow and hence mineralisation, include structure, alteration and breccias. This fluid breaks into a volatile rich phase which travels more quickly and produces the characteristic zoned advanced argillic alteration during progressive cooling and neutralisation by reaction with wall rocks and ground waters. This alteration which grades outwards from the feeder structure as mineral assemblages dominated by residual vughy silica, alunite, pyrophyllite-diaspore, dickite, kaolin to marginal illite, varies with crustal level (temperature) and control of fluid flow (lithology, breccias or structure). Alteration zonation and fluid flow controls are used as vectors towards hidden mineralisation. A later liquid-rich phase commonly deposits Au-Ag mineralisation with enargite, including the low temperature polymorph luzonite, and pyrite along with gangue of alunite, barite

and local sulphur. SW Pacific rim examples tend to be Au dominant whereas examples in Latin America also contain Ag, while some from Ag-only deposits. Examples in the Tasmanides include the relatively small deposits of Peak Hill, Gidginbung and Dobroyd in NSW and Mt Mackenzie in Queensland, and while some important examples occur in the SW Pacific rim (Lepanto, Martabe, Indonesia; Nena & Wafi, Papua New Guinea; Mt Kasi, Fiji), the home of high sulphidation deposits is in the high Andes (Yanacocha & Pierina, Peru; Pascua-Lama, El Indio, La Coipa, Chile; Veladero, Argentina). As apparent in the mining of Gidginbung and Peak Hill, and exploration at Wafi, Papua New Guinea (Erceg et al., 1991), these deposits are commonly worked only in the oxide zone as sulphide ores display refractory metallurgy.

If a high sulphidation fluid is sufficiently cooled and neutralised by reaction with wall rocks or ground waters, it may evolve to lower sulphidation mineralogy, characterised by higher Au grades and improved metallurgy. The bonanza Au grade direct shipping ore at El Indio, Chile is interpreted by many workers as of a low sulphidation epithermal quartz Au-Ag style (Corbett and Leach unpubl reports; Heberlein, 2008). Mt Carlton in Queensland displays initial zoned advanced argillic alteration and lower precious metal grade pyrite-enargite ore, but is overprinted by high Ag grade lower sulphidation mineralisation containing yellow Fe-poor sphalerite and Ag sulphosalts. The recent term "intermediate sulphidation" (Einaudi et al., 2003) used by some workers to describe carbonate-base metal Au and polymetallic Ag-Au ores (Sillitoe and Hedenquist, 2003) applies to only low temperature end members of carbonate-base metal Au and polymetallic Ag-Au systems characterised by yellow Fe-poor sphalerite, and lacks the zonation in time and space of those deposits. Although rare intermediate sulphidation mineralisation develops in the transition between high and low sulphidation (Mt Carlton, above), no significant intermediate sulphidation fluid exists of the same calibre as high and low sulphidation and so the original terminology of Leach and Corbett (1993-1998) should be maintained.

LITHOCAPS

The symposium run by the AIG to honour the late Terry Leach represented an opportunity (at the request of Kaylene Camuti, current AIG President) to begin to unravel lithocaps which contain a number of distinctly different (advanced argillic-argillic) alteration styles which display profoundly variable relationships to mineralisation, commonly lumped together by explorationists (figure 3; Corbett, 2008). The structurally controlled deeper crustal level locally high temperature advanced argillic alteration categorised as barren shoulders (Corbett and Leach, 1998) provide vectors to some Pacific rim porphyry Cu-Au systems (Lookout Rocks barren shoulder - Ohio Creek porphyry, New Zealand; Ekwai Debom barren shoulder - Horse Ivaal porphyry at Frieda River, Papua New Guinea) and may be used as exploration targeting tools. However, higher crustal level permeability controlled advanced argillic lithocaps (in the restricted use of the term herein; figure 3) are more challenging exploration targets throughout less eroded Pacific rim arcs than the Tasmanides, although alteration at Bulahdelah and Pambula and a number in the Esk Trough represent local examples. Two recently published porphyry-lithocap scenarios (Wafi-Golpu, Papua New Guinea; Menzies et al, 2013; Caspiche, Chile, Sillitoe et al., 2013) represent younger high sulphidation epithermal Au deposits related to younger deep unseen porphyry systems superimposed upon existing porphyries. At Golpu the later acid fluid upgrades Cu in the earlier porphyry (Menzies et al., 2013). Explorationists must distinguish initially barren zoned advanced argillic alteration from zoned advanced argillic alteration associated with high sulphidation epithermal Au deposits. (They display rare overprinting mineralisation). High sulphidation epithermal Au deposits represent difficult porphyry targets at depth. Acid sulphate and steam heated alteration caps to low and high epithermal deposits respectively (Corbett, 2008) are not likely to be preserved in the deeply eroded Tasmanides although resources have been identified below the former at Guadalupe at Palmarejo, Mexico and the latter at Quimsacocha, Ecuador, and so these alteration zones remain quality exploration targets in younger less eroded arcs.
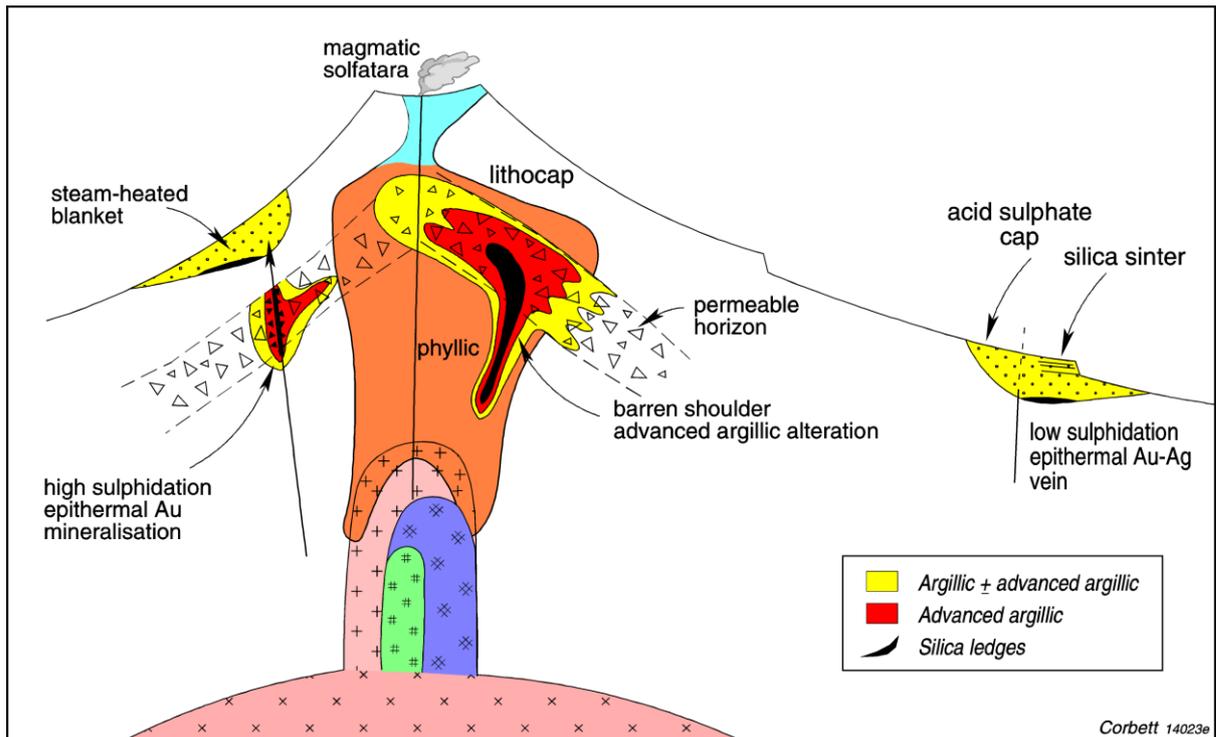
Figure 3. Styles of argillic-advanced argillic alteration included within the commonly regarded lithocap classification (from Corbett in prep., modified from Corbett, 2008).

EXPLORATION IMPLICATIONS

Analysis of more youthful Pacific rim ore systems without post-mineral deformation may aid in Tasmanide targeting as:

- WNW-NW trending transfer structures which may account for the great change in width between the southern and northern Tasmanides (Glen, 2013), could host intrusion-related mineralisation, particularly where the intersections of NS facture systems (with sinistral senses of movement) provide dilatant sites. Prospecting in NSW should consider these structures which display regular spacing and localise porphyry-epithermal mineralisation in Pacific rim arcs (Papua New Guinea; Peru).
- Arc parallel structures might host intrusion-related mineralisation in dilatant sites such as pull-apart/link/splay faults, as recognised in the Pacific rim. The orogeny-wide tendency for sinistral oblique movement on NS structures to localise ore systems allows rapid targeting by rapid examination of data bases for left stepping perturbations in throughgoing structures and links within fracture corridors.
- Structural intersections such as the arc parallel structures with conjugate fractures or transfer structures remain prospecting sites, and are not just local sites, but through oblique convergence represent larger dilatant settings such as pull-apart basins.
- Magnetite skarns derived from porphyry intrusion source rocks may, as recognised elsewhere, act as vectors towards porphyry mineralisation, if combined with other data such as geophysical interpretations.
- Mo and Zn anomalism may vector to porphyry Cu-Au mineralisation.
- The variety of low sulphidation epithermal Au deposits display controls dominated by structure, competent host rocks and efficient mechanisms of Au deposition as well as linkages that might in prospecting. Some low sulphidation epithermal systems display particular characteristics discernible during prospecting such as: boxworks after pyrite for commonly supergene enriched lower hypogene Au grade quartz-sulphide systems, or MnO as an indicator of weathered carbonate-base metal Au ores.
- Lithocaps represent prospecting sites for porphyry mineralisation elsewhere in the Pacific rim but require careful analysis as only some types of advanced argillic alteration might vector towards porphyry deposits. Acid alteration overlies epithermal ores in less eroded terrains than the Tasmanides.

- Exploration for porphyry Cu sources to high sulphidation epithermal Au deposits may be inhibited by the considerable physical separation between them, although some porphyry deposits are overlain by younger high sulphidation epithermal Au systems (Wafi-Golpu, Papua New Guinea; Caspiche, Chile). At Golpu the later acid fluids have upgraded the Cu content of the earlier porphyry.

CONCLUSIONS

Changes in the overall tectonic character of the Tasmanides (Glen, 2013) decrees that greater use of regional structure should be employed in prospecting for porphyry systems and analyses of deposit-scale structure might aid in the discovery of epithermal ores. WNW-NW transfer structures which account for the southward thickening of Tasmanides are prime targets, especially at the intersections of NS fractures. Prospecting in the southern Tasmanides may investigate left stepping perturbations in NS regional structures as sites of ore formation. In both northern Chile and the Tasmanides many ore systems are interpreted to have formed in conditions of oblique convergence (dextral in Chile, sinistral in NSW), although the arcs are considered to display overall orthogonal convergence. In this interpretation (Corbett and Leach, 1998), transient changes in the nature of convergence act as triggers for the forceful emplacement of spine-like porphyry intrusions or higher crustal level epithermal deposits. Further work might more carefully investigate whether oblique convergence discernible from ore system kinematics is long lived.

Styles of alteration and mineralisation and linkages between them provide vectors to aid explorationists when prospecting for porphyry and epithermal ore systems, including the likely distance to ore as well as viability of lithocaps as exploration tools, and consequently contribute towards the estimation of target priority in any exploration program.

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THE COLLAPSE CALDERA ENVIRONMENT FOR AU-AG MINERALISATION WITHIN THE DRAKE VOLCANICS, NEW ENGLAND: IMPLICATIONS FOR EXPLORATION

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Abstract

Recent geological mapping of over 250 square km in the Drake Volcanics of the New England Fold Belt (NEFB), Australia, integrated volcanic facies and structural analysis with litho-geochemistry to elucidate a new geological context for the Au-Ag mineralisation. The volcanic facies architecture and eruption and emplacement mechanisms for the volcanic rocks have been defined, along with the environment and depositional processes through time. Lithological and structural elements suggest a demagnetised region within the Drake Volcanics formed as a caldera with evidence for incremental collapse and later resurgence, while the caldera collapse structures control Au-Ag mineralisation.

Distinct pre-, syn- and post-caldera related facies associations were identified and assigned to stratigraphic units, which build on studies by previous workers. The volcanics were emplaced in a shallow submarine environment and comprise a complex assemblage of mixed - originally glassy and crystalline basaltic and andesitic lavas and syn-eruptive intrusions, reworked dacitic volcaniclastic facies, syn-eruptive dacitic to rhyolitic volcaniclastic facies and younger syn- and sub-volcanic andesitic to rhyolitic intrusions. Thick lobes and layers of dacitic-lithic and rhyolitic quartz-feldspar fiamme breccias are interpreted to represent caldera forming eruption products which are thickest and widespread in the demagnetized area. These felsic lithofacies record syn-eruptive explosive volcanism, where deposition was coeval with explosive activity. A large proportion of juvenile pyroclasts (fiamme) were deposited initially as water supported pyroclastic gravity flows or high concentration turbidity current, debris, grain flows and later as large volume, laterally expansive pyroclastic density currents. Contact relationships suggest that these flows in-filled old sea floor topography created by pre-existing lavas, domes, sills and debris avalanche deposits.

The caldera provides a primary control to Au-Ag mineralisation within flat-moderate dipping bedding planes activated during collapse, which represent major fluid feeder structures, and by movement to form smaller scale tension veins in adjacent competent host rocks. These structures are an important focus to mineralisation where they tap the late fertile intrusive source rocks. Low sulphidation epithermal Au mineralisation is typical of the styles recognised in association with sub-volcanic dome intrusive source rocks elsewhere in the Pacific rim.

Introduction

The township of Drake in northern NSW, occurs in the centre of the Drake Volcanics, approximately an hour's drive west of Lismore. Gold was first discovered in the region at Mt Carrington in 1886 and the project area was subject to significant gold, silver and copper mining to 1908. Open pit gold and silver mining on a small scale also occurred from 1988 to 1990, followed by a hiatus in exploration from 1994 to 2006.

Much previous exploration in the Drake mineral field has focussed on the known workings and leases (at Mount Carrington) at the expense of the substantial regional potential. White Rock Minerals Ltd. conducted a high resolution airborne magnetic survey over a $400km^2$ area in the central section of the EL's, focussed on the Drake Quiet Zone (DQZ). The magnetic survey provided a quality dataset to guide exploration and from which much of the volcanic and alteration facies have been established.

The DQZ spans approximately 250 square kilometres of forested hills, deep gullies and gorges which discouraged previous detailed mapping attempts. Over an intensive 2 year period approximately 250 square kilometres of ground was mapped covering the known mineralized zones at Mount Carrington, White Rock and Red Rock and areas in between. Along with detailed mapping, an intensive sampling program was undertaken. The resulting sample library is being utilised for mineral analysis (petrography and XRD) and geochemical characterisation using a hand held XRF on-site as mapping progresses.

Background Geology

The Mt Carrington project contains substantial precious and base metal mineralisation predominantly hosted by the Permian Drake Volcanics, within the New England Fold Belt (NEFB) in north-eastern New South Wales. The Drake Volcanics represents a 60km long by 20km wide north to northwest-trending sequence of Lower Permian felsic to intermediate volcanics which are intruded by syn-volcanic intermediate to felsic domes and sills. The volcanic sequence has an estimated thickness of 600 metres in the Red Rock area, while within the Mt Carrington group of MLs, it is at least 500 metres thick.

The Drake Volcanics overlie the older Carboniferous Emu Creek Formation to the east, which comprises predominantly sedimentary rocks that host the gold mineralisation of the Tooloom and Lunatic Goldfields. To the west of Mt Carrington the Drake Volcanics are in faulted contact with late Permian to early Triassic leucocratic granitoids which form part of the New England Batholith. These granitoids host numerous mineralisation occurrences including disseminated gold mineralisation at Timbarra and tin-tungsten-molybdenum mineralisation in the Wilsons Downfall and Stanthorpe areas.

The main regional geological feature of interest at Mt Carrington is a circular 15-20km diameter zone of low magnetic intensity (DQZ) delineated by concentric fault and fracture patterns within the central portion of the Mt Carrington Project area (Fig. 1).

New constraints for the Volcanic facies architecture of the Drake Volcanics

Detailed volcanic facies mapping has identified 4 mafic to rhyolitic facies associations or stratigraphic units/ formations. These units have been named DV1 – DV4 and comprise the formations defined by previous workers (Fig. 2). These units include:

> DV1: Basaltic facies association.
> DV2: Andesitic lava and volcaniclastic facies association
> DV3: Andesitic to dacitic breccias, fine sedimentary and fiamme bearing facies association
> DV4: Rhyolitic fiamme breccia and dacite to rhyolite facies association

DV1 includes basaltic lavas, shallow sills and dykes with highly amygdaloidal zones and peperitic monomictic basaltic breccia facies. The basaltic facies occur at the base of the volcanic succession. Textural features suggest that basaltic lava interacted with wet, unconsolidated sediment.

DV2 includes andesitic lavas and shallow sills which span out laterally into coherent in situ and resedimented autoclastic facies. The sills and flows display similar textures and mineralogy and are generally tabular, with broadly concordant and locally discordant contacts. These facies form a large part of stratigraphic unit DV2 and represent important competent host rocks for fracture-vein mineralisation. Graded granule lithic and glass-shard rich sandstone facies are interpreted to represent the products of effusive and small-scale explosive eruptions which were re-deposited in a shallow marine depocentre. Throughout the district, thicker sequences of andesitic rocks with

high proportions of coherent lithologies define the locations of volcanic centres. Thick beds of polymictic andesitic boulder breccia deposits are interpreted to represent the products of debris avalanches and slides, which probably originated from the steep sided slopes of these andesitic centers. The palaeo-scarp structures which initiated sector collapse and generation of debris avalanche deposits represent important focuses for hydrothermal fluid flow, resulting in the development of Au-Ag mineralization where they transect competent host rocks and so promote dilatant fracture formation.
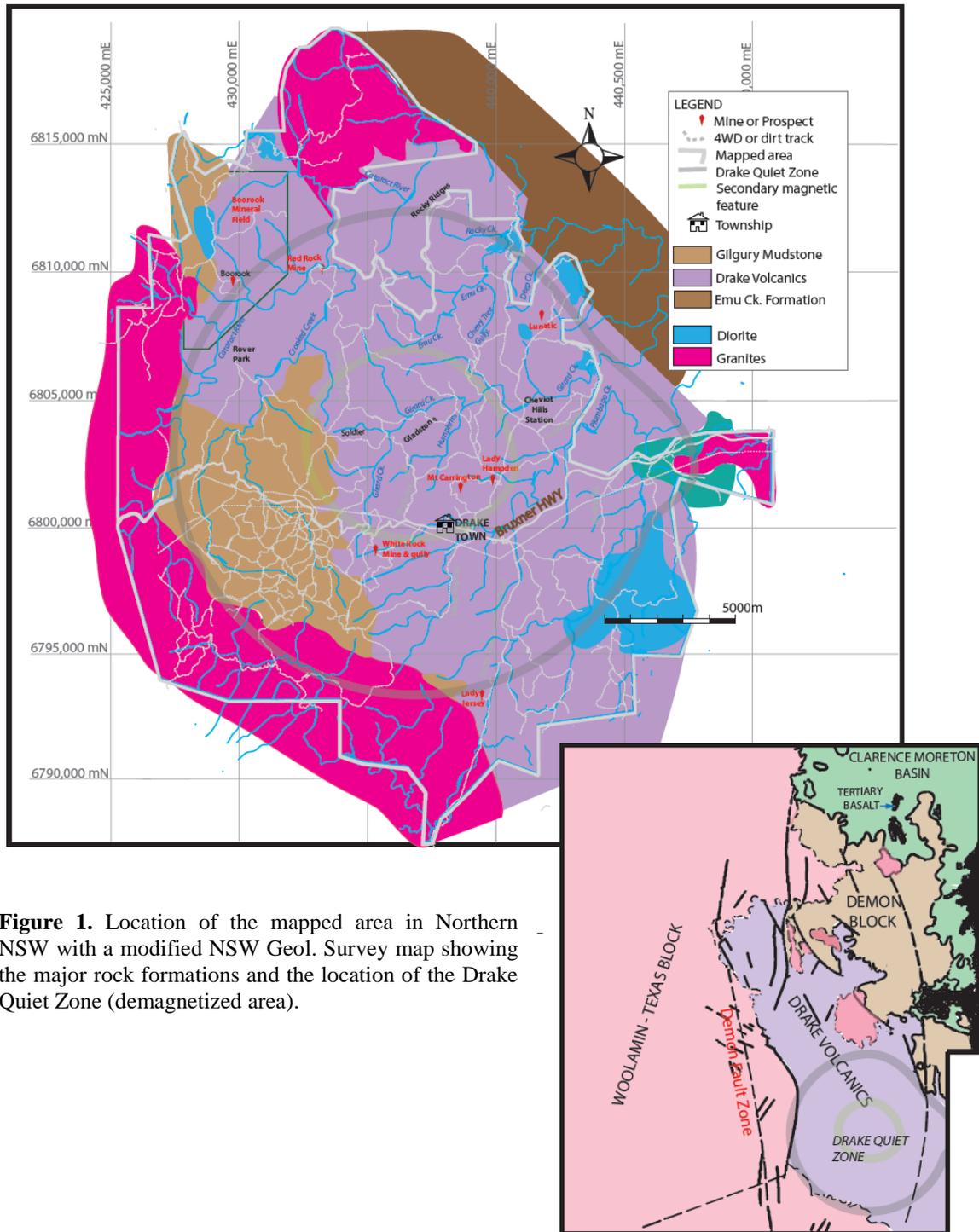
Figure 1. Location of the mapped area in Northern NSW with a modified NSW Geol. Survey map showing the major rock formations and the location of the Drake Quiet Zone (demagnetized area).

Stratigraphic unit DV3 marks a period of time where the volcanic system evolved, and several large scale explosive eruptions occurred. The components from these eruptions were re-deposited as mixed pyroclastic and lithic rich density currents evidenced by the fiamme bearing facies, including polymictic lithic fiamme breccia facies. Post-eruptive reworking and re-sedimentation is evident in several intervals of fine grained sedimentary facies within and overlying this unit.

Stratigraphic unit DV4 contains expansive, thick lobes of rhyolitic quartz-feldspar fiamme breccias which define more than 35 square km of eruptive material and are interpreted to represent caldera forming eruption products. These are thickest, and widespread in the demagnetized area, and thin laterally outside of the de-magnetised zone. They record a sustained period of syn-eruptive explosive volcanism, where deposition was episodic and coeval with explosive activity. A large proportion of juvenile pyroclastic clasts (fiamme) were deposited as water supported pyroclastic density currents or Neptunian eruptions (Allen & McPhie, 2009). Contact relationships suggest that these flows in-filled old sea floor topography created by pre-existing lavas, domes, sills and debris avalanche deposits.

These felsic units (DV3 and DV4) essentially cap the succession and provide evidence of a large, ancient caldera as:
  • Initial plinean style fall deposits (evidenced as accretionary lapilli bearing siltstones) beneath the main fiamme bearing (pyroclastic) breccia deposits;
  • Large scale, voluminous water supported pyroclastic density currents (hot gas or hot gas+ water supported flows) are evidenced throughout the lower polymictic dacitic fiamme bearing breccias (DV3) and upper rhyolitic quartz-feldspar fiamme breccias which span most areas in the DQZ. These units are thickest in the central and western portion of the DQZ.
  • Isolated quartz-feldspar rhyolitic fiamme breccia "ignimbrite-like outflow sheets" occur outside of the main DQZ zone at Boorook and;
  • There is a contrast in geology across the main DQZ bounding structures most apparent to the north and north-west where Lower andesite and andesite-basalt dominated lithologies dominate outside of the main DQZ bounding features.

Rhyolite and dacite syn-volcanic intrusions with coherent and autobreccia parts appear to dissect most layers in the stratigraphy and cross-cutting the basal, granule sandstone portion of the Gilgury Mudstone above. At Red Rock a flow banded rhyolite displays fluidal/curvi-planar contacts with the rhyolitic fiamme breccias facies (DV4). Regionally, many rhyolite (and dacite) sub-volcanic intrusions have fluidal clast breccias and open space sediment infill along the perimeter of these felsic complexes, which suggest that sediment was poorly lithified regionally at the time of intrusive emplacement, indicating that the timing of their emplacement was close to that of the host succession. The dacite to rhyolite domes vary in thickness and extent, from thin, narrow apophyses, dykes and cryptodomes and laterally extensive, voluminous units with high aspect ratios. The dacite and rhyolite complexes display a similar range in textures and morphology and are intrinsically related, both temporally, spatially and structurally to epithermal mineralization when hosted within stratigraphic unit DV2.

Specific units within the district provide better hosts for epithermal style gold - silver mineralization. Stratigraphic unit DV2 ; a sequence of andesitic flows, breccias and finer grained volcaniclastics is the most competent, brittle rock type which might fracture and so form conduits for migration of mineralized hydrothermal fluids.
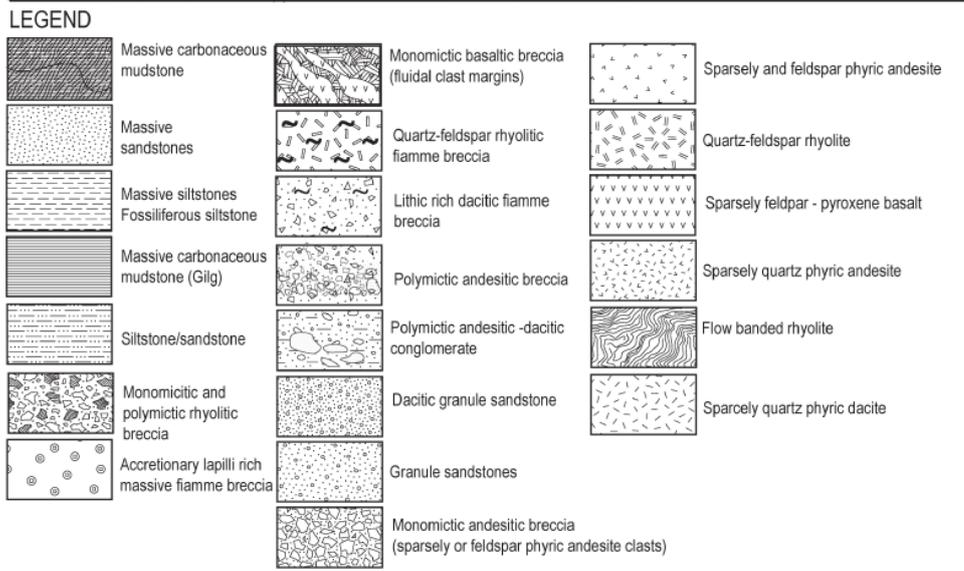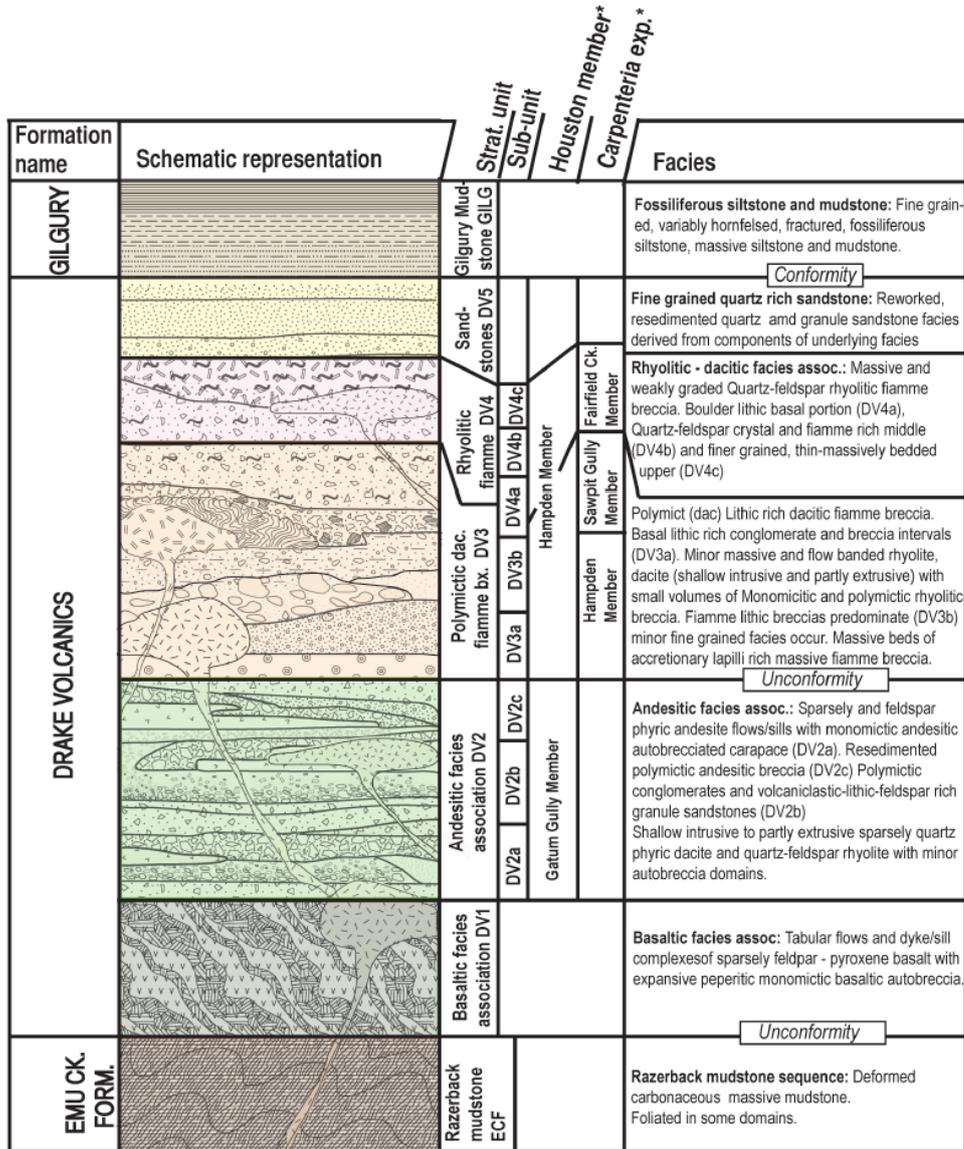
Figure 2. Stratigraphic framework for the DQZ showing a schematic, lithofacies arrangement diagram to the left and the major facies associations and facies in each unit. Previous subdivisions are included on separate columns.

Structural and genetic context for mineralisation

An apparent spatial and genetic relationship between numerous exposed and concealed rhyolitic intrusions and mineralisation at Mt Carrington is well constrained and commonly apparent as a gradation of alteration intensity away from the major DQZ structures. Caldera collapse has activated flat-moderate bedding plane faults as conduits for the transport of ore fluids and so mineralization dominates within smaller scale fractures hosted by competent host rocks proximal

to these feeder structures which are most apparent at Redrock and Lady Hampden (figure 3). These structures are likened to the mineralized flatmakes at the Tavua collapse caldera, Fiji (Corbett, 2003). The structural data for veins and faults in the Mount Carrington pits supports the interpretation that an underlying shallowly buried laccolithic rhyolite intrusion represents a source for mineralization.

The Mt Carrington project contains gold-silver-copper mineralisation typical of the intrusion-related low sulphidation epithermal systems catagorised here as, quartz-sulphide Au $\pm$ Cu grading to carbonate-base metal Au styles (in the classification of Corbett and Leach, 1998; Corbett, 2009), commonly formed marginal to sub-volcanic intrusive domes throughout the Pacific rim. Metal contents change through time and space governed by the controls to mineralisation at Mt Carrington as:

At the Kylo-Strauss open pits, Mt Carrington, a competent andesite sill hosts quartz-sulphide fracture, sheeted sulphide, lode mineralisation, while at depth movement on bedding plane shears has promoted the development of sigmoidal tension mineralisation within the intervening more competent host rocks.

Au-Cu mineralisation is associated with quartz-sulphide style early pyrite-chalcopyrite veins which pass to later Au-Ag bearing pale sphalerite > galena mineralisation. However, precious metal grades are restricted by the lack of Mn carbonate, normally deposited by the mixing reactions which result in ore formation in Pacific rim carbonate-base metal Au-Ag systems (Leach and Corbett, 2008).

At White Rock, a feldspar-quartz dacite dome provides the source of ore bearing fluids. Ag-rich carbonate-base metal style low sulphidation epithermal mineralisation extends from sulphide-bearing stockwork veins and breccias close to the dome margin, into the wall rock hosted as sulphide lodes. Pale coloured sphalerite is indicative of low temperatures of ore formation at a shallow crustal setting. This volatile-rich dome has intruded as a fine grained variably replaced quartz poor rhyolite (?) resulting in the formation of phreatomagmatic breccias which extend from the dome as cross-cutting breccia pipes into the DV2stratigraphic unit.

At Red Rock early mining focused upon a mineralised sulphide lode hosted within a bedding parallel fault. Recent exploration has identified some additional zones of competency contrast between fiamme breccia facies and sandstone layers, and a rhyolite cryptadome intruded into wet sediment. Ore bearing fluids dissipated from the dome through a highly porous sequence of fiamme breccias (stratigraphic unit DV4) and so have developed fluidal clast breccias with low grade mineralisation.

Near Lady Hampden drilling intersected competent and brittle host lithologies as well as mineralised bedding parallel structures. Ore shoots formed best along NNE trending splay zones which have intersected coherent (andesitic lithologies) or where early silicification caused the DV2 siltstone to become a competent host rock. These brittle rock types have fractured and brecciated to provide open space for the entry of metal-bearing hydrothermal fluids to deposit mineralised veins and breccias. High grade Au deposition was promoted by mixing of ore fluids rising up a flat-moderate dipping shears, with oxygenated ground waters collapsing down a the steeply dipping Cheviot Hills Fault.
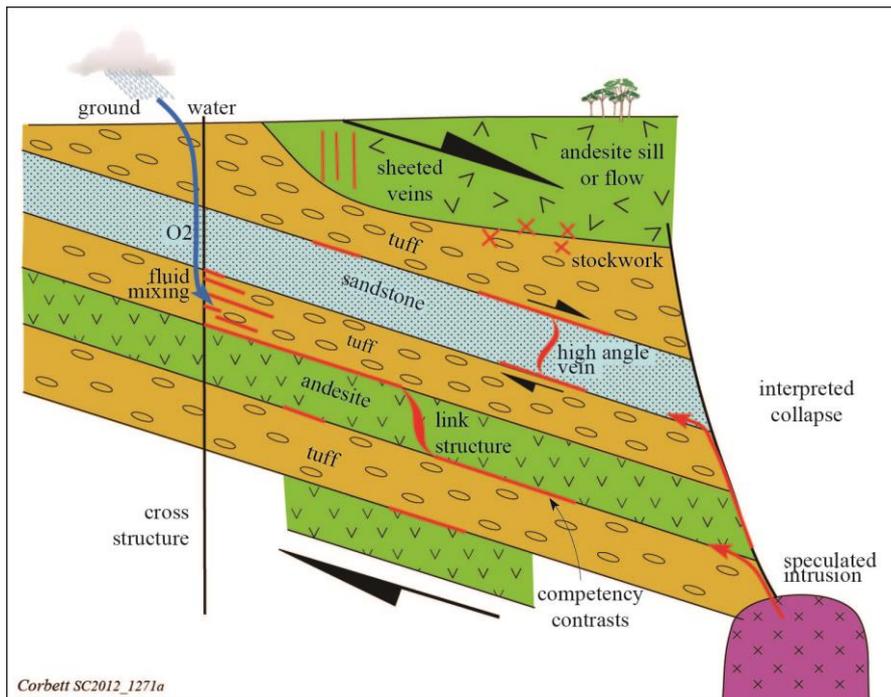
Figure 3. Conceptual model for the setting of stock work mineralisation within competent host rocks proximal to bedding plane shear feeder structures activated during caldera collapse.

Volcanic facies analysis and mineral potential in the Drake gold field

Careful volcanic and alteration facies mapping has defined the nature of the DQZ and delineated favourable rhyolitic-dacitic intrusive domains away from the historical discoveries. Further to this, areas of high alteration intensity and structurally important zones are being evaluated with evidence to support a collapse caldera providing the context and focus for regional exploration targets.

Field reconnaissance indicates there is a general thinning or absence of stratigraphic units outside the main caldera structure, while the competent DV2 andesite hosts the bulk of the mineralisation at Mt Carrington and elsewhere. The top-most stratigraphic unit (DV4) or the rhyolitic fiamme breccia is thinner, but still occurs outside of the DQZ. The apparent thinning of favourable host lithologies outside of the DQZ provides a framework for conceptualizing exploration targets regionally.

Acknowledgements

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GEOLOGY OF KEMPFIELD SILVER- BARITE AND BASE METAL (Pb-Zn) VOLCANIC HOSTED MASSIVE DEPOSIT, LACHLAN OROGEN, EASTERN AUSTRALIA

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ABSTRACT

The Kempfield silver-barite deposit contains an oxide resource of 6 Mt @ 55 g/t Ag; 0.11 g/t Au and a sulphide resource of 15.8 Mt @ 44 g/t Ag; 0.13 g/t Au; 1.3% Zn; 0.62% Pb. The deposit was previously explored by a number of companies, including International Nickel, Shell, Jones Mining, Golden Cross Resources and recently Argent Minerals Ltd. Argent Minerals Ltd completed a Definitive Feasibility Study and Environmental Impact Statement with a intention to mine this deposit in near feature.

The Kempfield deposit is hosted in Hill End Trough within felsic volcanic rocks known as the Kangaloolah Volcanics. The Kangaloolah Volcanics represent basin infill sequence of the Late Silurian Mumbil Group, comprising sub-marine, carbonate-shale facies intercalated with extensive felsic volcanic piles, which grade conformably upwards into turbiditic sandstone and siltstone. This sequence is folded and faulted against Ordovician basement of the Molong High along the major thrust system called Copperhania Thrust Zone which controls structural pattern in Kempfield area. The deposit is deformed and distorted by antithetic normal faults and anticlockwise block rotation develop in the hinterland of Capperhania Thrust front. The rocks at Kempfield underwent lower green-schist metamorphic facies reflected in presence of different schist types.

Silver and lead-zinc mineralisation is hosted in barite-rich horizons of reworked felsic tuffs near the boundary to tuffaceous quartz-phyllite rocks. Stratabound barite-rich horizons appears to be hosted in the highest concentrations within the coarser grained volcanoclastic sandstones and grits, whilst intercalated siltstones are volumetrically minor and tend to contain low-grade Ag-barite and minor base metal mineralisation. The primary mineralogy comprises barite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, argentite, native silver and pyrargyrite. Silver occurs in galena, tetrahedrite, argentite, pyrargyrite and as native silver. The gangue is primarily barite (approximately 20% of the ore at a 40 g/t cut-off) with lesser quartz, sericite and chlorite. The oxide zone is dominated by limonite/jarosite staining associated with silver minerals identified as chlorargyrite, native silver and argentite.

The deposit consists of three main and several small mineralised zones of generally disseminated mineralisation, including high-grade (Ag and/or Pb-Zn) mineralisation, along the 3 km strike length of NE trending volcanoclastics-sedimentary sequence. These main zones are:
1) BJ zone - a barite-silver rich zone (250 m x 100 m) with steeply west dipping lenses in the eastern portion;
2) The McCarron Zone - two mineralised horizons over a strike length exceeding 800 m. These horizons consist of steep westerly dipping mineralised zones varying from 10 m to 25 m wide (generally disseminated Ag-Pb-Zn and barite with some narrow, more massive Pb-Zn sulphide bands).
3) Quarries Zone (northern) – zone of high barite and silver content centred on small historical barite quarries.

Remaining zones include: South Conglomerate Zone (low grade Ag-barite); Mather Zone (Pb-Zn mineralisation); Hill Zone (high grade barite and low grade Ag) and Causeway Zone (low grade Au-only mineralisation hosted in a sricite altered rhyolite).

Considering alteration, mineralogical assemblage, metal zonation and the cluster geometry of mineralised lenses, the Kempfield deposit represents a classic barite-rich polymetallic VMS deposit hosted in a back-arc basin within host rocks of volcanic-volcanoclastic lithology. Mineralisation is interpreted to be exhalative, formed during submarine sedimentation in a subsiding basin in an area of felsic volcanic activity.

INTRODUCTION

This paper represents a geological review of Kempfield deposit - a silver-barite rich volcanic massive sulphide hosted (VMS) hosted in Hill End Trough, a Siluro-Devonian intra-arc basin within the Eastern Lachlan Orogen. The paper illustrates structural geological setting of the deposit, its structural and geological feature and mineralisation with alteration styles. It also proposes genetic model and compares it with other deposits in the Lachlan Orogen.

Kempfield area was mined at the turn of the 20th century for alluvial gold from terraces overlying and adjacent to the current Ag-barite resources at BJ Zone. Small scale barite mining first commenced in 1918 and was occasionally mined at up to 1500 tonnes per annum until 1990.

Geological Survey of NSW conducted first systematic geological work including geological mapping and geochemical studies in the period from 1971 – 1975. International Nickel Australia Ltd commenced exploring for polymetallic base-metals in 1972, focussing on the drilling of a single stratigraphic horizon, which is now known as the Mather Zone. Modern exploration started with Shell Company of Australia Ltd exploring the area for silver from 1979 to 1983. They discovered silver rich BJ Zone under alluvial cover using modern techniques such as magnetics, gravity, IP survey and ground electromagnetic. Jones Mining Ltd undertook diamond drilling and a pre-feasibility study for silver and barite on the BJ and Quarries Zones in 1984 -1985. Plutonic Operations Ltd evaluated the existing data for gold in the early 1990's, showing that there is a low level of elevated gold within some zones. Golden Cross Resources exploration between 1998 and 2007 identified new mineralised zone at McCarron and expanded the resource in other zones.

Since 2007, Argent Minerals Ltd employed a comprehensive exploration strategy, which included VTEM survey, pole-dipole survey and several drilling programs. Argent's exploration strategy resulted in 80% increase in the silver resource. During 2012 Argent completed Definitive Feasibility Studies and submitted Environmental Impact Statement for the proposed silver-barite mine at Kempfield.

REGIONAL GEOLOGY

The Kempfield deposit is located in Hill End Trough in the eastern province of Lachlan Orogen, a convergent margin terrane, dominated by mafic to felsic volcanic rocks and thick turbidite successions of Ordovician to Devonian age (Glen, 1998; Glen et al., 1995; Glen, 2002). During mid-Silurian to Middle Devonian, a number of north-trending, back-arc rift basins similar to Hill End Trough formed in the eastern Lachlan Orogen (Glen, 2002).

The Ordovician basement in these back-arc basins is characterised by quartz-rich turbidites, black shales, volcaniclastic rocks, felsic and mafic calc-alkaline volcanic (Pogson & Watkins, 1998), whilst basin infill sequence mostly comprises felsic volcanic and volcanoclastics rocks grading to sediments. The basin infill sequences were inverted and overprinted with green-schist facies regional metamorphism event and regional cleavage development during Tabberabberan Orogeny (Middle to Late Devonian age, 380–370 Ma).

Within the Hill End Trough, the principal stratotectonic unit hosting VMS mineralisation include the basal to lower middle units of late Silurian volcanics, volcanoclastics and associated siliciclastic sedimentary rocks of Campbells Group, Mumbil Group, Chesleigh Group and the Tannabutta Group (Pogson and Watkins, 1998).
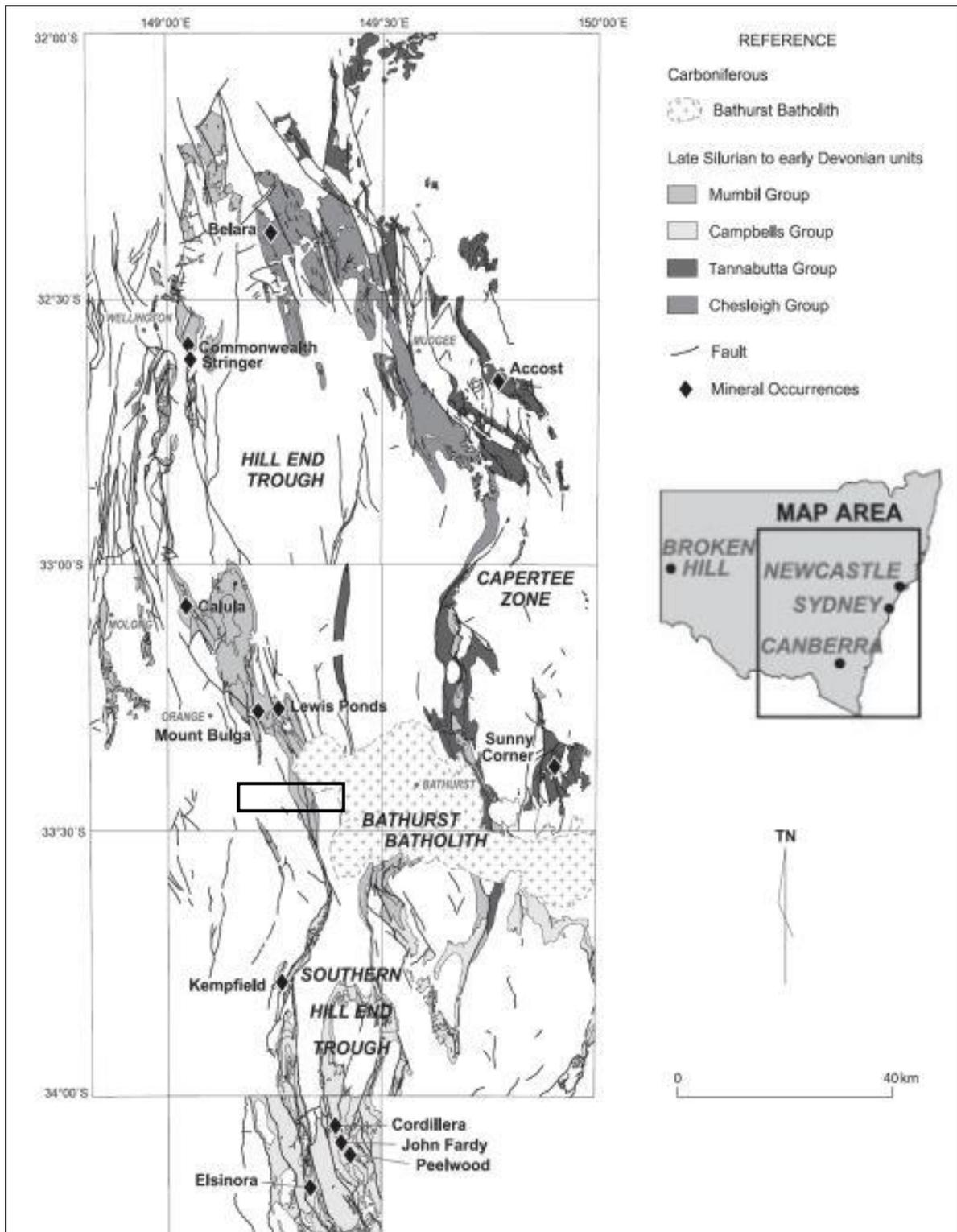
Figure 1. Location of the Kempfield and other VMS deposits, distribution of Late Silurian felsic volcanic and related sedimentary units within and adjacent to the Hill End Trough. Geology adapted from the Bathurst (Raymond *et al.,* 1998), Dubbo (Morgane *et al.,* 1999a) 1:250 000 and Crookwell (Johnson *et al.,* 2000) 1:100 000 map sheets.

The major VMS deposits within the Hill End Trough are shown in Figure 1. The largest VMS deposit Lewis Ponds (6.35 Mt @ 2.4% Zn; 1.4% Pb; 0.2%Cu; 68 g/t Ag; 1.5 g/t Au) and the adjacent Mt Bulga deposit are hosted in northern portion of the Hill End Though within the lower Mumbil Group of pyritic and calcareous siltstone, limestone and rhyolitic volcanics to (Scott and Meakin, 1998). The overlying volcaniclastic sandstone with minor trachytic and rhyolitic lavas, tuffaceous siltstone and volcanic breccia (Scott *et al.* 1998) hosts the nearby Calula deposit and further north Commonwealth and Stringers deposit.

In the southern part of the Hill End Trough Campbells Group (Kangaloolah Volcanics) hosts Kempfield and Peelwood including several small deposits (John Fardy, Peelwood and Cordillera, Elsinora) within rhyolitic and dacitic volcanic rocks, and feldspathic sandstone and siltstone (Wyborn *et al.*, 1998).

Towards the eastern margin of the Hill End Trough, the felsic volcaniclastic rocks of the upper Chesleigh Group (Colquhoun *et al.*, 1999b) host massive sulphide mineralisation at Sunny Corner deposit, and the Belara deposit in the north of the region. The base metal mineralisation at the Accost deposit southeast of Mudgee is associated with the Tannanbuta Group, which comprises rhyolite to dacite lava, fine- to coarse-grained volcaniclastic rocks, conglomerate and limestone (Colquhoun *et al.* 1999a).

LOCAL GEOLOGY

In the Kempfield area, the oldest (Ordovician) rocks belong to the Ordovician Coombing Formation. This formation comprises tremolite schist, biotite hornfels, porphyritic andesite and black carbonaceous slate intruded by S-type Silurian granites (Figures 2 and 3). Unconformably overlying these rocks are felsic Siluro-Devonian Kangaloolah Volcanics, which can be subdivided into three lithological units:

1) felsic volcanic unit containing lithic felsic tuffs, crystal lithic tuffs, porphyritic rhyolites and reworked lithic tuffs locally with barite lenses; stratigraphic footwall to Kempfield mineralisation.

2) volcanoclastic unit, which hosts silver-barite and lead-zinc mineralisation. The upper part of this sequence contains minor allochthonous crinoidal limestone/dolomite and massive barite and grades up into sediment dominated sequence. This is host unit to Kempfield mineralisation;

3) unaltered siltstone locally slate (unaltered and barren without mineralisation); this represents stratigraphic hangingwall to Kempfield mineralisation.

Mineralised volcanoclastic unit is poorly sorted, with graded sandstones and grits characterised by subangular to angular grains, locally with well-rounded pebble conglomerates as well as primary tuffs. This unit is interpreted to be submarine, immature reworked felsic ash tuffs, probably located proximal to their source lithology. Texture characteristics of submarine debris flows are common. Determination of protolith is, in places, obscured by later metamorphic and shear induced recrystallisation of barite.

The Kangaloolah Volcanics are interpreted to have undergone mid-green-schist metamorphic facies with a northeast trending, steeply dipping, metamorphic cleavage (S_1) which occurs throughout the Hill End Trough region.
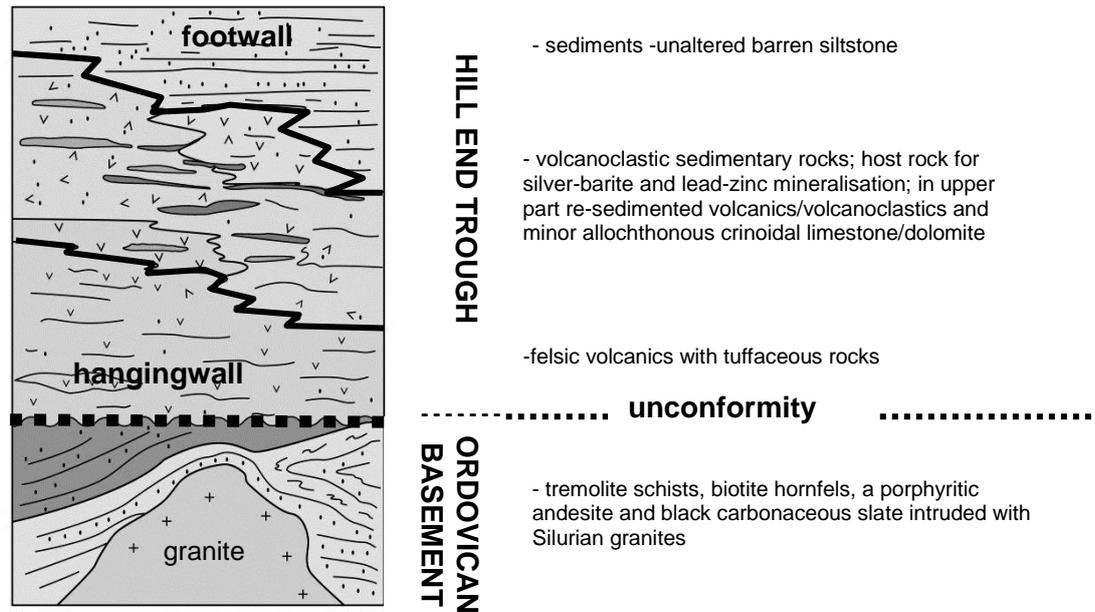
Figure 2. Kempfield deposit – Geological column.

The Kangaloolah Volcanics trough infill sequence is folded and faulted against Ordovician basement of the Molong High along the major thrust system called Copperhania Thrust which controls structural pattern in the Kempfield area. The main structural pattern is characterised with NE trending faults offset by NW trending faults (Figure 3). The NE trending faults are steeply dipping normal faults, which are formed as antithetic to Copperhania Thrust in its hinterland. The NW trending faults were developed to accommodate displacement on NE trending faults. These faults are interpreted to be vertical with dip-slip and left-lateral sense of movement.

The precursor stratabound deposit is deformed and distorted by antithetic normal faults. These faults are developed at the hinterland of Copperhania Thrust as a result of extensional stress distribution and motion of anticlockwise block rotation. The block rotation forms the apparent repetitions of mineralised horizons.

ALTERATION AND MINERALISATION

The alteration assemblage at Kempfield deposit is dominated with pervasive barite, sericite/muscovite, chlorite and disseminated quartz, sulphides and a minor albite (Ashley, 2009). In the most eastern BJ Zone (Ag-barite rich), the dominant alteration style is pervasive sericite. and disseminated pyrite. At the same time in western McCarron Zone (Ag-barite-Pb-Zn +/- Au) pervasive chlorite-sericite locally with quartz veins is the dominant alteration style. The formation of a moderate to strong sericite/muscovite-defined foliation that wraps around altered fragments occurred subsequently with deformation.

Mineralisation at Kempfield deposit can be observed in two domains: primary (sulphide) mineralogy and oxide (Ag-barite) mineralisation.
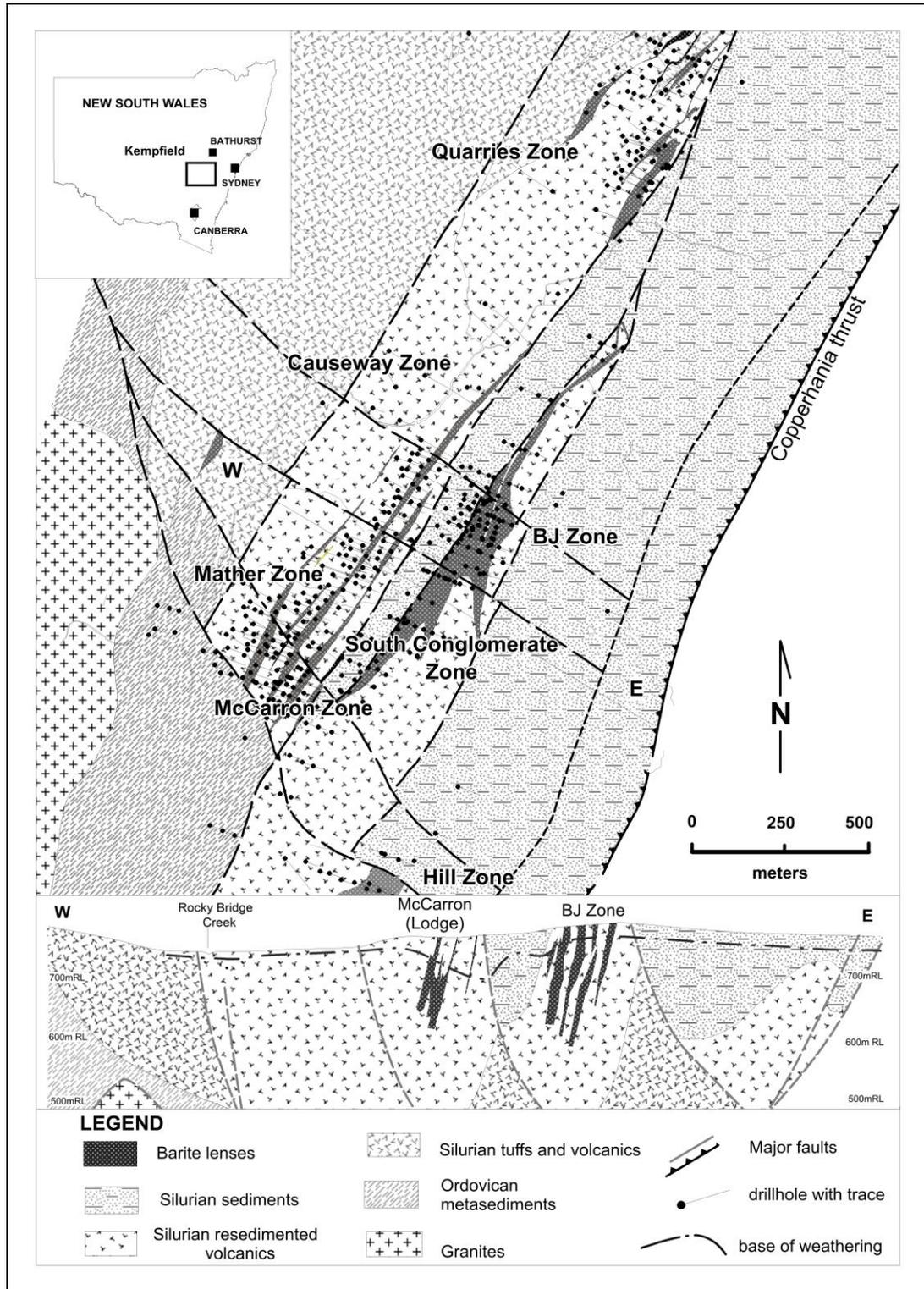
Figure 3. Kempfield simplified geology map with cross section modified after David *et al*, (2013).

The primary (sulphide) mineralogy comprises pyrite, chalcopyrite, galena, sphalerite, argentite, tetrahedrite, native silver and pyrargyrite. Pyrite is the main sulphide mineral, with traces of Fe-poor sphalerite, Ag-sulphosalts (tetrahedrite, proustite-pyrargyrite), galena (containing pearceite-polybasite) and chalcopyrite. Fe-poor sphalerite and pyrite are commonly disseminated and locally form composite aggregates. Silver is also present as native silver, argentite/acanthite and in galena (Ashley, 2009). The gangue is primarily barite with lesser quartz and sericite. The mineralisation is dominated by disseminated grains and small aggregates of pyrite, but there is also mineralisation associated with Fe-poor sphalerite, traces of galena, tetrahedrite, argentite/acanthite and a ruby silver phase (e.g. proustite-pyrargyrite),

In oxide mineralisation zone locally developed goethite and jarosite is associated with chlorargyrite, native silver and argentite (Ashley, 2009). The elevated Ag and Pb correlate with jarosite zones. The gangue in oxidised zone comprises primarily barite with lesser quartz and sericite.

Significant Pb-Zn intercepts have been encountered at depth at the northern margins of BJ Zone and at McCarron Zone along with low level gold. No significant copper has been intersected. Barite is the most abundant mineral in BJ Zone and Quarries Zone where it forms part of the resource. This is observed to a lesser extent in McCarron South where the content of base metals (Pb-Zn) is higher.

Sulphur isotope signatures for sulphide mineralisation from the Kempfield deposit have average $\delta^{34}S$ values from 5.4‰ to 8.1‰. This is similar to other VMS in Hill End Trough (Commonwealth, Peelwood and Sunny Corner). These deposits appear to have formed from ore fluids that were more oxidising than the deposit itself. Such an example is Lewis Pond where the mineralisation is represented as a mixed contribution of sulphur derived from partial reduction of seawater sulphate, with the addition of sulphur from other sources (Dowes and Seccombe, 2004).

The Kempfield lead isotopic ratios plot within the range of typical VMS mineralisation within the Lachlan Orogen of NSW (Timms and David, 2011). Specifically, the ratios plot at the low $^{206}Pb/^{204}Pb$ end of the range and have crustal $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values. The median lead isotopes ratios for Kempfield deposits are: $^{206}Pb:^{204}Pb$ = 18.037 (in range 18.037 to 18.044); $^{207}Pb:^{204}Pb$ = 15.609 (in range 15.610 to 15.618) and $^{208}Pb:^{204}Pb$ =38.100 (in range 38.082 to 38.126), (Dean, 1994).

DEPOSIT DESCRIPTION

At Kempfield, seven mineralised zones (lenses accumulation) have been identified along a 3 km strike length of mapped barite horizons. The barite horizons are contained within the volcanoclastic sequence of Kangaloolah Volcanics (Figure 3 and 4).

McCarron Zone (Western)

The McCarron zone includes three mineralised zones over a strike length exceeding 800 m: McCarron West, McCarron East and Lodge. The westerly steeply-dipping mineralised volcanoclastic horizon contains up to 25 m wide intervals of massive sulphides, locally with up to 15% combined lead and zinc over narrow intervals (drill holes). This zone also exhibits elevated Au and Cu values. The overall resource Au-grade averages 0.15 g/t, locally with high grade shots (AKRC117 2m @ 8.4 g/t Au). The mineralisation in this zone in general has a moderate (45º) plunge to the north, where it is transacted by a west-northwest trending sub-vertical fault. At the southern end of the deposit, mineralisation is transacted by a west-northwest trending sub-vertical fault (Figure 3 and 4).The McCarron zone contains 35 % of the resource tonnes with 27 % of the contained Ag and 57 % of the contained Pb-Zn estimated to occur within the Kempfield deposit.

BJ Zone (Central)

The BJ zone contains broadly developed, stratiform, silver-barite-rich mineralisation covering an area of 250 m x 100 m. The zone is interpreted to occur within the steeply west-dipping volcanoclastics, containing three lenses which can be correlated with outcropping barite horizons.

The BJ zone has high grade Ag intersections in the central part (22 m @ 195 g/t Ag and 0.21 g/t Au) and high grade base metals in the northern part (36 m @ 2.3% Pb and 2.0% Zn including a 10 m zone of 150 g/t Ag, 1.83% Pb, 4.06% Zn and 0.44 g/t Au). High grade lead and zinc mineralisation within the BJ Zone primarily occurs at the northern margin. At depth mineralisation occurs as fine-grained disseminations and poorly defined bands in altered phlogopite-Mg chlorite volcanoclastic rock. Silver occurs in sericitic altered, barite-rich volcaniclastics. These may locally include thin allochthonous crinoidal limestone bands, overlain by baritic volcanoclastic, matrix-poor grits. Silver exhibits a moderate correlation with barite. The BJ zone contains 42% of the Kempfield resource tones with 50% of the contained Ag and 20% of the contained Pb-Zn (in the northern part at depth).
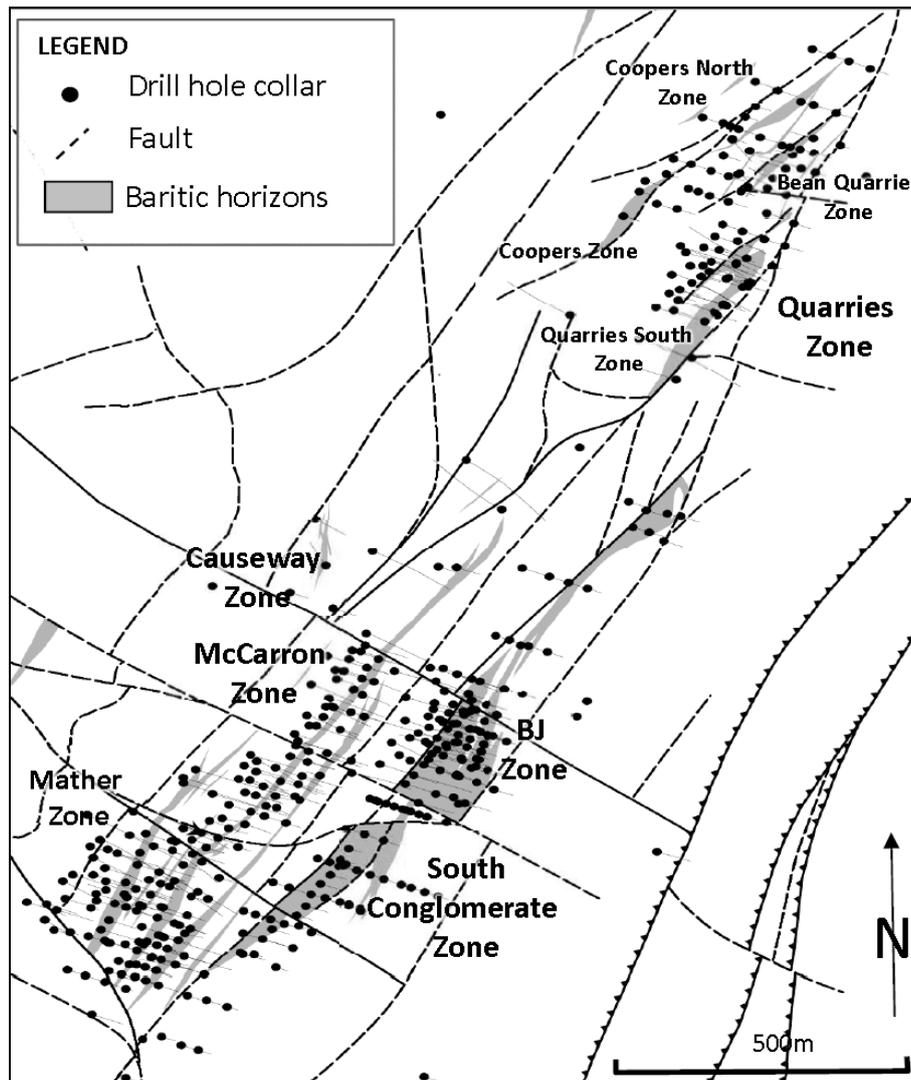
Figure 4. Ore Zones – simplified geology with drillhole locations

Quarries Zone (Northern)

The Quarries Zone represents the northern extension of the Kempfield deposit (Figures 3 and 4), characterised by high barite and silver grades. High grades occur in westerly steeply dipping lenses centred on small barite historical quarries. This zone extends with a north-easterly trend over 600 m length and with 250 m width. It contains multiple barite (silver rich) lenses; Quarry South Zone, Quarry Zone, Bean Quarry Zone, Coopers Zone and Coopers North Zone (Figure 4). The Quarry South Zone is intruded by a rhyolite dome characterised by intense silicification and elevated gold grades. The Quarries zone contains 23% of the resource tonnes with 23% of the contained Ag and 23% of the contained Pb-Zn estimated to occur within the Kempfield deposit.

Remaining Mineralised Zones

The remaining mineralised zones are less significant contributors to the total mineral resource, and include the following (Figure 3 and 4):

1) The South Conglomerate Zone, a narrow zone of low grade silver-barite mineralisation extending southeast from the BJ zone for approximately 400 m.
2) The Causeway Zone, where Au-only mineralisation is developed within a silicified rhyolite over a strike length of 300 m extending southwest from the Quarries Zone. The best drillhole intersection in this zone yielded 52 m @ 0.37 g/t Au (GFK-44).
3) The Mather Zone - this horizon was originally tested by Inco Ltd, who encountered Pb-Zn mineralisation over a strike length of 250 m west of the McCarron Zone. This zone is characterised with Pb-Zn mineralisation (32 m @ 3.5%Zn, 0.57% Pb and 22 g/t Ag).
4) The Hill Zone contains high grade barite and weak to moderate silver mineralisation over a strike length of 450 m on the southeastern margin of the Kempfield deposit (10 m @ 76.5% barite).

DISCUSSION AND CONCLUSION

Kempfield deposit is hosted within the Hill End Trough which represents an intra-arc basin. The Hill End Trough formation (extension) is related to oblique collision in Lachlan Orogen associated with accumulation of siliciclastic-felsic lithostratigraphy. VMS deposits in Hill End Trough are controlled with the basin margin faults adjacent to Ordovician volcanics with arc related volcanic basement rocks (David *et al.,* 2003). The analysis in this study leads to the conclusion that tectono-stratigraphic setting in a convergent margins and polymetallic nature of VMS deposits suggests the High Sulphidation VMS systems as introduced by Franklin *et al,* (2005) and Huston *et al* (2010). Hill End Trough hosts numerous polymetalic VMS deposits in the basal felsic volcanic dominated sequence along the basin margins (Table 1).

Kempfield deposit is located at the south-western Hill End Trough basin margin adjacent to the marginal growth fault. This growth fault zone is characterised by high rate of basin subsidence followed with intense felsic volcanic activity and rapid sedimentation (basin infill). In this region the zone of growth fault is recognised by distribution of Kangaloolah Volcanics lithology

A trend of increasing based metals grades (Pb-Zn) has been observed in the Kempfield deposit, from the BJ/Southern Conglomerate Zones (predominantly Ag-barite) in the east to the McCarron Zone in the west (with narrow veins of high grade base metals and gold). This trend is further evident in isolated intersections with elevated copper mineralisation in the west (12 m @ 0.18% Cu in drill hole AKRC82). Furthermore, there is metal zonation with depth. For example, barite and Ag concentrations are decreasing with depth, whilst Pb, Zn, Au are increasing with depth in each individual ore system

Deposit name	Tonnage Mt	Cu %	Au g/t	Ag g/t	Pb %	Zn %	Barite	Source
Lewis Pond	6.35	0.2	1.5	68	1.4	2.4	No	http://www.triausmin.com/projects.asp
Sunny Corner	1.5	0.4	0.3	24	2.1	3.7	No	http://www.argentminerals.com.au/sunny-corner.html
Kempfield	21.8	n/a	0.12	47	0.62	1.3	Yes	Argent Minerals (ASX Announcement from 26th April 2012
Commonwealth	0.085	0.5	6	250	3	10	No	Lee, 1993
Commonwealth South	0.2	n/a	2	30	n/a	n/a	No	Lee, 1993

Table 1. Summary of VMS deposits in Hill End Trough.
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. A distinct zonation of alteration also follows metal zonation. Such is alteration assemblage from BJ Zone which is dominated by moderate to strong sericite – barite and weakly disseminated pyrite whilst McCarron Zone is dominated with moderate chlorite-sericite alteration and locally intense silicified zones.

Based on the structural geological relations and metal/alteration zonation, the genesis of Kempfield deposit can be discussed considering two models:

1) Deposit is a part of the spectrum of VMS deposits (Figure 5) - a strabound barite-rich mineralisation with low grade zinc-lead-silver is at the low temperature end of the sea floor VMS spectrum defined by Large *et al*, (2001).

2) Deposit is an outcropping distal part (Ag-barite) of a larger VMS system where base metal rich feeder zone is buried at depth or eroded. The apparent repetitions of mineralised barite horizons may be due to deformation and/or the presence of multiple mineralised layers within the original sequence.
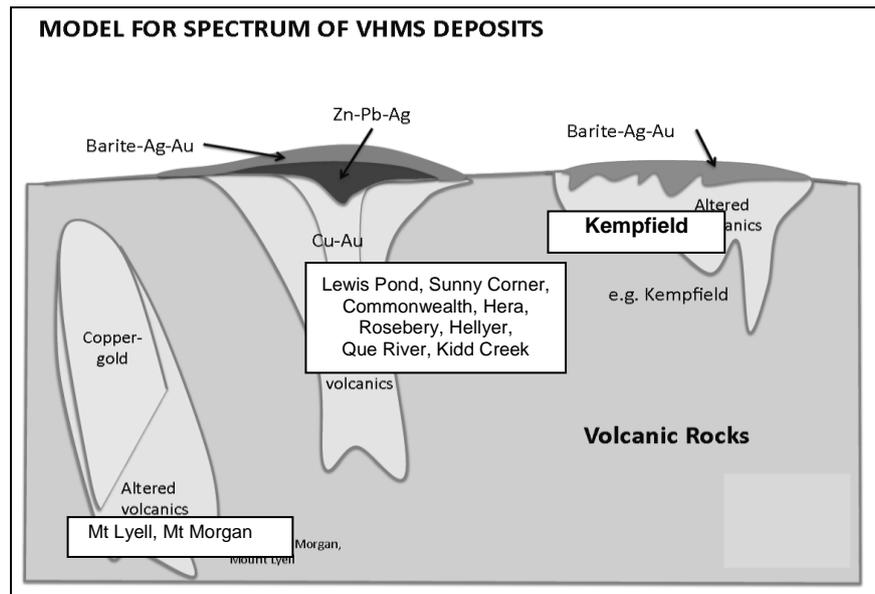
Figure 5. Kempfield deposit in the spectrum of VHMS deposit - ore genesis model modified after Large *et al.* (2001).

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KEYS TO UNDERSTANDING THE CENTRAL LACHLAN — THE NYMAGEE MINERAL SYSTEMS STUDY

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Key Words: Nymagee, Cobar Basin, Mount Hope Trough, Canbelego–Mineral Hill rift zone, mineralisation, dating, bedrock geology, volcanic facies, alteration

Abstract

The Nymagee mineral system study in central NSW is aiming to update the geological, geochronological, geochemical and mineral systems framework for the Nymagee 250 000 map sheet and adjacent areas. In total, samples for 21 U–Pb SHRIMP and 11 Ar–Ar dates with over 230 S-isotope and 50 Pb-isotope samples have been submitted for analysis — many of the results are still outstanding. In addition, over 40 diamond holes have been scanned using a HyLogger spectral scanner to map alteration response to mineralisation. The preliminary results include the highlighting of a major magmatic event between 427 and 420 Ma, identification of magmatic-, reduced seawater sulfate (basinal)- and mixed-sulfur isotope reservoirs contributing to mineralisation, a revised basement interpretation and the identification of distinct coherent rhyolites units (flows and/or high level intrusions/domes) within the Mount Halfway Volcanics with a number of possible volcanic centres being identified. Also, the rhyolitic lavas associated with the Mount Halfway Volcanics contain probable fayalite suggesting that these volcanic rocks were high temperature and relatively anhydrous.

INTRODUCTION

The Nymagee project is being undertaken by the Geological Survey of New South Wales' MinSys (Mineral Systems) group to update the geological, geochronological, geochemical and mineral occurrence framework for the Nymagee 250 000 map sheet and adjacent areas. The project is being undertaken to better understand the prospectivity of the area and controls to mineralisation.

The Nymagee project area was selected as the area covered a complex geological environment with different mineralisation types associated with several separate events; many companies wee exploring in the area; three projects were transitioning from exploration to production (Mineral Hill — KBL, Wonawinta — CCR, and Hera — YTC); a number of new deposits/zones had been identified; the was recognised potential for U and strategic metals; and, little work had been undertaken by the Geological Survey of New South Wales since the completion of the Nymagee metallogenic project in the early 1990s (Suppel & Gilligan 1993).

Major regional studies completed since the Nymagee metallogenic mapping project (Suppel & Gilligan 1993) include the PMD–CRC Cobar project in mid 2000s — the results of which went largely unpublished, and a PhD project by Vlad David (David 2005) on the structural setting of the Cobar Basin. However, the timing of magmatic events and mineralisation, and the nature of the ore forming fluids was still poorly constrained.

GEOLOGICAL SETTING

The Nymagee project area includes a number of key stratotectonic units that form part of the Central Subprovince of the Lachlan Orogen. The area itself covers a complex geological environment with mineralisation associated with Ordovician basement rocks, granites of late Silurian to Early Devonian age and units forming the overlying late Silurian to Early Devonian basinal sequences.

Basement to the study area consists of the multiply deformed and metamorphosed siliclastic turbiditic rocks of the Early to Middle Ordovician (Burton et al. 2012) Girilambone Group, the black shale dominated package of the Late Ordovician Bendoc Group (Colquhoun et al. 2005) and granitic intrusions including the Erimeran, Derrida and Thule granites. Approximately east–west

extension in the late Silurian to Early Devonian resulted in the development of a series of basins with adjacent palaeographic highs. These include the Canbelego–Mineral Hill rift zone in the eastern part of the study area, the shallow to deep water Cobar Basin and the associated Mount Hope and Rast troughs to the south and the adjacent Kopyje and Winduck shelves to the east and west respectively (Glen et al. 1985). Terrigenous sedimentation was associated with extensive volcanism and the emplacement of contemporary granites in the late Silurian at ~422 Ma and again in the Early Devonian at ~415 Ma.

The timing of basin inversion and deformation of the late Silurian to Early Devonian sequences, which host the majority of mineralisation, is poorly constrained. A major stratigraphic constraint on the timing of deformation is provided by the post-deformation Mulga Downs Group which para- to un-conformably overlies the Early Devonian Winduck Group (Winduck Shelf). Glen et al. (1992) proposed that the initial deformation of the Cobar Basin occurred between 395 and 400 Ma (their 'Cobar Deformation') while Sun et al. (2000) proposed a somewhat later timing at around 385 to 389.2 Ma — essentially correlating this event with the Tabberabberan Orogeny.

Mineralisation styles within the project area include volcanic associated massive sulfide base metal deposits (Great Central); massive to colloform and crustiform banded, zoned gold–base metal epithermal systems (Pipeline Ridge, Mineral Hill); carbonate-hosted silver–lead–zinc Mississippi Valley-type deposits (Wonawinta); intrusion-related tin, tungsten and molybdenum mineralisation; and, structurally controlled low sulfide gold (orogenic gold — Gilgunnia) and high sulfide gold–base metal ('Cobar-type') deposits including Hera, Nymagee and Mallee Bull.

PROJECT OUTLINE

The Nymagee project is undertaking targeted studies to update the geological, geochronological, geochemical and mineral occurrence framework for the Nymagee 1:250 000 map sheet and adjacent areas. Key elements of the project include: the dating of volcanic units, granites and mineralisation to better understand the timing of events; investigating potential sources of metals and mineralising fluids by using sulfur- and lead-isotopes; reviewing the petrology of key volcanic units including the Mount Hope Group, to map the distribution of volcanic facies — and to identify possible volcanic centres; and to map alteration associated with mineralisation, using the HyLogger spectral scanner at Londonderry. In addition, the geological framework for the area is being upgraded with a new basement interpretation, updated mineral occurrence data and an improved whole rock geochemistry dataset.

PROJECT OUTCOMES

Age dating

Prior to the present study few high precision dates were available for the Nymagee area. The previous dating studies carried out over the last 20 years include Spandler (1998), Isaacs (2000), Blevin and Jones (2004), Morrison et al. (2004), Norman et al. (2004), Black (2007) and Bull et al. (2008). In total, there were 13 U–Pb dates for zircons for volcanic rocks and plutons — three of which were analysed by the laser ablation ICPMS technique (i.e. Bull et al. 2008 — Mount Hope Volcanics ~411 ± 5 Ma) with the remaining analyses by U–Pb SHRIMP dating of zircons. In addition, there is a Re–Os date for molybdenite from the Fountaindale prospect (Melrose anomaly, DDH AOG 8A, 424.7 ± 1.5 Ma — Norman et al 2004). Prior to these studies, the constraints to the age of geological units and timing of mineralisation was largely based on palaeontology, field unit relationships and on older K–Ar and Rb–Sr dates.

As part of the present study 21 samples (mainly from granites or volcanic rocks) were submitted for U–Pb SHRIMP dating with an additional 11 samples of micas, mainly from mineralisation, submitted for Ar–Ar dating. Many of the analyses are outstanding.

Preliminary results for the new U–Pb SHRIMP dating has identified a major magmatic event in the late Silurian. The Thule, Gilgunnia, Mount Allen and Erimeran granites and the Mound Halfway Volcanics all formed about the same time at between 427 Ma and 420 Ma whilst the Derrida Granite may be slightly older. By contrast, the Boolahbone Granite and Tarran Volcanics are younger — forming in the Early Devonian at ~416 Ma.

Isotopes

Regional sulfur and lead isotope studies combined with insights from the deposits and geological setting can provide constraints as to the sources of metals, fluids and ore forming process at both deposit and district scales. As part of the present study over 230 samples were submitted for sulfur-isotope analysis with 55 samples submitted for lead-isotope analysis. This includes samples from 23 separate deposits/systems as well as background reservoir samples from un-mineralised igneous rocks. In addition, 132 sulfur- and +160 lead-isotope analyses have been compiled from previous studies. The majority of lead-isotope analyses and the results from the background reservoirs study have yet to be received.

The sulfur isotope data for the Condobolin Au–Ag–base metal- and the Melrose Anomaly (Group 1) show a clear magmatic signature — supporting previous interpretations of the mineral deposit-type. By contrast, a number of deposits including Yellow Mountain (Cu–Pb–Zn) and Caroline (Cu) have S-isotope signatures that overlap with those for Gundaroo (Pb–Zn–Ag) and Mallee Bull (Cu–Pb–Zn–Ag–Au) (Group 2) with no magmatic input being inferred — suggesting that sulfur in these deposits was sourced from reservoirs containing only reduced seawater sulfate. By contrast, the signatures for Hera (Au–Ag–Cu–Pb–Zn) and Nymagee (Cu–Pb–Zn–Ag) are very different from that for Mallee Bull and other Group 2 deposits — requiring at least some of the sulfur being sourced from a magmatic reservoir in addition to sulfur being sourced from a reservoir containing reduced seawater sulfate. Based on the available data, it is likely that separate reservoirs contributed sulfur to Hera and Nymagee. Sulfur isotope zonation is evident for a number of deposits including Mineral Hill (Au–Cu–Pb–Zn–Ag) and Pipeline Ridge (Au) — indicating that for these two deposits mixing of fluids from different sulfur reservoirs (magmatic vs reduced seawater sulfate) probably occurred.

Bedrock Interpretation

Reinterpretation of the bedrock geology for the Nymagee 1:250 000 map sheet area is being carried out as part of the project (Figure 1). The main outcomes from the interpretation to date are:

- The Tarran Volcanics and associated intrusions as well as dolerite dykes, which are spatially associated with the the Erimeran Granite, are probably more extensive than previous mapping suggests and, as previously recognised, their distributions are strongly structurally controlled.
- There are interpreted granite plutons below the Ordovician outcrop in the area to the east of the Erimeran Granite.
- Probable subsurface continuation of the Gilgunnia Granite. That body appears to have influenced the distribution of strain around itself during deformation. The interpretation of northeast-trending transpressive shearing at the May Day mine (see below) is a probable effect of this and it suggests that the area may be analogous to the Cobar mineral field.
- The Scotts Craig Fault is more extensive than previously mapped, extending across the entire north–south length of the map sheet to intersect the Rookery Fault in the vicinity of the Queen Bee mine. It appears to be an old basement feature which has had some affect on the eastern boundary of the Gilgunnia Granite and the eastern depositional limit of the Mount Hope Group.
- The Thule Granite is more extensive than is apparent in outcrop and continues beneath Devonian cover.
- Other granites have been interpreted to be present beneath Siluro-Devonian cover to the east and southwest of Mount Hope.

Field work is planned to test some of the interpretations, where feasible.
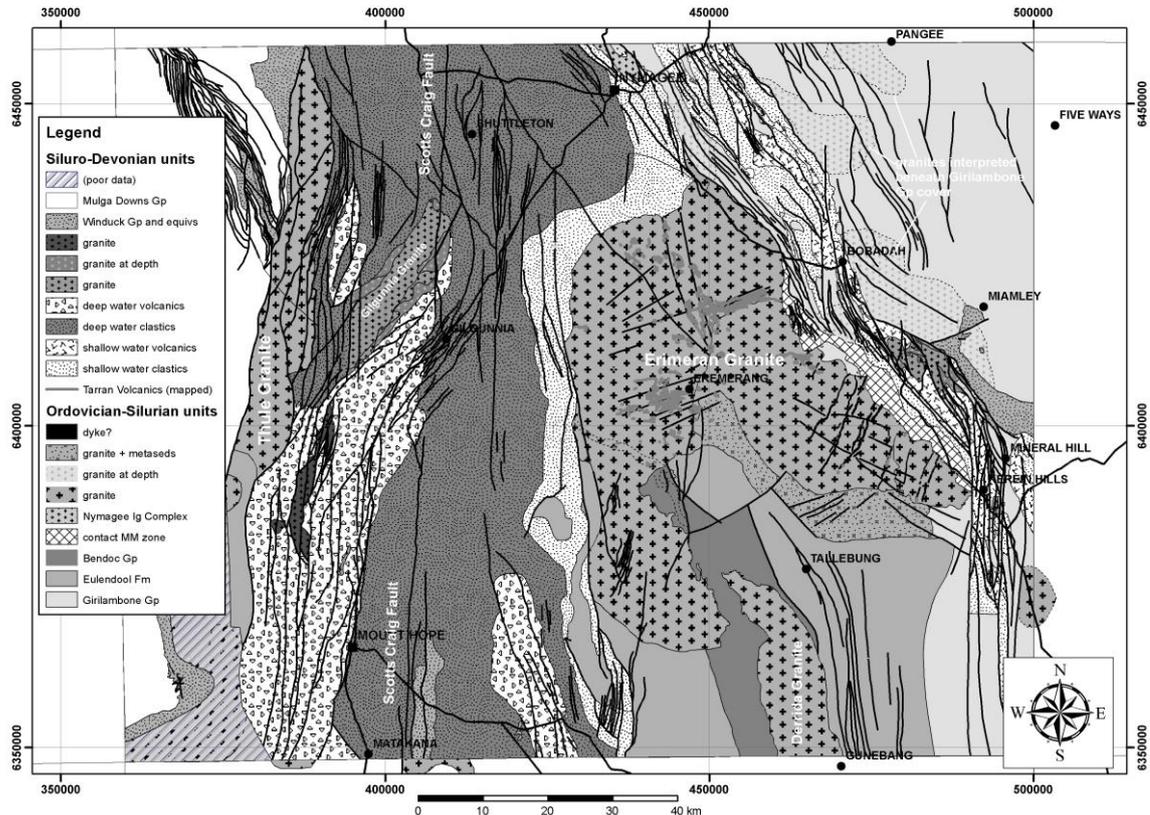
Figure 1 — Updated bedrock geology for the Nymagee 1:250 000 map sheet area.

Volcanic facies

The volcanology of the Mount Hope Group is being re-assessed using the large collection of thin sections from past mapping projects. As currently defined, the Mount Hope Group includes eight individual formations, each of which has been further subdivided into a number of unnamed units composed of multiple lithologies. This study aims to: better understand the range of volcanic lithologies and their mode of emplacement/depositional environment; delineate individual volcanic facies and/or facies associations; test if the distribution of volcanic facies can be used to identify possible volcanic centres; and test whether the current complex stratigraphic division of this group is necessary.

In this study eight types of coherent rhyolitic lavas have been identified within the Mount Halfway Volcanics, separated on the basis of total phenocryst content, relative proportions of quartz, plagioclase, alkali feldspar and replaced ferromagnesian minerals and to a lesser extent by the grainsize and groundmass textures. The ferromagnesian phenocrysts have been almost entirely replaced by phyllosilicates, however some have the distinctive crystal form of olivine (fayalite), complete with secondary serpentine. The presence of probable fayalite in rhyolites, along with probable pyroxene and biotite phenocrysts, suggests that these were high temperature, relatively anhydrous lavas. The groundmass in most of the rhyolites was originally glassy as indicated by the widespread development of microspherulitic, micropoikilitic and very abundant perlitic textures.

Of the identified lavas, four are closely spatially related suggesting that they may be part of a lava flow or dome. In some instances, lavas are intercalated with coarse- and fine-grained volcaniclastic rocks which may suggest proximity to a submarine volcanic centre. The volcaniclastic facies include crystal-lithic volcanic sandstones, crystal-vitric volcanic sandstones, vitric siltstones/mudstones and less abundant pumice breccias and peperites. Many of the sandstones contain rhyolitic lava clasts and abundant fragmented perlitic groundmass material, possibly reflecting non-explosive fragmentation of some of these lavas while still hot and glassy. Relict glass shards have also been identified in many of the vitric siltstones and mudstones but they are invariably non-welded. Welded pyroclastic rocks or units emplaced as pyroclastic flows

as interpreted by Scheibner (1987) in the Mount Allen 1:100 000 map sheet area, have not been confirmed.
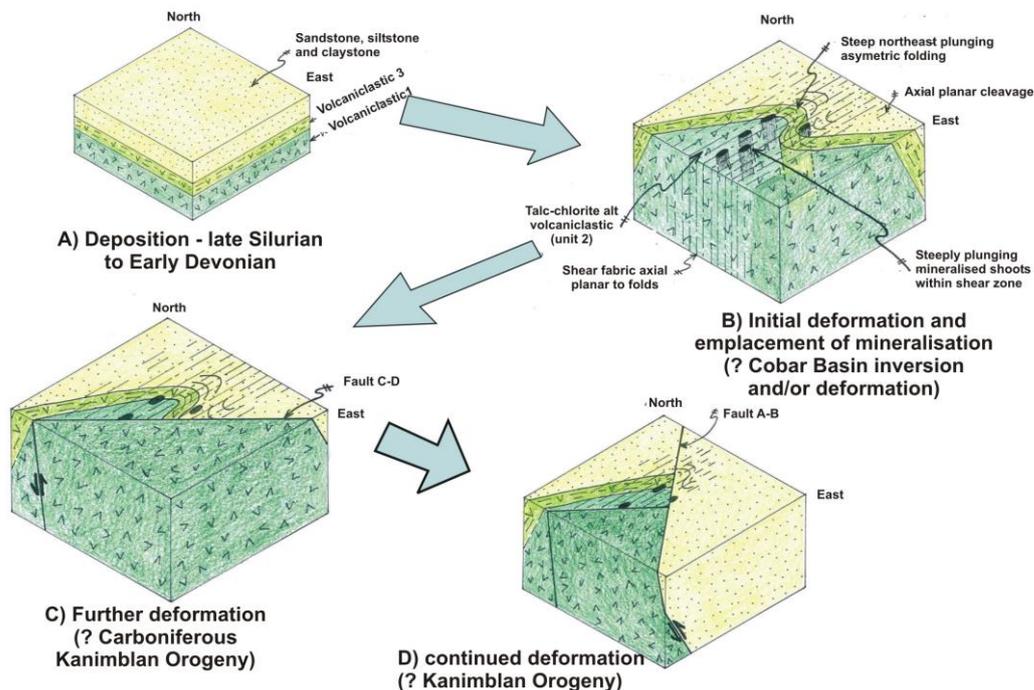
Figure 2 — Interpreted geological/structural history of the May Day mine area (modified from Burton 2012).

ALTERATION

Over 40 diamond drill holes from 22 deposits have been scanned using the HyLogger spectral scanner at Londonderry. The project is aiming to document the variability of alteration within host units for a range of deposit types. Preliminary data is now available for several deposits including May Day, Mount Allen, Mount Solar, Shuttleton, and Wonawinta.

Mineralisation at the May Day gold mine (Gilgunnia) is hosted by volcaniclastic rocks of the Mount Halfway Volcanics with some mineralisation also hosted by clastic units of the Upper Amphitheatre Group (Burton 2012). At May Day, alteration associated with mineralisation is characterised by a tal-carbonate (calcite>ankerite>siderite), phengite Mg-chlorite assemblage. Trending away from the mineralised zone the phengite grades to muscovite and chlorite becomes Fe-rich.

At the Mount Allen gold mine, 16 km north of Mount Hope, gold and silver mineralisation is associated with massive to disseminated magnetite–hematite zones. Here the mineralisation is hosted by siltstones and volcaniclastic rocks of the Early Devonian Double Peak Volcanics. The alteration assemblage is dominated by Fe-chlorite, muscovite/phengite and kaolinite within the mineralised zone. In addition, there is a correlation of gold–silver with Fe–Mg-chlorite and kaolinite at the bottom of hole PMA 7 — suggesting a change in rocktype.

The Mount Solar gold mine, 9 km southeast of Mount Hope, is associated with auriferous quartz veins hosted by clastic units of the Early Devonian Broken Range Group. The mineralised zone is strongly altered to a Fe-chlorite, sericite and lesser kaolinite assemblage. The hanging wall is largely unaltered whereas the footwall is moderately phengitic/muscovitic-rich.

Polymetallic (Cu–(Pb–Zn–Ag)) mineralisation at Shuttleton (Crowl Creek and South Shuttleton) is hosted by or adjacent to rhyolites (Shuttleton Rhyolite Member — Shume Formation) which locally underlie sandstones and siltstones of the Early Devonian Shume Formation (Suppel & Gilligan 1993). At South Suttleton pervasive intermediate chlorite and phengite dominate the

unmineralised zone. Phengite dissipates in the mineralised zone where the hangingwall is defined by Fe-chlorite, this grades into Mg-chlorite and talc in the footwall of the mineralised zone.

The Wonawinta Ag–Pb–Zn MVT-type deposit is hosted by carbonate units of the Winduck Group (Booth Limestone Member). Within this area, ore zone alteration is dominated by dolomitisation with minor ankerite (and siderite) also being present. Outside the mineralised zone unaltered limestone and peripheral muscovite are present.

Mapping

Geological mapping, including structural analysis, was undertaken at the May Day gold mine (recorded production totals 0.404 t gold) to resolve the timing of mineralisation. Previous work indicated that gold and base metal mineralisation occurs in steeply plunging shoots and Burton (2012) interpreted these to be aligned parallel to the fold axes of steeply plunging folds. Folding and mineralisation are considered to have been initiated within a transpressive shear system during Stage 1 deformation with later faulting (Stage 2) re-shuffling the geology and dismembering the system. This structural setting for the mineralisation is similar to that in the Cobar mineral field. Figure 2 summarises the geological history at May Day.

Reconnaissance work at the Break O'Day Amphibolite has shown that this unit crops out as a series of disconnected, reversely magnetised, variably calc-silicate altered metabasalts. Based on whole rock geochemistry, Burton (in prep) suggested that the progenitor basalts formed as intraplate oceanic islands (seamounts) during the Ordovician and are similar to basalts identified in the Sussex–Byrock area further north. This contrasts with the earlier interpretation of Pogson (1991) that the basalts formed as tholeiitic ocean floor basalts.

PLANNED OUTCOMES

It is not the intention of the Nymagee project to write an extensive set of geological notes, rather it is planned to present the majority of data as digital layers and datasets with an updated time-space plot intergrading the new dating of magmatic events and mineralisation. The digital layers will include an updated basement interpretation with the revised volcanic facies interpretation, a reactive rocks layer and an updated mineral occurrence layer. In addition, a small number of papers/reports will be prepared to highlight the outcomes of specific studies. These include: the implications of the new dating results; interpretation of the sulfur and lead isotope data to discuss potential sources of metals and fluids involved in mineralising processes; and to outline the alteration response to mineralising events for specific units and mineralisation types as an outcome of the HyLogger alteration mapping.

CONCLUSION

The Nymagee project has provided a focus for new work in a key part of the Central Subprovince of the Lachlan Orogen. The results to date have already made significant changes to our understanding of this area and companies have been enthusiastic in supporting the project.

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GEOLOGICAL SETTING AND MINERALISATION STYLE OF THE AUGUSTA ANTIMONY-GOLD DEPOSIT: COSTERFIELD REGION, CENTRAL VICTORIA

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INTRODUCTION

The Costerfield region is located approximately 10 km east of Heathcote within the far western portion of the Melbourne Zone, southern Lachlan Fold Belt (figure 1). The region has long been associated with narrow-vein type antimony sulphide (stibnite) and gold mineralisation, with historic lodes being worked since the mid nineteenth century. Lodes occur as narrow veins (typically less than 500 mm in thickness) hosted within weakly metamorphosed mudstones and siltstones of the Lower Silurian–aged Costerfield Formation.

Current exploitation of the field by Mandalay Resources is focussed on the Augusta and Cuffley deposits located in the southern Costerfield area. The Augusta deposit has been actively mined since 2005, with a further mine-life expected until resource depletion. The Cuffley deposit (located ~400 m west of the Augusta deposit) is currently un-mined. Traditionally the Costerfield area has been economically significant for its unusually abundant and relatively pure stibnite occurrences, while gold has typically been considered an accessory or 'associated' commodity.
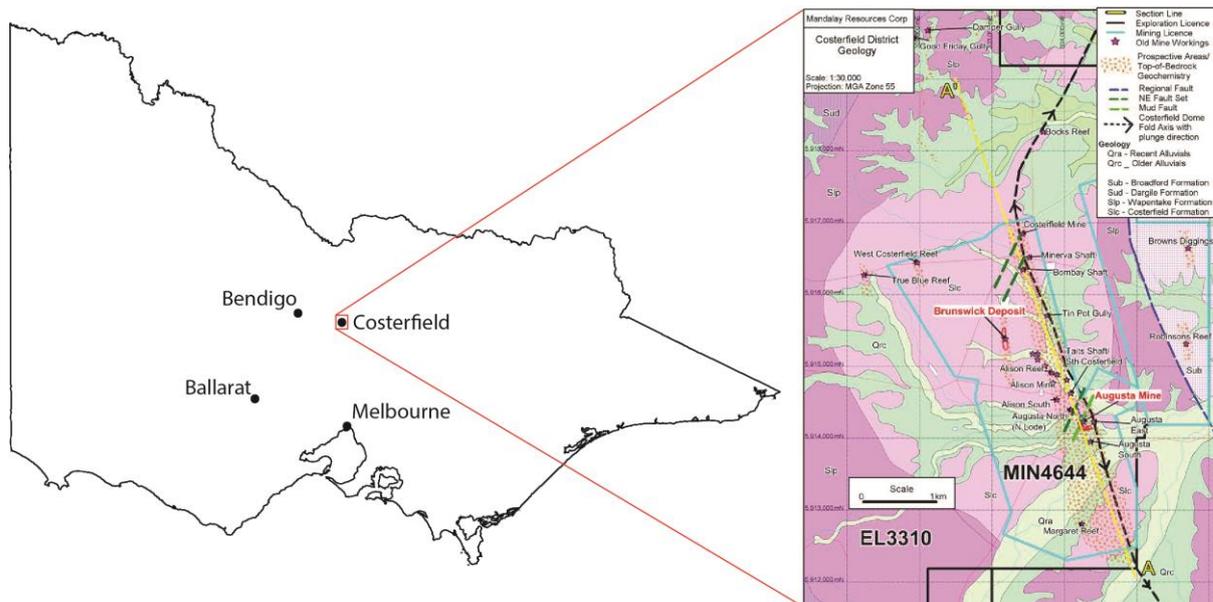
Figure 1. Locality map of the Costerfield region with inset geological map.

GEOLOGICAL SETTING

The Costerfield antimony-gold mining field is located within the northern margins of the Darraweit Guim Provence close to the western-most boundary of the Melbourne Zone within the southern Lachlan Fold Belt. The western boundary of the Darraweit Guim Province in the Heathcote region is defined by the north-trending Cambrian Heathcote Volcanic Belt and Mt William Fault zone. The Mt William Fault is a major crustal-scale structural terrain boundary that separates the Bendigo and Melbourne zones (VandenBerg, 2003).

In the Heathcote region, the Darraweit Guim Province is represented by a think sedimentary succession assigned to the Murrindindi Supergroup (VandenBerg 2003). These sediments are earliest-Silurian to mid Devonian in age and largely consist of shales, fine-grained siliciclastics and minor carbonate occurrences. The true stratigraphic thickness of this succession is unknown.

However, an estimated total stratigraphic thickness in this area is in the order of approximately 3000 - 4000 metres.

In the Costerfield area, the geology consists of Lower Silurian-aged calcareous mudstones and siltstones belonging to the Costerfield Formation (as defined by Talent, 1965). This unit is only known from the Costerfield area. The Costerfield Formation is overlain by siliciclastics of the Wapentake Formation, followed by mudstones of the Dargile Formation. To the east of Costerfield, the lower Silurian-aged Costerfield Formation is thrust above Devonian sediments belonging to the upper portions of the Murrindindi Supergroup by the regionally extensive Moormbool Fault (figure 2) (Edwards *et al.*, 1998).
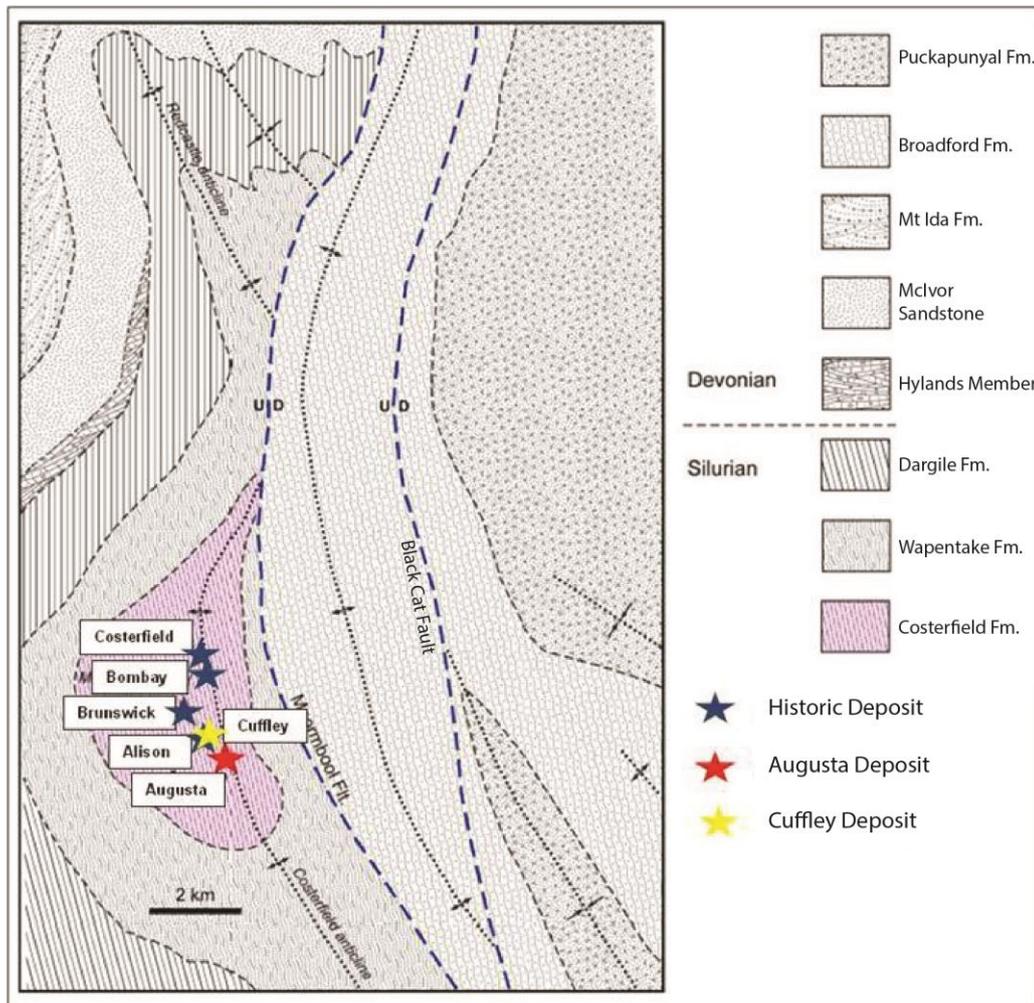
Figure 2. Local geological map of the Costerfield region displaying relative position of the regionally extensive Moormbool and Black Cat faults (modified from Edwards *et al.*, 1998).

Locally, the sedimentary succession of the Costerfield area has been deformed into a broad anticlinal dome structure with numerous cross-cutting reverse thrust faults. The anticlinal hinge zone of the Costerfield Anticline has been thrust over its eastern limb by the north-south striking thrust zone. This domal structure is thought to be the result of two separate tectonic events, the first producing significant shortening in an east-west direction (regional folding and reverse faulting), the second producing minor north-south shortening (localised warping and minor faulting). The more significant east-west shortening event is assigned to the mid-Devonian-aged Tabberabberan Orogeny that dates between 410-390 Ma (Gray *et al.*,2003; Foster *et al.*, 1998).

Stratigraphy

The stratigraphy of the Heathcote-Costerfield region is presented in figure 3. The oldest outcropping strata documented in the region is the Costerfield Formation and is regarded as

lowest-Silurian in age (Sandford and Holloway, 2006). The Costerfield Formation is then overlain by muddy siltstones and sandstones of the lower Silurian-aged Wapentake Formation, then Dargile Formation. Upper Silurian sedimentation is recorded in coarser siliciclastic successions of the McIvor Sandstone that is then finally overlain by the early-Devonian Mt Ida Formation (see figure 2). The Mt Ida Formation records the terminal faze of sedimentation in the greater Heathcote region. The overall stratigraphic thickness of this succession is unknown. However, estimations of true stratigraphic thickness have been in the range of 6-7 km, without any significant depositional hiatus (VandenBerg, 2003).
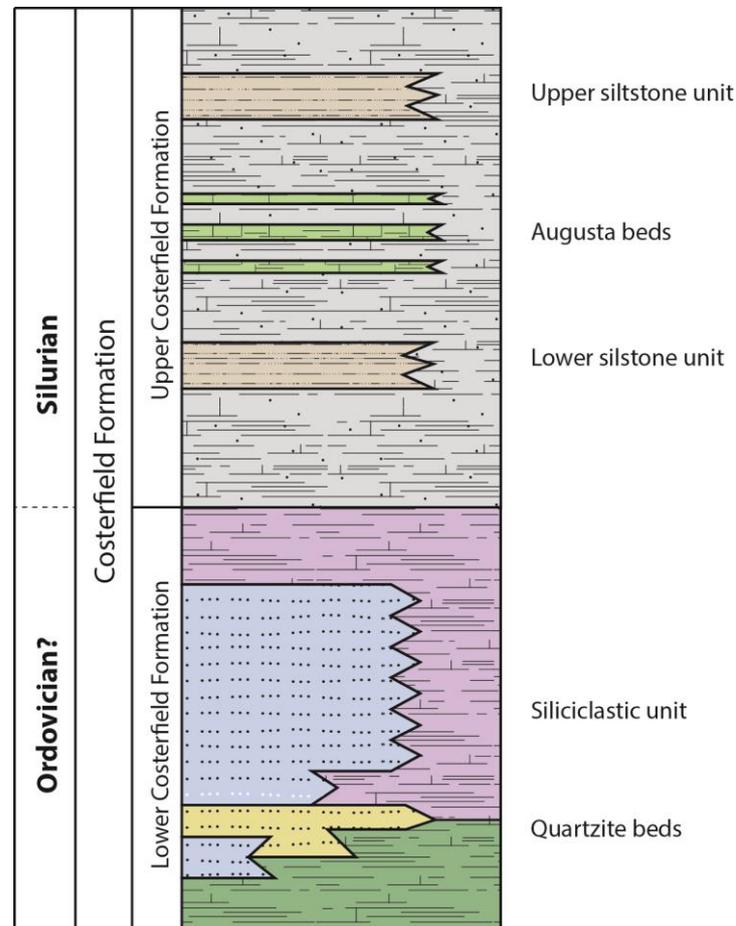
Figure 3. Stratigraphic column of the Costerfield Formation illustrating relative positions of informal lithostratigraphic units.

The Costerfield Formation is informally divided into lower and upper portions on the basis of a significant lithological change mid-way through the succession. Estimations of the true stratigraphic thickness of the Formation are made difficult due to significant faulting in the area; however it is estimated to be in the range of 450-550 m in thickness, with the lower and upper portions of the Formation being around 200 m and 300 m thick respectively. Informalised litho-stratigraphic units defined from the Lower Costerfield Formation are named the siliciclastic unit, quartzite beds and calcareous mudstones. Litho-stratigraphic units defined from the Upper Costerfield Formation are named the lower siltstone unit, Augusta beds and the upper siltstone unit (see figure 3).

The Lower Costerfield Formation occupies a true stratigraphic thickness of approximately 200 m. This succession does not outcrop in the Costerfield area, and is only recognised and recorded from drill core and within the lower depths of the current Augusta mine workings (> ~200 m depth). As such, there is no appropriate type locality to officially define this succession. The lithology of the Lower Costerfield Formation is dominated by banded calcareous mudstones and interbedded siltstones and fine sandstones. Overall, carbonate content decreases upwards throughout the Formation, with the most notable decrease in carbonate content occurring across

the transitional contact of the Lower and Upper Costerfield Formation; this transition forms the basis of where this intra-formational contact is defined.

Structural Geology

Recent resource-definition diamond-drilling for the Augusta and Cuffley deposits has resulted in a comprehensive collection of geological data from the South Costerfield area. From this, construction of highly refined cross-section interpretations has been possible. These cross sections have revealed that the Augusta and Cuffley deposits are bounded between two large, low-angle west-dipping parallel thrust faults named the Adder Fault (upper) and the King Cobra Fault (lower). They are typically in the range of 250 m apart in the South Costerfield area where they are recognised (see figure 4). The area between these two large faults is also heavily faulted resulting in a defined zone of intense brittle deformation. Three significant second order faults occur within the fault zone. These faults (named the Flat, Black and Queen faults) are interpreted as having listric geometry, most likely mimicking the larger structure of the Adder and King Cobra faults. These faults are all observed as extremely brittle structures, with larger faults (namely the Adder and King Cobra faults) occurring as a 1 – 2 m zone of fault pug, with several metres of extremely heavily fractured and sheered rock in both the foot- and hanging-walls. This zone of intense brittle deformation and shortening is bounded by the larger Adder and King Cobra faults, and regarded to represent a regional scale thrust fault or thrust zone and is here informally named the Costerfield Thrust. We correlate the Costerfield Thrust as the southern continuation of the historically recognised 'Costerfield Fault'. Stratigraphic interpretations suggest that overall shortening (stratigraphic displacement) across the Costerfield Thrust is in the order of around 1 km.

An additional series of brittle faults are observed within this thrust system striking in a north-north-easterly direction (i.e. the East Fault). These faults have a sub-vertical north-west dip and are generally observed as one to two metre thick zones of unconsolidated breccia with minor pug on the fault plane itself. The lateral extent of these faults is uncertain however they appear to be localised structures as correlation through the entire suite of drilling data is highly problematic. Offset across these steep dipping faults appears mostly strike-slip and overall vertical offset tentatively estimated to be on the scale of less than 50 m. Lateral offset is at present unknown.

Ductile deformation of the Costerfield area occurs a broad anticlinal structure with a wavelength in the estimated range of 1.5 – 2 km. Smaller parasitic folds are observed to have a northerly striking fold-axis that dips slightly to the east, with fold plunges oriented at very shallow angles (~10°) to the south. These parasitic folds are assumed to mimic the larger scale folding of the area. Ductile to semi-ductile veining/faulting is evident within the Costerfield Formation and occur as 20 -100 mm laminated quartz veins. They are typically bedding parallel, although laminated veins cross-cutting stratigraphy are not uncommon. Displacement across these faults/veins is uncertain as their bedding-parallel characteristic mean displacement estimations through stratigraphic observations are not always possible. Veins that do cross-cut bedding record offset displacement in the range of tens to one hundred metres or more.

Stibnite and stibnite-quartz bearing veins in the Augusta and Cuffley deposits occur as NNW striking (~330-340°), sub-vertical to shallow westerly dipping veins that measure between 2 to 50 cm in thickness, but at times measuring in excess of 1 m. Additional stibnite stringer veins occur as obliquely diverging structures off the main ore lodes. Ore-bearing veins typically cut across bedding at more oblique angles. Uneconomic vein structures (i.e. barren veins) include bedding parallel structures, as well as structures that cross cut bedding.
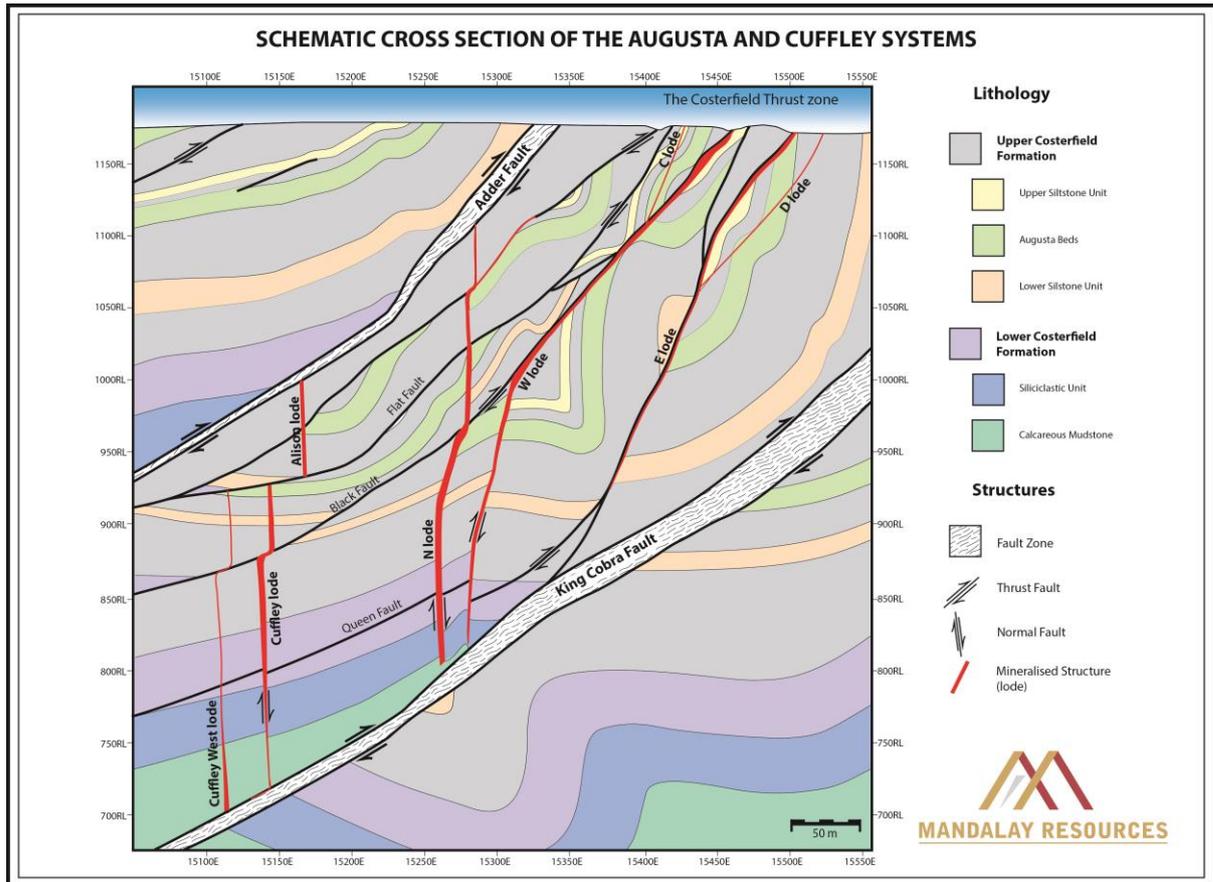
Figure 4. Schematic cross-section of the Augusta and Cuffley system illustrating the relationship between stratigraphy, fault and lode systems.

THE AUGUSTA DEPOSIT

The Augusta Deposit is located within the southern portions of the 'Costerfield line', south of South Costerfield. Geologically, the Deposit is located within the Costerfield Thrust consisting of three major economic lodes: E-lode, W-lode and N-lode. The mineralised structures of E and W lodes are mostly hosted within second order thrust faults within the Costerfield Thrust named the Queen Fault and Black Fault respectively (see figure 4). No major mineralisation is known from within the first order lower bounding thrust structure of the King Cobra Fault. N-lode is not hosted within these re-activated thrust structures, and is instead hosted within a tectonically later vertically oriented extensional structure (syn-mineralisation structure). The Black and Queen faults strike at ~330° (E and W lodes), while N-lode strikes in a more north-south orientation of ~350°.

E-lode

E-lode has a strike length of approximately 600 m and a down dip extent of 200 m. The lode sub-crops beneath shallow alluvium and has been mined by open-pit and underground methods. Where it has been mined, the dip of the lode varies from 42° in the south to 72° in the north, whilst its thickness ranges from less than 0.1 m up to 2.4 m and averages 0.28 m. Typically, the lode is hosted within the brittle fault structure of the Queen Fault often anastomosing through the fault-breccia into both the foot-wall and hanging-wall zones of this host fault structure (see figure 4).

W-lode

W-lode lies about 50 m west of E lode and occurs over a strike length of around 420 m. It has a known down-dip extent of approximately 350 m, and it remains open at depth. The dip of W lode is approximately 55° above 1100 mRL, and below this elevation it gradually steepens to between 70 - 80˚ at around 900 mRL. Its true thickness ranges from less than 0.1 m up to 2.2 m and

averages 0.33 m where it has been mined. Similarly to E-lode, W-lode is hosted within an early stage, re-activated thrust fault. This fault is named the Black Fault (see figure 4).

N-lode

N-lode lies approximately 80 m to the west of E lode. The lode is sub-vertical and occurs over a strike length of over 600 m with a down-dip extent of approximately 300 m. The true thickness ranges from less than 0.05 m up to 2.23 m and averages 0.2 m where it has been mined. Unlike E- and W-lodes, N-lode is not hosted within west-dipping pre-existing fault structures, but rather has its own 'unique' geometry (i.e. near vertical dip) in the Augusta System.

THE CUFFLEY DEPOSIT

The Cuffley Lode is located below the historic Alison Mine workings that are located towards the southern end of Costerfield Gold-Antimony Field, approximately 400 m west of the Augusta decline. The Alison and Cuffley lodes are separated based on the spatial relationship to the Flat Fault (see figure 4). The "Alison Shallows" is the reef above the flat fault that was historically mined at the Alison and New Alison 'reefs' whereas the Cuffley Lode (previously names 'Alison Deeps'), is the area of high grade mineralisation below the Flat Fault and Alison reefs.

The Cuffley Lode appears to be an offset depth continuation of the Alison Mine east and west lodes (possibly correlates with the 'west lode'). The Cuffley Lode is situated under the flat (30°-40°) west dipping fault, which has an *apparent* reverse offset of 30 - 50 metres. Recent drilling below this Flat Fault has since proven that the Cuffley Lode turns to a steep easterly dip at depth. The steep lode cross-cuts shallow west-dipping to flat bedding in the Costerfield Formation on an open, parasitic, anticlinal fold-limb. The Cuffley Lode system appears to be dominated by one single structural trend that dips around 75-85°E with a dip direction that varies from 061-68°. Recent drilling has shown that lode width and grade varies considerably ('pinch-and-swell') along strike and down dip.

MINERALISATION

Vein fill mineralogical contents and proportions are found to differ from vein-to-vein throughout the Augusta and Cuffley lodes however, textural and chronological order of each vein mineral generation remains remarkably consistent across all lodes. The overall paragenetic sequence is ordered as follows (oldest to youngest): laminated quartz, fibrous carbonate (siderite and ankerite), crystalline quartz (gold-bearing rhombic quartz), stibnite, opaline quartz and milky quartz.

Stibnite

Stibnite lodes of the Augusta and Cuffley deposits are often associated with crystalline quartz veins, where they may both overlie and/or replace quartz. Stibnite veins are easily divided into two important forms, a finely crystalline to micro-crystalline generation where individual crystals are less than 1mm in diameter, and a coarsely crystalline generation where individual grains are well in excess of a 1 mm in diameter where they form larger cleaved sparry crystal masses. Both fine and coarse generations of stibnite vein-fill are found to overlie the last generation of crystalline quartz vein-fills. Needle-like acicular forms of stibnite are found on joint planes and within brittle fault structures located near the main Augusta and Cuffley deposits, namely the King Cobra and Adder fault systems (see figure 4). These stibnite accumulations form a relatively minor constituent of sulphide mineralisation in the area and are therefore not of any economic significance.

Gold

Gold mineralization is often encountered within quartz veins in the Costerfield area, although a certain percentage of gold recovered does originate from within stibnite lodes as both aurostibite and free gold (albeit in its 'rusty' or 'spongy' filigree varieties). Free gold from quartz veins (auriferous quartz veins) is typically represented as free gold with grains between 20 – 500 μm, and occurs solely within crystalline quartz (i.e. rhombic quartz) veins (Figure 5). This auriferous phase of veining has often been associated with an observed increase of arsenopyrite in the veins and wall-rock.
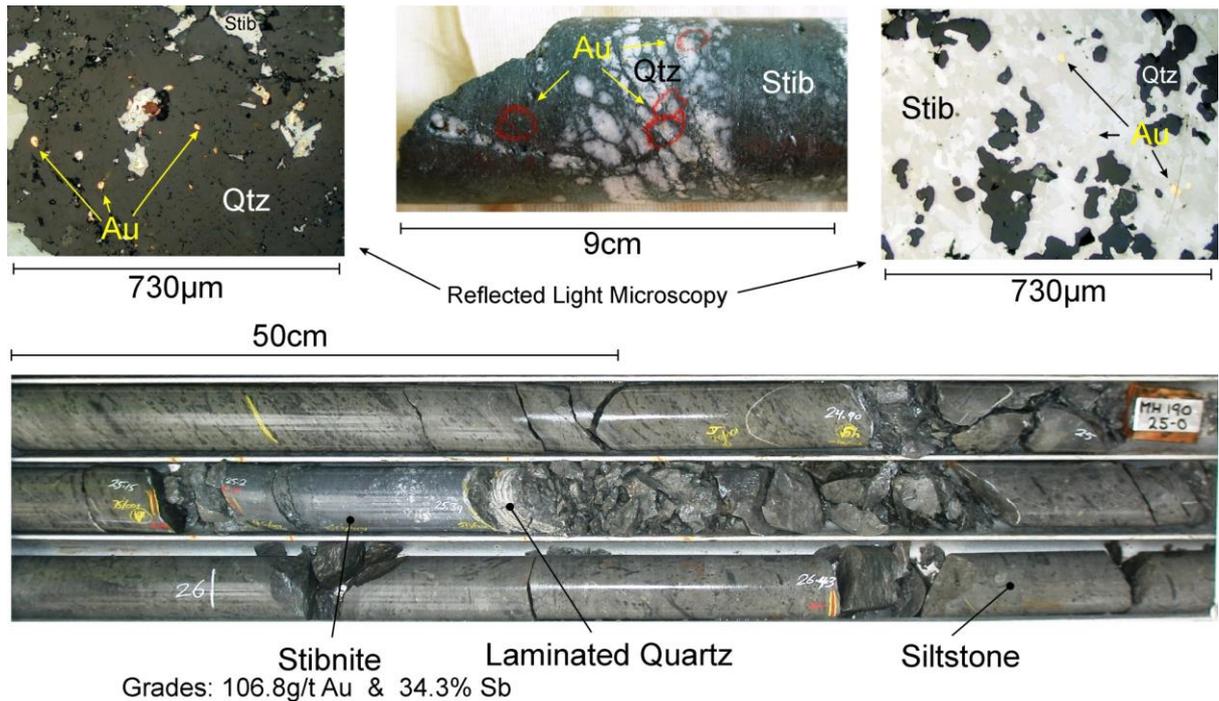
Figure 5. Reflected light microscopy samples (top left and right), core sample (top centre) and cored interval through ore zone (bottom of figure) of E-lode. Reflected light micrographs illustrate typical gold-in-quartz (top left) and gold-in-stibnite textures (top-right). Top centre photograph illustrates quartz replacement textures (by stibnite) with occurrences of gold in both quartz and stibnite.

CONCLUSIONS

Costerfield stibnite/gold mineralisation occurs as sedimentary hosted, narrow vein lodes. The host sediments are a series of interbedded calcareous and non-calcareous pyritic mudstones of early Silurian-age assigned to the Costerfield Formation. The mineralogical evolution and paragenetic sequence found in the Costerfield area seems to be very closely related to the structural evolution of the western Melbourne Zone. Pre-mineralised structures are mostly in the form of west-dipping brittle faults that define a complex array of parallel thrusts structures. Stibnite/gold mineralisation is hosted within both west-dipping brittle faults (i.e. E and W lodes), as well as syn-mineralisation structures occurring as near vertical dipping, north-south striking extensional veins. Gold deposition occurs as free gold within rhombic quartz and as gold in stibnite.

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IN THE BEGINNING THERE WERE THE TASMANIDES: THE TECTONIC FRAMEWORK OF MINERAL DEPOSITS OF EASTERN AUSTRALIA

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INTRODUCTION

Translating scattered, weathered outcrops of rocks in the field into some sort of coherent understanding of the evolution of the Tasmanides of eastern Australian is fraught with difficulties. The main barrier to this understanding is the widespread cover of younger rocks, new aeromagnetic imagery notwithstanding. Other issues include lack of progress in extracting paleogeographies (such as the location of any intraoceanic arcs and thus dips of subduction zones) and in that absence, the necessary, but perhaps over, reliance on igneous geochemistry for the interpretation of tectonic settings. Another key aspect is the speed of plate tectonics. The short time scale of some key plate interactions, such as ~6 million years for arc-continent collisions, is less than error margins in the isotopic dating of events 500-300 million years ago. As a consequence, we are seeing only part of the story. In such situations, it's not surprising that different interpretations are commonly based on different datasets and are thus not unique. What we need are metadata statements attached to each interpretation!

With these caveats, let us now look at the tectonic evolution of the Tasmanides and how an interpretation, based on ideas presented in Glen (2005, 2013), Glen and Roberts (2012) and Glen et al. (2013), might help in the recognition of potentially mineralised localities, regions and time periods.

Figure 1 summarises the subdivision of the Tasmanides in terms of orogenic belts and the internal Bowen-Gunnedah-Sydney basin system that developed from latest Carboniferous-early Permian rifts into a late early Permian to Triassic foreland basin system yoked to the New England Orogen to the east.

SUMMARY OF PLATE EVOLUTION OF THE TASMANIDES

Major differences exist between the very wide (>1500 km) southern part of the Tasmanides preserved in NSW, Victoria and eastern South Australia, and the very narrow (<300 km) northern part of the Tasmanides preserved in far north Queensland. Tectonic and economic implications of these differences will be discussed below.

Summary of plate evolution in the southern Tasmanides
Breakup of Rodinia rifting and passive margin formation from 830-580 Ma

Two main rift events can be recognised, the first beginning at ~830 Ma, the second beginning at ~600 Ma. The first was a consequence of breakup of the Rodinia supercontinent, with separation of Laurentia (or possibly another continent) occurring east of present day Australia. The Adelaide Rift Complex in eastern South Australia preserves the best record of the slow, repeated and magma-poor extensions that accompanied this breakup. In the second rifting event, beginning at ~600 Ma, breakup is preserved in the Tasmanides, in the Delamerian Orogen, in a line of alkaline to picritic to tholeiitic volcanics, which runs from northwestern NSW (Koonenberry Belt) through western Victoria (based largely on the interpretation of aeromagnetic data with few drill hole data) into western Tasmania. These volcanics seem to be unmineralised in any of their key outcrop areas.

I suggest that a key feature of this second rifting event is the calving of crustal blocks away from Gondwana, leading to the recognition of Precambrian continental blocks of (allochthonous) west Tasmania, and its probable extent in the Selwyn Block thrust beneath the Melbourne Zone of central Victoria, the possible Precambrian substrate to the Hay-Booligal Zone beneath the Murray Basin, and an inferred Precambrian block under parts of the New England Orogen. These

continental blocks lie between large areas of the Tasmanides inferred to be underlain by oceanic crust, mainly Cambrian in age, but with some early Ordovician oceanic crust as well. They blocks are key elements in the 3D architecture of the Tasmanides, with boundaries forming anisotropies, and potential fluid pathways during subsequent tectonism.

Convergent margin activity

Several belts of supra-subduction zone igneous activity can be identified in the southern (to middle) Tasmanides, ranging in age from Cambrian to Cretaceous. For reasons which are as yet unclear, mineralisation is only associated with some of these.

LA-ICMS analysis of zircon crystals in andesite and monzodiorite provide some evidence of ~585 Ma continental margin arc magmatism along the southern margin of the Thomson Orogen in response to localised north-dipping (present coordinates) subduction.

Subsequent convergent margin magmatism began by 535 Ma, possibly by 540 Ma. It is now represented by tectonic blocks in serpentinite matrix melange along the Peel-Manning Fault System in the New England Orogen. Blocks of plagiogranite and gabbro represent parts of an (upper plate) arc system, whereas blocks of eclogite represent parts of the subducted lower plate. Unsurprisingly, the subduction vector is not known

Now for the surprising bit. Except for the period ~525 to ~510 Ma, frontal arc magmatism from the latest Cambrian through to the Triassic, if not the Cretaceous, seems to have been localised along or near (± 250 km) the Peel-Manning Fault System in the New England Orogen. This fault system seems to have been the site of major, long-lived largely continental margin magmatism in response to west-dipping subduction, disrupted by major Mesozoic tectonism, and folded around four oroclines from the late Carboniferous to the middle Permian. Stepping back a little in time, from 525 to 505 Ma, arc magmatism occurred in the Delamerian Orogen, where it is reflected by volcanism in the Koonenberry Belt in the far northwest of NSW (possibly extending northwards beneath the Cooper Basin in South Australia and into western Queensland), in western Tasmania and from interpretation of aeromagnetic data, in western Victoria.

If this interpretation is right, then four implications are: i) from 530/540 to 525 Ma, the plate boundary moved westwards by an unknown amount; ii) from 510-502 Ma, the plate boundary moved eastward between 2250 and 3250 km, (see later); iii) subduction was mainly west-directed (present coordinates) beneath Gondwana; and iv) for most of its life the Lachlan Orogen occupied a 'backarc' setting.

Mineralisation in the Tasmanides

Within the above tectonic framework, major deposits occur in the following settings:
   i)   associated with ~516 Ma mafic volcanic rocks in the backarc basin at Stawell in the Delamerian Orogen;
   ii)   associated with 506-494 Ma post-collisional Mt Read Volcanics after rollback and extension in the west Tasmania block of the Tyennan Orogen, part of the Delamerian Orogen (Crawford and Berry 1992);
   iii)   within the ~480-440 richly endowed Macquarie Arc. In the new interpretation by Cam Quinn and others, the Macquarie Arc is really a belt of backarc rift-related volcanics developed behind fragments of frontal arc volcanics just west of the Peel-Manning Fault System in the New England Orogen and coeval accretionary complex rocks at Port Macquarie;
   iv)   in Silurian-Devonian volcanic and sedimentary-related mineralisation (commonly structurally modified if not emplaced) developed in an actively extending rift environment developed west of a supra-subduction zone system. The frontal arc of this system is the Late Silurian to mid-Devonian Calliope arc in the New England Orogen, which is mineralised at Mount Morgan and at Nundle. I infer it to have been part of a long-lived, continental margin arc although parts have also been interpreted as an accreted intraoceanic arc;
   v)   In latest Carboniferous to early Permian rift volcanics associated with initial rifting in the Gunnedah and Sydney basins as a consequence of plate rollback;

vi)   in the granitic roots of late Permian and Triassic backarc and ?arc in the New England Orogen;

vii) in the Permian accreted Gympie arc in the New England Orogen of southeast Queensland.

Interestingly, the long-lived middle Devonian to latest Carboniferous continental margin arc of the New England Orogen seems to have been singularly un mineralised although most of it is has been overthrust by westerly thrust forearc basin rocks in the southern part of that orogen.,

Summary of plate evolution northern Tasmanides

The two Neoproterozoic and early Cambrian rift events recognised from the southern Tasmanides can also be recognised ,albeit less clearly, in the northern Tasmanides. In the northern Tasmanides (Mossman Orogen and northern part of the Thomson Orogen) Early and Late Ordovician arcs and backarcs and granitic roots all lie within ~300 km of each other, with no clear sign of age migration. Inferred and hidden meridional Silurian–Carboniferous arcs lie just to the west or to the east of the Mossman Orogen, depending on whether the Hodgkinson Formation accumulated in a backarc or forearc setting. These arcs all lie now within 300 km of Precambrian cratonic Australia, and above inferred Precambrian crust and thrust over inferred Thomson Orogen. The finding of Mortimer et al. (2008) that offshore islands are underlain by a continuation of the New England Orogen rules out possible offshore extensions of, and thus a wider, extended Mossman Orogen. Thus, it appears that the northern paleo-Pacific-Gondwana plate boundary was anchored close to cratonic northern Australia from the Cambrian through to the Devonian.

MINERALISATION PATHWAYS

Ultimately mineral exploration targets the locations of ore bearing fluid or magma pathways. Locations of ascending ore-bearing fluid pathways into the upper crust, which were derived either in the mantle or deep/middle crust are controlled by major fault systems, by crustal architecture and ultimately by tectonics. As summarised above, these fault systems in the Tasmanides were either formed during the long early period of rifting and crustal extension as the Rodinia continent was slowly broken up (beginning at ~830 Ma), during subsequent rifting and calving of continental blocks (beginning at ~600 Ma) or during the longer period (540-100 Ma) of convergent margin activity flanking the Pacific plate. Fault systems might have also formed or become reactivated after the plate boundary rolled eastwards, as a result of the opening of the Tasman Sea. As a result, fragments of the Tasmanides now occur in New Zealand and New Caledonia, with the Australian part of the Tasmanides occupying a backarc setting after 60 Ma. Transfer of material to the upper crust in a supra-subduction zone setting is especially important since that setting is marked by generation and upward movement of mantle-derived magmas.

Potential pathways may be hard to recognise, especially if they haven't undergone recent reactivation. Let's look at three examples of pathways developed along crustal anisotropies.

1. Cross Orogen Anisotropy--- the Lachlan Transverse Zone

The Lachlan Transverse Zone is a near collinear set of ~310° tending set of fractures in the southern Tasmanides extending from east of the Bathurst Granite in the east to west of the Mount Jack gravity high in western NSW (Glen and Walshe 1999). Parts were initiated in the Ordovician and in the Macquarie Arc or Macquarie volcanics in the backarc interpretation. It is reasonable to infer middle Ordovician-Early Silurian control on the localisation of the Cadia valley group of deposits, in the some mineralisation at Tomingley, and with a bit less certainty the mineralisation at Northparkes. The lack of reactivation after the Carboniferous contrasts with Permian- Triassic (re)activation of other ~310° trending elements such as the Hunter River Transfer Zone in the Sydney Basin just west of the Hunter Thrust. Fractures with this orientation belong to the 'cross arc' or 'cross orogen' set recognised from major arcs and orogens around the world, such as the Andes and PNG. They are hard to predict from conventional plate tectonics.

2. Orogen- parallel anisotropy-margins of a Precambrian continental block

A good example of this type of mineralisation along an orogen-parallel anisotropy may be provided by the world class gold province of central Victoria. In the Bendigo Zone, gold is associated with steeply west-dipping, east-verging thrust faults that become more shallowly dipping at depth (Cayley et al. 2011; Willman et al. 2010). As far as I can see, there is no clear reason in the seismic image as to why one set of imbricate thrusts should form more gold-rich pathways than any other. Willman et al. (2010) suggested locations above parts of the Bendigo Zone where basal mafic volcanic rocks had been greatly thickened and dehydrated, and they invoked locations above (west of) first-order thrusts. I speculate that the fluid pathways formed from a crustal architecture dominated by west-dipping thrusts, which formed as a result of shortening across an anisotropic crust. A block of Precambrian continental crust (the Selwyn Block, Cayley et al. 2011) largely underlies the Melbourne Zone and separates the Bendigo and Tabberabberan zones, both of which developed on a substrate of Cambrian oceanic crust. But why the western parts of the Tabberabberan Zone, dominated by west vergent thrusts air not as equally mineralised is not clear.

3. Cross Orogen Anisotropy---boundaries of the Thomson Orogen

I mentioned earlier the first order differences between the narrow northern Tasmanides (largely exemplified by the Mossman Orogen in far north Queensland) and the super wide southern Tasmanides. I suggested that this difference reflected super wide rollback of the plate boundary between 525 and 502 Ma in the south compared with no roll back in the north where the Mossman Orogen lies above Precambrian continental crust and only a short distance east of the Precambrian core of Australia. The kinematic problems set up such different rates of rollback of the Pacific plate, with the southern part retreating quickly, the northern part largely stationery, may have been solved by development of transform zones. A key question is whether these zones propagated into the Tasmanides as 'cryptic fault' zones such as transfer or strike-slip zones. I suggest that such an structure occurs along the northern margin of the Thomson Orogen might explain the east– west trend of the mineralised Lower Ordovician Seventy Mile Range Group back arc basin in the northern Thomson Orogen, reflected in regional geophysical datasets (e.g. Murray et al. 1989; Wellman 1995) and accommodated to the north by the oroclinal 'Big Bend' megafold of Bell (1980). An original east-west origin for this back arc basin lies oblique to what we think is the regional original north to NNW-trending grain of the Tasmanides (although this could be simplistic) and supports Henderson (1986), who regarded this unusual trend as an original feature, rather than a tectonically rotated one (e.g. McElhinny et al. 2003). A similar but wider structure might occur in the southern Tasmanides, as part of a ~250 km wide zone of anomalous east–west gravity and magnetic trends north of the bounding Olepoloko Fault and along the southern margin of the Thomson Orogen. While this structural zone is thought to have been generated by the inferred Neoproterozoic to Cambrian, older, opening to the north of the ocean-floored Barcoo Basin that underlies most of the Thomson Orogen of Queensland, subsequent reactivation was possible. Propagation of such structures into the continental interior may have helped nucleate the subsequent enigmatic intraplate Alice Springs Orogeny.

CONCLUDING POINTS

An understanding of Tasmanide tectonics and evolution provides the critical framework within which to predict the presence of possible fluid pathways recognized from anisotropic elements embedded within 4D crustal architecture. The Selwyn Block, the inferred Precambrian basements to the Hay-Booligal Block and parts of the New England Orogen represent first order examples of such elements. Others may be inferred from more subtle analysis.
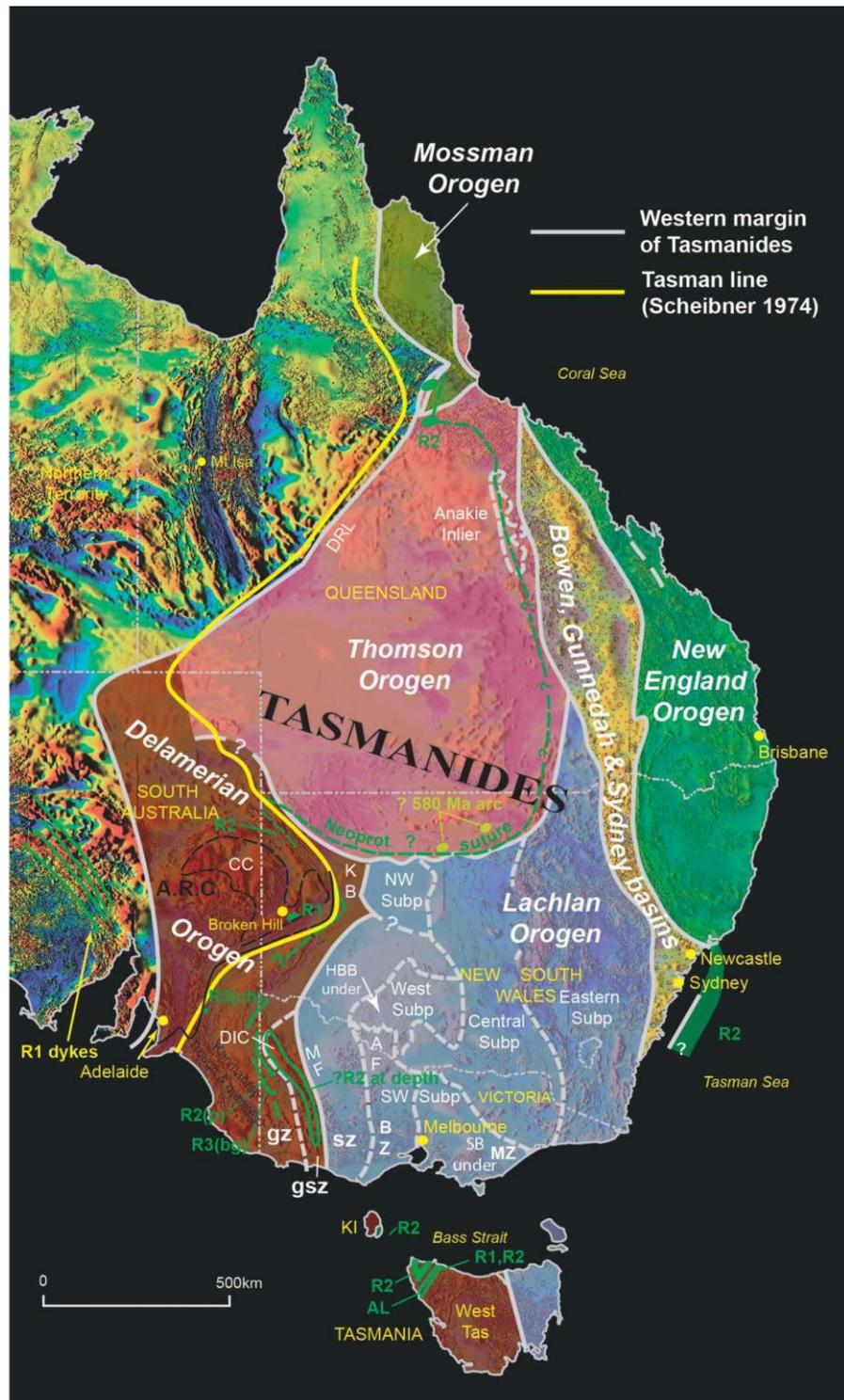
Figure 1 Map of Tasmanides and components. Tasman Line from Scheibner (1974). Bowen, Gunnedah and Sydney basins are foreland basins to the New England Orogen, and most of the Thomson Orogen is overlain by the Mesozoic Eromanga Basin. Abbreviations: Faults: AF, Avoca Fault; DRL, Diamantina River lineament; MF, Moyston Fault. Provinces: AL, Arthur Lineament; ARC, Adelaide Rift Complex; cc, Paleoproteorozic to Neoproterozoic Curnamona Complex; dic, Dimboola Igneous Complex; KI, King Island; kb, Koonenberry Belt. R2 (bg), Brindalbert Gabbro; R2(o), cc; R3(ch), from Chen & Liu; Subprov., subprovince of Lachlan Orogen. Structural zones: gz, Glenelg Zone; gsz, Grampians Stavely Zone; sz, Stawell Zone; BZ, Bendigo Zone; MZ, Melbourne Zone; HBB, Hay-Booligal block. R1, R2, R3 = rift phases (shown schematically in N Queensland). Updated from Glen (2005).

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MINING NUGGETTY GOLD IN CENTRAL VICTORIA

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Key Words: nuggetty, gold, Central Victoria, Slate Belt, Bendigo Zone, orogenic

Introduction

Slate Belt hosted orogenic gold deposits of Central Victoria present unique challenges for a mining company. The narrow, high-grade, and inhomogeneous or "nuggetty" characteristics of these deposits make the accurate estimation of resources difficult with many deposits only achieving the Indicated Resource category after intensive drilling or trial mining. This style of deposit presents many technical challenges for a mining company and numerous commercial challenges for a junior publicly listed company.

Octagonal Resources Limited ("Octagonal") or ("Company") is a junior gold mining company that is listed on the Australia Securities Exchange. The Company's corporate objective is to develop a small, but sustainable, gold-producing operation in Central Victoria centred around its 150,000tpa CIL gold processing plant at Maldon. The Company is currently underground mining at the Alliance South Deposit in Maldon and developing a pipeline of open pit ore sources to supplement the underground ore.

Regional Geology

The Maldon Goldfield is located 140km NW of Melbourne within the Bendigo Zone of the western Lachlan orogen (fold belt) (Figure 1). The Bendigo Zone is a world-class gold producing district, having produced 2,000t (64Moz's) of gold from alluvial and hard-rock (primary) sources (Phillips et al 2003). Thousands of gold deposits are clustered into numerous goldfields, with the largest historic hard-rock gold producers being Bendigo, Ballarat, and Maldon (Lisitsin et al 2007).

Gold mineralisation in the Bendigo Zone occurred during two main events between 455-435Ma (peaking at about 440Ma) and a less prolific event from 420-400Ma (Bierlein et al 2001).

Local Geology

The host rocks for the Maldon Goldfield are early Ordovician metasediments folded in to north-south trending tight/chevron folds formed during numerous deformational events. Substantial west-east shortening of the upper crust resulted in various major north-south striking, steep west dipping, first-order (thrust) faults that flatten with depth and connect with mid-crustal detachments. The Maldon Goldfield is located 5km to the west of the Muckleford Fault, which is one of these first-order faults.

Most of the Maldon Goldfield is located within the contact metamorphic aureole of the late Devonian Harcourt Granodiorite, which has caused the formation of successive K feldspar, cordierite and biotite alteration assemblages with increasing distance from the granite margin. The shallow southeast dipping granite contact appears to have been important in focusing granite-related mineralising fluids (Mo, Bi, Te, Au) during reactivation of various reef-related faults.

The Maldon Goldfield consists of several large reef systems (lines of reef) ranging from 0.5km to greater than 2km in length. Most of the reef systems occur within the Central Maldon Shear Zone, which was the source for over 70% of the total gold production (1.32Moz's) from the goldfield. The main lines of reef in the Central Maldon Shear Zone are arranged in an en echelon pattern (Figure 2), and are the Nuggetty, Sailor, Linscotts-Eaglehawk, German-Beehive, Nelson-Wilson, and Derby-Victoria reefs (Ebsworth & Krokowski de Vickerod, 2002).

The largest reef system is the 2.2km long Linscotts-Eaglehawk system, which includes the 1.6km long Eaglehawk Reef that has produced 491,000oz gold.

The reef systems consist of one or more faults/structures infilled with various styles of quartz vein. The reef systems trend in a northerly direction, and host discrete reefs, deposits and ore shoots, the latter extending up to 300m in length, as shown in Figure 4.
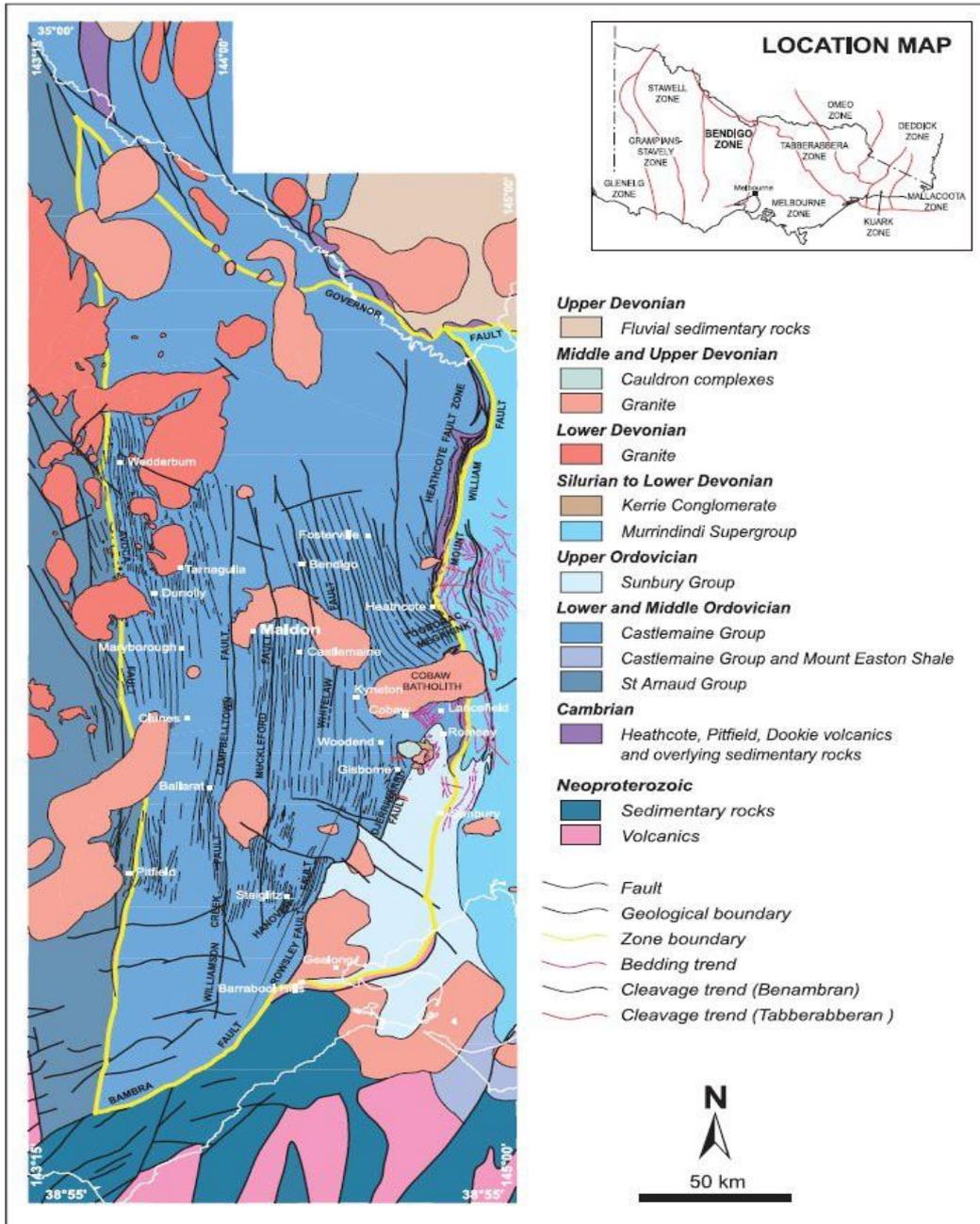
Figure 1.   Regional Geology of the Bendigo Zone [shown in yellow] (from Vandenberg et al 2000)

Mining History

Alluvial gold was discovered at Maldon in 1853 with around 300,000oz mined. Reef mining was first reported on Wilsons Reef in 1854 and within ten years a further fifty two reefs had been identified at Maldon. The last company mine (North British) closed in 1926, after an estimated 1,750,000oz of gold had been produced from reef mining at an average grade of 28g/t Au. During this time, six reef lines each produced over 100,000oz of gold (Table 1).

In 1987 Triad Minerals NL recommenced mining in the Maldon Goldfield. The company constructed a 150,000tpa CIL gold processing plant and between 1987 and 1992 mined 1,000,000t of remnant ore and spurry veins from the Union Hill Open Pit to produce 55,000oz of gold at an average grade of 1.7g/t Au.
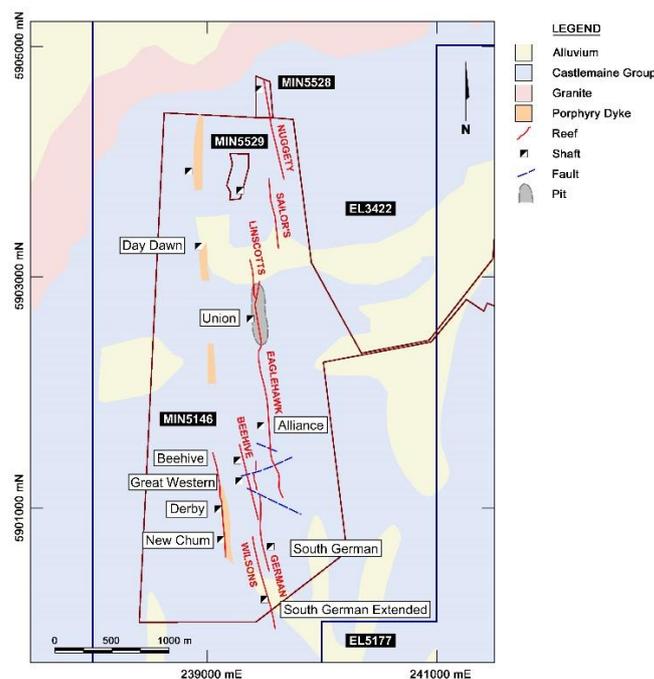
Figure 2. Reef of the Central Maldon Shear Zone

Table 1.			
Historic Reef Production form the Maldon Goldfield			
Reef System	Gold Production	Deepest Workings	Period Mined
Nuggetty Reef	303,000oz	750' (230m) level	1856 - 1900
Eaglehawk Reef	491,000oz	1,550' (470m) level	1854 - 1912
Beehive Reef	250,000oz	1,300' (400m) level	1854 - 1918
German Reef	277,000oz	2,200' (670m) level	1855 - 1920
Victoria & Derby Reef	150,000oz	1,250' (380m) level	1855 - 1909
North British Reef (Parkins)	242,000oz	1,650' (500m) level	1856 - 1926

Modern Exploration

In 2003 Alliance Resources Limited commenced a detailed geological review and computer-based modelling of the Maldon Goldfield to identify shallow resources that could be exploited using underground mining techniques. The review included compilation of historical mining and modern exploration data into a digital database and generation of 3D wireframe models of the old workings and interpreted geology.

The results of this work identified ten priority exploration targets areas in structural positions known to control historically mined gold-bearing shoots (Figure 3).

Drilling at the Alliance South Prospect, in the southern area of the Eaglehawk Reef, commenced in July 2004 and immediately intersected ore-grade gold. Hole DDH089 returned three visible gold intersections and a best assay result of 2.55m grading 7.0g/t Au.

During 2004 and 2005 32 diamond holes, for 8,487 metres, were drilled at the Alliance South Prospect using a combination of 40m x 50m and 20m x 25m spaced grids to ultimately define the Alliance South Deposit. Holes were drilled using HQ sized core to provide a large sample for analysis and allow NQ size core wedge holes to be drilled if required.

Several mineralised zones were identified associated with the Eaglehawk Reef, however the dominant mineralised structure occurs along the western margin of the main lode, close to the west bounding fault or "wall". The gold is associated with two moderately south-plunging flexures in the reef. The upper flexure mineralisation displays continuity over +350m down plunge and both flexures remain open to the south.

Gold grades returned from drilling reflect the nuggetty nature of the mineralisation at Maldon, with 14 visible gold intersections in the first 18 holes drilled only returning two economic assay results (>10g-m Au).

The relatively wide drill spacing and nuggetty nature of the gold at the Alliance South Deposit led Alliance Resources to conclude that a JORC-compliant resource estimate could not be confidently produced and an exploration decline from the Union Hill Open Pit was commenced in 2006 to access and mine a bulk sample from the Alliance South Deposit.

Between 2006 and 2008 a 4.0m x 4.5m sized decline was developed over 1,900m to within 100m of the Alliance South Deposit, however on 3 November 2008, in the midst of the Global Financial Crisis, Alliance Resources announced the suspension of mining operations at Maldon, in order to focus its resources on the development of the Four Mile Uranium Deposit in South Australia.

The mine was kept on care and maintenance until December 2010 when Octagonal acquired the Maldon Gold Operation and subsequently re-commenced underground mining activity in February 2012.

Cross-Section   Plan
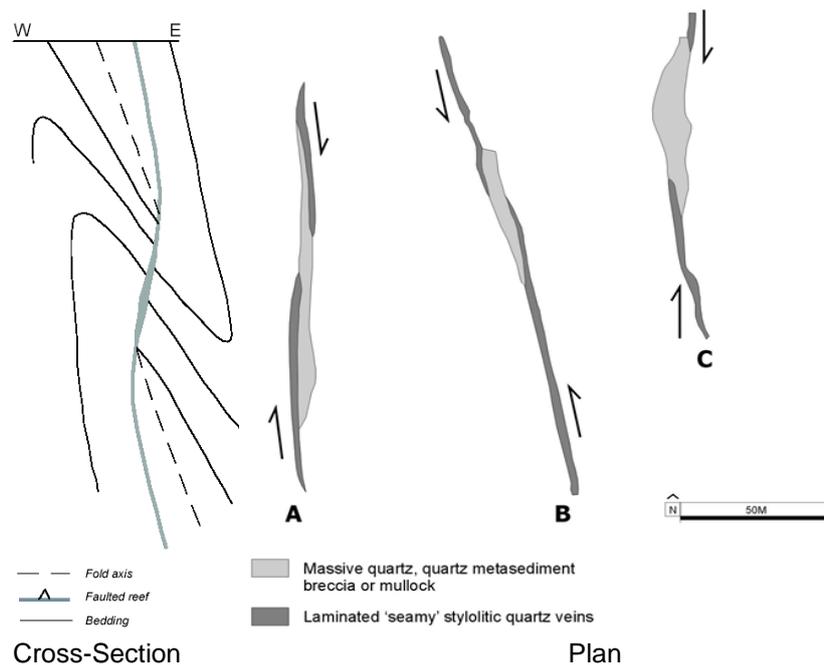
Figure 3. Favourable structural positions for the deposition of gold in the Maldon Goldfield (after Ebsworth & Krokowski de Vickerod. 2002)

Commercial Challenges

The greatest issue that narrow vein nuggetty gold deposits present for a mining company is the lack of ability to accurately estimate the quantity and grade of gold contained within a gold-bearing reef. This characteristic presents a risk that affects all areas of the business from investor confidence, promotion, and fund raising through to exploration, resource definition, and mining.

The traditional business model for a junior gold exploration company to elevate itself to a mid-tier gold producer is:

1. Discover a gold deposit (drilling),

2. Increase resource base targeting +1Moz's (drilling),

3. Increase resource confidence (drilling),

4. Complete financial modelling targeting ~100,000oz pa gold production over 7 to 10 years,

5. Convert resources to reserves,

6. Debt or equity financing to raise $100 - $150M for construction of mine and processing facility, and

7. Construct operation and commence gold production.

This type of business model appeals to banks and institutional investors because the underlying resource confidence provides a level of certainty in the performance of the mining company and the mine, and returns on investment can be predicted. For banks this also means that a proportion of future gold production can be hedged (forward sold) to cover production costs and protect the mine against a down turn in the gold price.

Nuggetty gold deposits cannot fit into this traditional gold business model because the inhomogeneous nature of the deposit style does not allow for cheap or easy definition of Indicated Resources that are required for financial modelling before Reserves can be estimated. There is no doubt however, as history has shown, that nuggetty gold deposits can be very rich and can generate a significant return for investors. The appeal of these deposits and desire to develop them has led to some innovative means of raising capital, however the underlying risk of ore quantity and grade remains.

Mining Strategy

If a company is to successfully develop a nuggetty high-grade gold deposit it is essential that all levels of the organisation understand the risks associated with mining this style of deposit and actively conduct its business in a manner that seeks to de-risk the operation.

The key to de-risking mining of a nuggetty high-grade gold deposit is to actively improve the understanding of the structural and lithological controls on the distribution of gold. This involves analysis of the largest representative sample size possible; from lots of drill holes, to large drill holes, to bulk samples, to developing and mining the deposit; and requires not only assay results, but structural measurements, geological observation, and interpretation.

The questions when considering commercial viability are: "When is enough drilling enough?", "When is it cost effective to take a bulk sample?", and "When is trial mining an option?" This is often determined by the cash position of a business or the level of support provided by shareholders to assist the company with raising additional funds.

Octagonal has endeavoured to de-risk the Maldon Gold Operation by:

- Understanding the structural and lithological controls on the deposit – bulk sample to be collected in the upper area of the Alliance South Shoot to determine the grade, ground conditions, and most appropriate mining technique for an ongoing operation,

- Identifying structural, lithological, and geochemical indicators of ore-bearing reef – 3D modelling, historic research, and drill hole analysis,

- Completing narrow vein mining using small mining equipment – reduce ore grade dilution,

- Mining as owner operator – small mining team focussed on grade and profit not development tonnes and metres,

- Small automated CIL gold processing plant – does not require a high volume throughput to be profitable,

- Small multi-skilled professional and experienced work force – keeps administrative and fixed costs to a minimum,

- Mining a combination of underground and open pit ore sources – open pit mines are less capital intensive and lower risk than an underground only mining operation,

- Treat third party ore – commercially favourable toll treating arrangements provide risk-free income from external ore sources, and

- Aim to become self-funding – removes requirement to rely on equity raisings and market sentiment to fund mining operations.

Alliance South Deposit

The Alliance South Deposit is estimated to contain an Inferred Mineral Resource of 473,000t grading 12g/t Au for 182,000oz of gold (Summons et al 2009; Figure 4 and Table 2).

		Estimated Gold Resource and Category								
Deposit	**Location**	**Measured**			**Indicated**			**Inferred**		
		'000t	Au g/t	'000oz	'000t	Au g/t	'000oz	'000t	Au g/t	'000oz
Alliance South	West Zone							287	12	110
	East Zone							186	12	72
Total								473	12	182

Table 2. Alliance South Mineral Resource Estimate (October 2009)
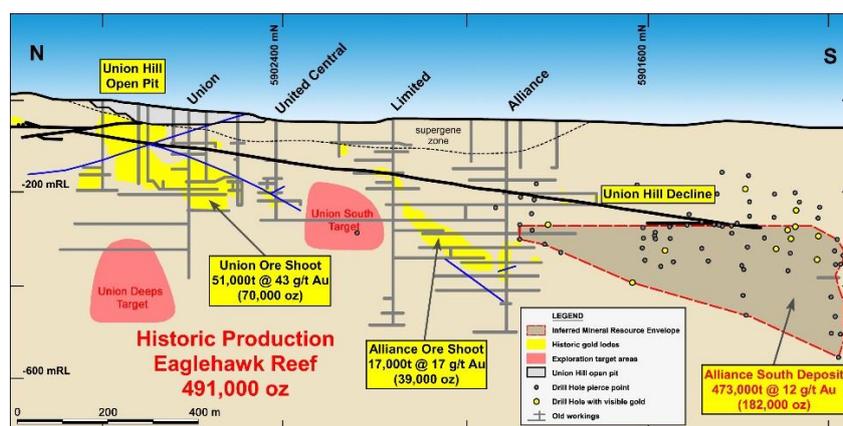
Figure 4. Eaglehawk Reef: Long section with the Union and Alliance shoots and the Alliance South Deposit

In August 2013, following 18 months of development, underground mining of the Alliance South Shoot commenced on the 1100 level of the Union Hill Decline to collect a bulk sample for ore processing. The decline will also be extended 180m to the south to allow for the development and bulk sampling of the 1080 level. Figure 5 illustrates the area of planned mine development, with purple stars indicating drill holes that have intersected visible gold.

It is important when viewing this diagram to understand that the sampling methodology applied required cutting of half core and sampling of the south side of the core, unless visible gold was identified, in which case the half of the core without the gold was sent to the laboratory for analysis and the half of the core with gold was retained as evidence of the visible gold intersection.

This sampling methodology was applied with the intention of demonstrating integrity by retaining proof of the gold in hole, however due to the nuggetty nature of the gold it has biased the assay results and does not provide a best estimate of gold intersected in hole. Octagonal is currently analysing the half of the core retained to provide a better and unbiased estimate of total gold intersected in hole.

All samples sent to the laboratory during the original drilling program were pulverised before splitting to try to improve homogeneity and analysed for gold using a 400g to 1kg BLEG analysis with fire assay of residue if samples returned >0.4g/t Au. Samples were also routinely analysed for As, Ag, Cu, Pb, Zn, Bi, Te, Mo, Ni and Sb.

Detailed multi-element analysis found no correlation between gold and other elements until sorted by arsenic (Krokowski et al 2012). For populations with >200ppm As there are strong positive correlations between gold and Bi, Te, and Sb and possibly Cu and Ag. This correlation is interpreted to be genetic and associated with second phase of gold mineralisation at Maldon related to the intrusion of the Harcourt Granodiorite.

As a result of this work the Maldon Gold Operation has modified its diamond drill sampling procedures and interpretation techniques. All diamond core is photographed and whole core samples collected through ore zones. Analysis is completed using a 2kg BLEG to ensure "all of the drill core sees the acid" and fire assay analysis is completed on residues returning >5.0g/t Au (this is a commercial decision based on underground economic cut-off grades). All samples from the ore zone are also routinely analysed for As, Bi, and Ag.

Drilling programs are now planned using a 40m x 50m spaced grid because this spacing is able to define the broad geometry of the gold-bearing reefs and was sufficient to discover the Alliance South Shoot. When interpreting drilling results the key characteristics considered indicative of an ore shoot are; visible gold in core, high gold assay results, high arsenic assay results with bismuth and silver, seamy or laminated grey quartz, and holes that define a favourable structural position.

During 2011, prior to re-commencing underground mining at Maldon, 16 diamond holes were drilled in the area of the Union Hill Decline between the historic Alliance Shaft and the Alliance South Shoot, using a 40m x 50m spaced grid, to test for near-development mining opportunities. This drilling failed to return any assay results greater than 5g-m Au, however two holes intersected historic workings, one hole intersected visible gold with arsenic and seamy grey quartz, and two other holes intersected arsenic and seamy grey quartz.

All holes are located in a favourable structural position and have defined a secondary exploration target that will be drill tested when an underground drilling position is available (Figure 5).
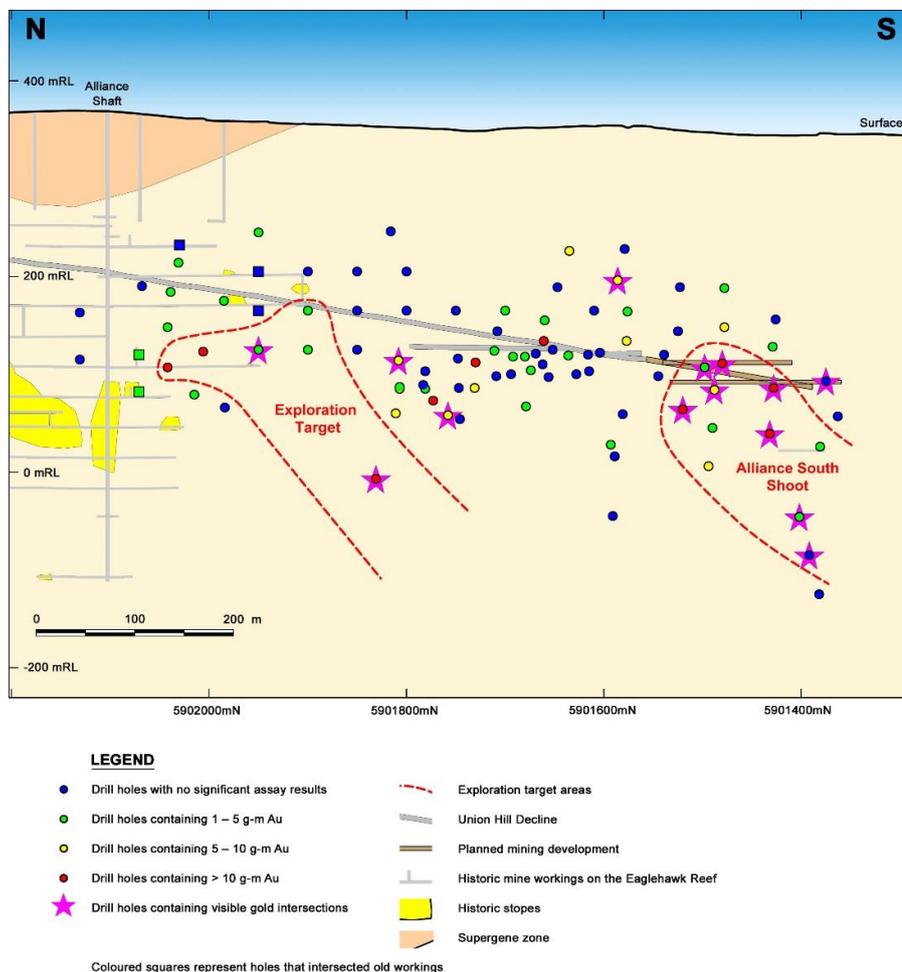
Figure 5. Eaglehawk Reef: Long section illustrating planned development at the Alliance South Shoot

Discussion

Mining of nuggetty high-grade gold deposits, such as those that occur within the Bendigo Zone of the Lachlan orogen in Central Victoria, are both commercially and technically challenging, but have the potential to generate significant wealth. The style of mineralisation and mining operation required does not lend itself to a traditional gold mining business development model and requires an innovative approach to capital raising, resource definition, and mining.

A detailed understanding of the structural and lithological controls on the distribution of gold is essential for a successful mining operation and can only be gained through collecting large and representative samples; be it through extensive drilling, bulk sampling, and / or mining.

The technical risks in mining a nuggetty gold deposit must always be weighed up against the cost of drilling and bulk sampling to determine the most cost-effective means of resource definition and mining.

Acknowledgments

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THE FOSTERVILLE GOLD MINE: PRESENT GEOLOGICAL UNDERSTANDINGS OF THE DEPOSIT.

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Abstract

The Fosterville Gold Mine, owned and operated by Crocodile Gold Corporation, is located in the Bendigo Zone of the Lachlan Fold Belt, approximately 20km north-east of Bendigo in Victoria, Australia. The goldfield was discovered in 1894 and oxide gold production up to 2001 totalled 240k oz of gold. Treatment of refractory sulphide ore through a BIOX processing plant between 2005 and 2012 has produced a further 671,886 ounces of gold. At the end of 2012 identified mineral resources (exclusive of reserves) and ore reserves at Fosterville respectively totalled 1.54Moz of gold and 305koz of mineable gold.

During the Ordovician Benambran Orogeny (~455-440 Ma) and Late Devonian Tabberabberan Orogeny (~380 Ma) deformation of the Lower Ordovician Lancefieldian (486~488 Ma) turbidites in the Fosterville district produced north-south oriented upright chevron, occasional open style folds and a reverse fault array. Porphyry dykes, commonly observed in anticline axial planes in the Robbin's Hill area were intruded during the Late Silurian to Early Devonian. Gold mineralisation occurred at 380-370 Ma in the Fosterville area and is structurally controlled, with high-grade gold zones localised by discordant relationships between bedding and faulting. Minor lamprophyre dykes, Middle Jurassic in age, postdate gold mineralisation and intrude faults along the Fosterville Fault trend.

Gold mineralisation at Fosterville mainly occurs within arsenopyrite and pyrite, forming as a disseminated selvage to quartz-carbonate stockwork veinlets. Wall rocks are very weakly to moderately sericite altered. A later stibnite-quartz event, varying from replacement and infill of quartz carbonate veins to stibnite-only veins ≤0.5m in width, is commonly associated with the Phoenix Fault. Nuggety gold (≤3mm in size) occurs sporadically within stibnite-quartz zones.

The Fosterville Fault Zone trend contains the most significant known gold mineralisation in the Fosterville district; in particular to the south of a fold culmination where folds plunges ~20°S and a large west-dipping fold limb, containing faulting, have been well-drilled over a 4km strike length. The gold mineralisation in this area also plunges south and is localised by late brittle west-dipping reverse faulting that offsets syncline and anticline fold closures. Mineralisation shoots are typically 4-15m wide, 50-150m in dip extent and 300-1500m+ down plunge. In general mineralisation is wider in regions of structural complexity and more continuous on faults that have greater reverse movement. The Phoenix Fault system is presently the most important mineralised structure at Fosterville, has about 150m of reverse offset and has been mined over a 1.5km down plunge length. As underground mining has progressed to deeper levels in recent years Phoenix related faulting has become more complex, with the presence of hangingwall splay faulting and west dipping footwall faults emanating from bedding parallel laminated quartz veins. Drilling has also identified significant down-dip mineralisation associated with anticline fault offsets.

Other faults at structurally higher positions than the Phoenix Fault have comparable fault offset and are also well mineralised. These include the Harrier and Osprey Faults that have over 200m of collective reverse movement, and both are now being mined at the southern end of the the mine lease.

In the Fosterville district within exploration licences held by Fosterville Gold Mine there are several interpreted and mapped faults whose trends are similar to the Fosterville Fault, have isolated Fosterville-style gold occurrences close to them and occur in the hangingwall of the Redesdale Fault. The latter is a major interpreted fault in the area and possibly an important conduit for gold mineralising fluid. Hence there is a structural framework that may be used to focus exploration towards discovery of significant Fosterville-style mineralisation in future years.

Introduction

The Fosterville Gold Mine is located approximately 20km north-east of Bendigo and 130km north of Melbourne in Victoria, Australia, where present day mining operations are located on Mining Lease 5404, which is 100% owned by Crocodile Gold Corporation.

Gold was first discovered in the Fosterville area in 1894 and oxide mining up until 1903 produced approximately 28k ounces of gold. Minor tailings retreatment was undertaken in the 1930's and again in the 1980's.

The goldfield lay dormant for a lengthy period and since 1988 company ownership of the goldfield has changed five times. Heap leach oxide open pit operations between 1988 and 2001 produced 240k ounces of gold (Roberts et al, 2003). Perseverance Exploration (PSV) successfully explored for sulphide resources and completed a sulphide gold feasibility study in 2003. The project comprised open pit and underground reserves totalled 910k mineable ounces and a 0.8Mtpa BIOX® processing plant to mill sulphide ore. Gold production began from open pits in April 2005 and from underground sources from September 2006 and since 2008 underground ore has been the main Fosterville mill feed.

The ownership of operation has changed in the recent years commencing with PSV being taken-over in 2008 by Canadian company, Northgate Minerals, who later merged with Canadian company, AuRico Gold Corporation. In May 2012 the Fosterville operation along with all of AuRico Australian assets, including and Stawell Gold Mine, was sold to Crocodile Gold Corp (CrocGold).

Regardless of changes in corporate ownership, sulphide mining operations at Fosterville have remained continuous since 2005, and by the end of 2012 total sulphide gold production amounted to 671,886 ounces.

During the years since the completion of sulphide feasibility study, exploration and mining activities have provided more extensive and detailed geological and geochemical data that has allowed a better understanding of the complexities of Fosterville deposit. Current understandings of the Fosterville goldfield are presented.

Regional Geology

The Fosterville Goldfield is located in the Bendigo Zone of the Lachlan Fold Belt, in central Victoria, where turbidite host rocks were deformed in the Late Ordovician Benambran Orogeny (~455-440 Ma) and the Late Devonian Tabberabberan Orogeny (~380 Ma) (Vandenberg et al, 2000). These events resulted in a fold and thrust belt extending from the Moysten Fault, near Stawell, to the Heathcote Fault Zone east of Fosterville (Figure 1a).

During the deformational events Cambrian mafic volcanics and sediments and Ordovician sediments were subjected to east-west compression resulting in the formation of north-south upright folds. Continued compression caused steepening of fold limbs and progressive development of a series of west-dipping reverse faults. These faults are interpreted to have listric geometries and were likely conduits for providing a regional control on mineralising processes (Figure 1b) in conjunction with intrazonal west dipping faults, such as the Redesdale Fault that is mapped (Cayley et al, 2008) south of Fosterville. In addition, smaller reverse faults propagated across fold limbs, linking bedded faults and are well mineralised in the classic Central Victorian Slate Belt Gold Deposits of Bendigo and Castlemaine (Roberts et al, 2003).

There are three periods of gold mineralisation recognised across the western Lachlan Fold Belt. The first is the 455-440 Ma event and is thought to have involved the circulation of metamorphic fluids through the crust (Vandenberg et al, 2000) and formed gold deposits at Bendigo, Castlemaine, Maldon and Daylesford. The second period of mineralisation spanned 420-410 Ma and brought new pulses of gold as well as remobilising gold into new structures, and includes the Tarnagulla and Ballarat goldfields (Bierlein et al, 2001).

The third event occurred at 380-370 Ma (Bierlein and Maher 2001) and is responsible for the emplacement of gold at Fosterville and several deposits in the Melbourne Zone. All three gold mineralising events are characterised by carbonate and sericite alteration, but only the later two events have elevated Mo, Cu, Sb and W. The two later mineralising events post-date the emplacement of Late Silurian to Late Devonian felsic dykes and are spatially related and possibly genetically related to magmatism (Arne et al, 1998; Bierlein et al, 2001). During the third mineralising event a range of mineralisation styles resulted and include quartz-carbonate vein hosted free gold through to sulphide hosted refractory gold in association with arsenopyrite, pyrite and stibnite (Roberts et al, 2003).

The Bendigo Zone was intruded by two granitic suites during the Early and Late Devonian, with examples of the latter cropping out 30km to the south of Fosterville.
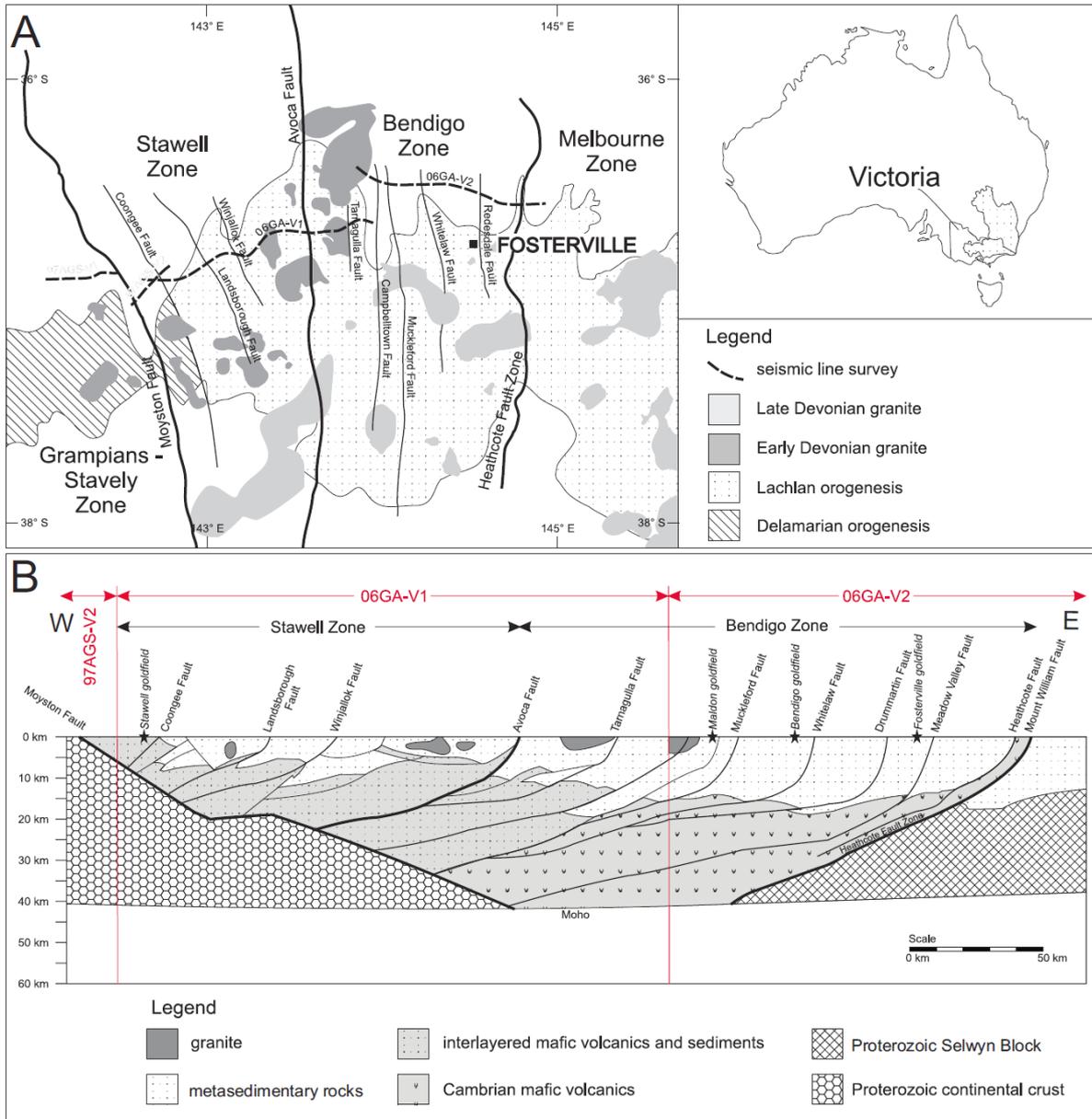
Figure 1. Map and cross section of the Western Lachlan Fold Belt in central Victoria. (a) Distribution of major geologic units and major faults of the Bendigo and Stawell Zones and ocation of seismic lines. (b) Geological interpretation from seismic surveys. Adapted from Leader & Wilson, 2010.
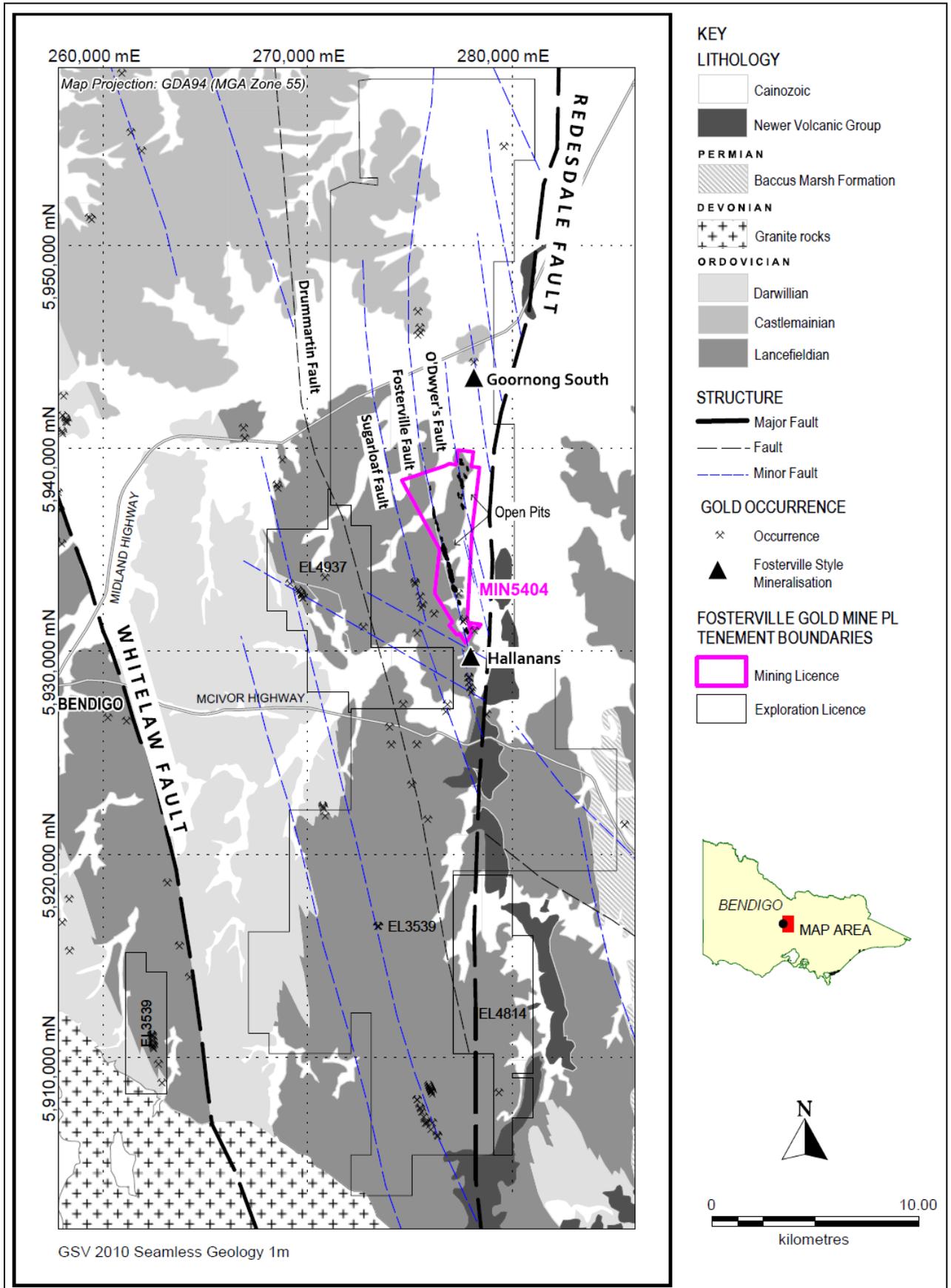
Figure 2. Regional Geology of the Fosterville District showing Fosterville Mining licences, Exploration Licences, open pits and hard rock gold occurrences.
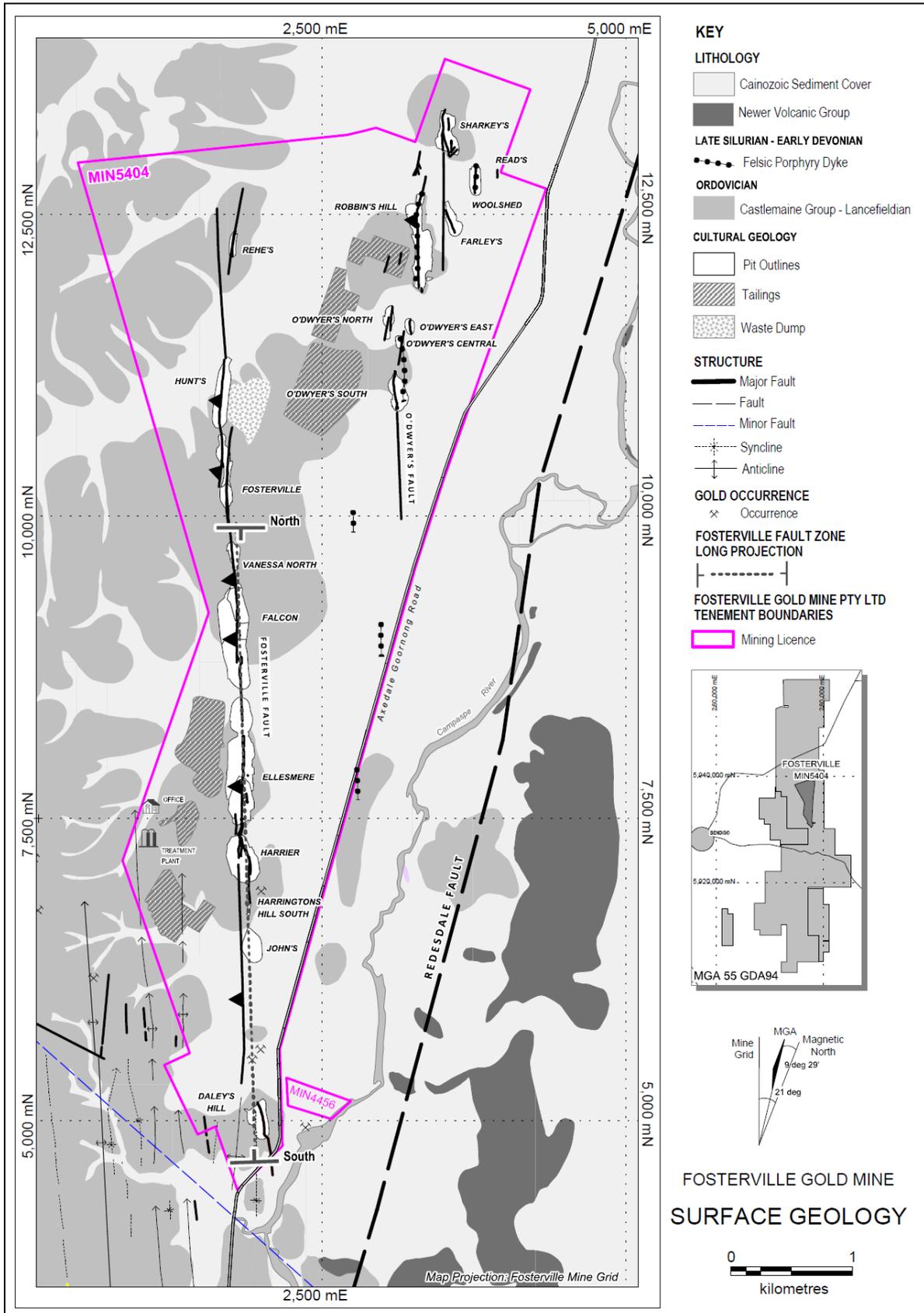
Figure 3. Fosterville Gold Mine Surface Geology, showing surface mining activity and location of Fosterville Fault Zone long projection.

Deposit Geology

The Fosterville Goldfield is hosted by Lower Ordovician Lancefieldian (486~488 Ma) turbidites within the Ordovician Castlemaine Group rocks (Figures 2 and 3). The turbiditic sequence comprises interbedded sandstones, siltstones and shales, which are interpreted as having formed in a meandering submarine channel setting. The sequence is dominated by shale topped sands ranging from 0.2m to 1.5m in thickness, with lesser amounts of massive sandstone, shale and black shale (Roberts et al, 2003). Detailed drill core logging has confirmed almost 1000m of stratigraphic succession exists at Fosterville and correlation of sedimentary units has been possible over a 10km distance within the Fosterville mine lease (Boucher et al, 2008).
The sequence is metamorphosed to sub-greenschist facies or more precisely, Anchizone to lower Epizone (Melling, 2008) and fluid inclusion work indicates that the Fosterville goldfield formed at ~270°C and at 2.6-5.7km crustal levels (Mernah, 2001).
The stratigraphic sequence was folded into a set of upright chevron, occasional open style folds, with fold wavelengths in the order of 350m and parasitic fold wavelengths of 50m. During folding vertical axial planar (in finer sediments) and radial cleavages (sandstones) developed and are best observed in fold hinges. Bedded laminated quartz veins (<1mm to 0.8m wide) were also formed during early folding and were preferentially formed in shales and at or close to the contact with sandstone units.
The north-south trending Redesdale Fault, lying approximately two kilometres to the east of the Fosterville Mine area, is an important intrazone fault and occurs in the hanging wall of the Heathcote Fault Zone (Figures 1a and 2). Subordinate faults (third or fourth order), such as the Fosterville, O'Dwyer's and Sugarloaf Faults (Figure 2) all have associated gold mineralisation and are located in the hangingwall of the Redesdale Fault.
Within the Fosterville mine area the NNW trending Fosterville Fault is strike extensive and dips steeply west. In its footwall are moderately west dipping faults with varying reverse offsets and associated gold mineralisation. In general faults with greater offset have larger gold mineralisation dip and plunge lengths. Where faulting is more complex, wallrock fracturing is enhanced and mineralisation width increases.
 A fold culmination exists in the Falcon pit area (Figure 3) about which a fold plunge reversal occurs. South of the culmination, folds plunge approximately 20° southwards, and a large west-dipping fold limb, containing parasitic folds and faulting has been well drilled over a 4km length to as far south as Daley's Hill. Extensive drilling focussed on south plunging gold mineralisation associated with late brittle west dipping reverse faulting that offsets syncline and anticline fold closures (Figure 4.)
In the northern portion of the mine lease, in the Robbin's Hill - O'Dwyer's area, a number of west dipping faults occur and parallel the Fosterville Fault. Mid-Devonian porphyry dykes (Arne et al, 1998) also occur in this area, are up to 10m in width, intrude the stratigraphic sequence along anticlinal axial planes (King, 2005; Reed, 2007) and postdate all significant faulting, The porphyry dykes are sericite altered, have associated gold mineralisation that was sufficient to support oxide and minor sulphide (O' Dwyer's South) open pit mining.
Lamprophyre dykes, typically <1m in width, intrude along the general Fosterville Fault trend and are unmineralised. These dykes were emplaced in the Middle Jurassic (157-153 Ma) (Bierlein, 2001) and are of similar age to those that occur at Bendigo.
Erosion of the area followed by Cainozoic Murray Basin sediment valley backfill and weathering has resulted in local clay - conglomerate alluvial channels and complete oxidation to about 40m below surface. Immediately below the base of complete oxidation is a 10m to 15m thick zone of partial oxidation of sulphide minerals. Feldspar destruction and partial carbonate dissolution extends from the base of oxidation to about 150m depth. Approximately 2km to the east of Fosterville Miocene aged Newer Basalt Group rocks mask the Ordovician rocks and Murray Basin sediments.

Schematic Cross-Section

The geological knowledge of the Fosterville Fault Zone fault architecture has progressively improved over the last decade as diamond drilling explored new areas and mining progressed deeper underground. Present understanding of the faulting is shown as a schematic cross section (Figure 4). Pictured is the moderate-steep west dipping Fosterville Fault, which has several en echelon array of footwall reverse faults that link across from a western anticline to a syncline in the east.
The deeper level footwall faults, to the east of their respective hangingwall synclines, exist as bedded laminated quartz veins, commonly with pug on one margin. However, west of hangingwall synclines, the faulting has discordant hangingwall bedding contacts and wall rocks are brecciated, up to several metres in width. To west of the footwall synclines the faults have discordant contacts with bedding

and the faults' dip generally shallows. Approximately 50m down dip of the footwall syncline, the character of the faulting changes to a zone of distributed faults then reforms 50-75m down dip into a single fault strand, before passing across an anticline and becoming bedding parallel on its western limb.

The Phoenix Fault system is the most important structure at Fosterville for gold mineralisation, has 120-150m of reverse offset and as underground mining has progressed to deeper levels, faulting becomes more complex. Nearer to surface the Phoenix Fault was a relatively simple single stranded west-dipping reverse fault, but down-plunge the faulting also includes mineralised hangingwall splay faulting and west dipping footwall faults emanating from bedding parallel laminated quartz veins. Other faults at structurally higher positions have comparable fault offset and are well mineralised. These include the Harrier and Osprey Faults (exposed at Harrier Pit) that are footwall splays of the Fosterville Fault. The faults have over 200m of combined reverse movement, and are being mined at the southern end of the the mine lease.

Where wall rocks faulted are brecciated, the fractures are also healed by quartz-carbonate veining, commonly having arsenopyrite and pyrite disseminated in the wall rock up to 50cm from veins. The wall rock proximal to faults is also sericitised, sometimes with alteration visually subtle, and has similar spatial extents to the gross sulphide distribution. Bedded faults exist as laminated quartz veins are poorly mineralised.

Drilling at Fosterville has generally concentrated a 200m zone east of the Fosterville Fault to where footwall faults become bedded.

Primary Mineralisation

Primary gold mineralisation at Fosterville is structurally controlled with high-grade zones localised by discordant relationships between bedding and faulting (Figure 4). Gold mineralisation is more continuous and of higher grades in fault segments where east-dipping hanging wall beds overlie west-dipping footwall beds, such as along the Phoenix Fault (Boucher, 2008), i.e. discordant-concordant structural setting (locally termed oblique/parallel). Mineralised shoots are typically 4m to 15m wide, 50m to 150m in dip extent and 300m to 1500m+ down plunge (Figure 5). Gold grades are relatively smoothly distributed with both extremely high values and extremely low values rare.

The primary gold mineralisation occurs within disseminated arsenopyrite and pyrite, forming as a selvage to quartz–carbonate stockwork veinlets. The arsenopyrite occurs as fine grained (0.05mm - 6 mm) acicular needles with no preferred orientation. The disseminated pyrite associated with gold mineralisation occurs as crystalline pyritohedrons 0.1mm to 2mm in size. Electron microprobe analyses and metallurgical test work indicates that the arsenopyrite contains 100 g/t Au to 1000 g/t Au and the auriferous pyrite 10g/t Au to 100g/t Au (Roberts et al, 2003). Approximately 80% of the gold occurs in arsenopyrite, with the remaining 20% hosted by pyrite. Silver grades are very low with only ~1% reporting to poured gold bullion.
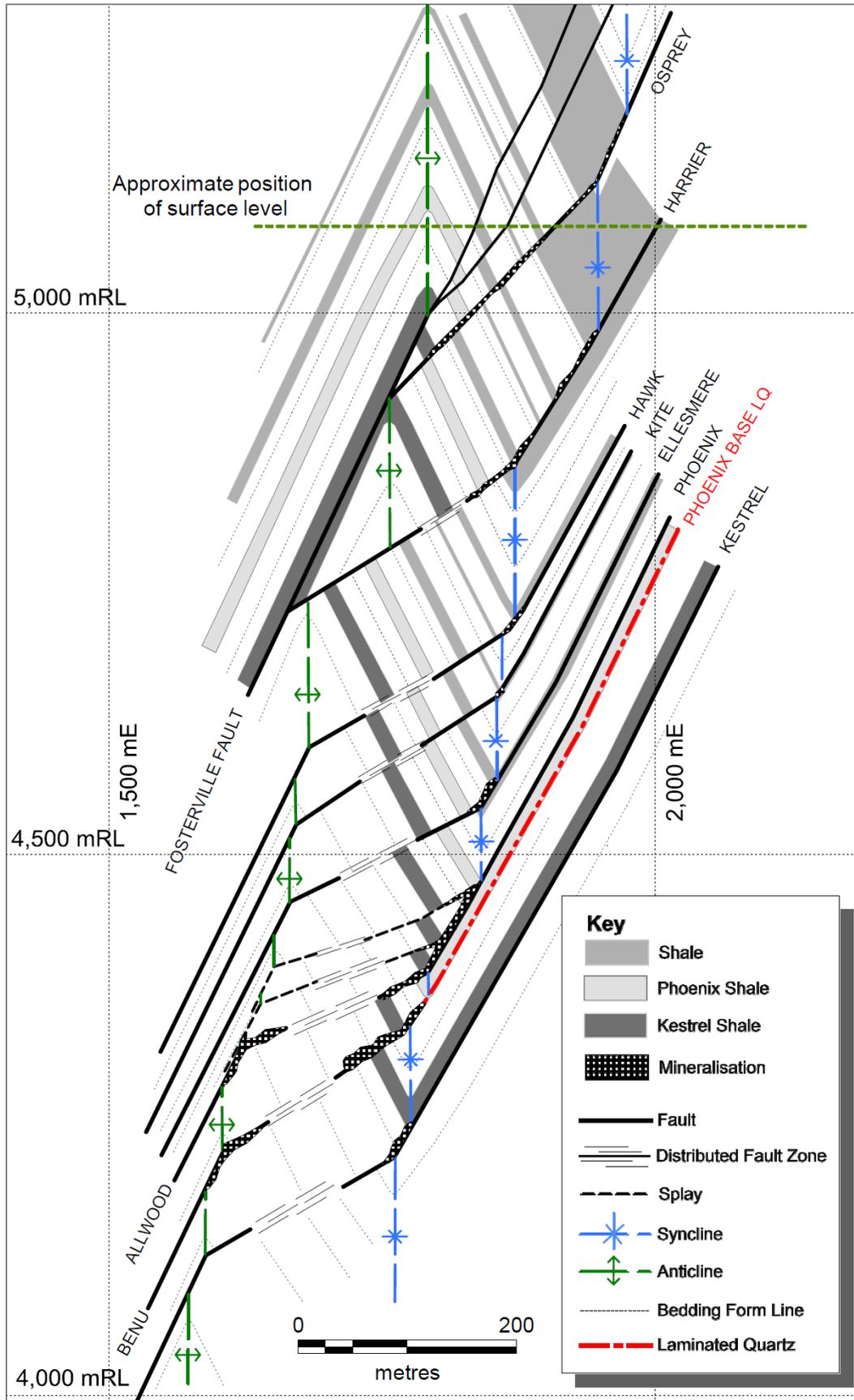
Figure 4. Fosterville Fault Zone schematic cross section showing faulting, major shales and gold mineralisation.
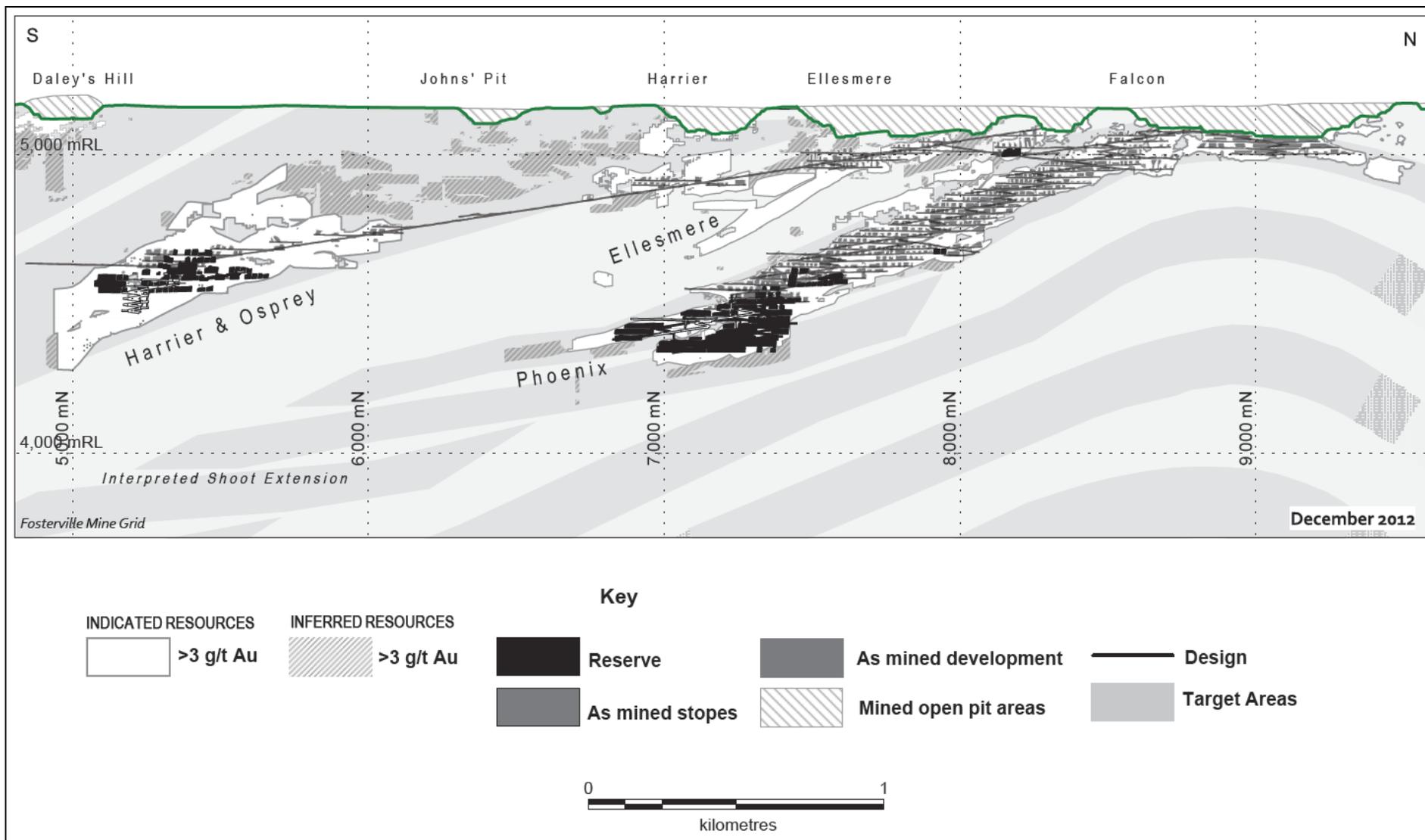
Figure 5. Fosterville Fault Zone Long Projection (looking west) showing resources, reserves, open pits, underground development and target areas.

Antimony mineralisation, in the form of stibnite, occurs with quartz and varies from replacement and infill (up to several metres in width) of earlier quartz-carbonate stockwork veins, to massive stibnite-only veins of up to 0.5m in width. Gold content of stibnite-quartz zones is highly variable gold owing to the presence of visible gold nuggets (≤3mm in size). The stibnite-quartz zones are commonly associated with the Phoenix Fault, occasionally within the Harrier Fault and were mined with felsic dyke material in the O'Dwyer's South pit during 2012.

Other sulphides present at Fosterville in small quantities include galena, sphalerite and chalcopyrite and rarer still are tetrahedrite ($CuFe_{12}As_4S_{13}$), bournonite ($PbCuSbS_3$) and boulangerite (Pb_5Sb4S_{11}).

Framboidal pyrite aggregates (≤50mm in dia.) and laminations of pyrite (≤20mm widths) are common in the stratigraphic sequence, especially in black shale units. The framboidal pyrite is diagenetic and drill core assaying returns grades <5ppb Au.

Oxide Mineralisation

Minor re-mobilisation of primary gold through weathering processes at Fosterville from mineralised structures into adjacent Ordovician sediment has resulted in about 50% increase in the width of mineralisation and consequently a general reduction in oxide gold grade. There is no evidence of a wide spread high grade supergene zone immediately below the water table.

Sulphur and arsenic have been significantly affected by weathering processes. Dissolution of sulphur by oxidising groundwater above the water table has effectively removed all sulphur from the oxide zone. Arsenic has been strongly remobilised over a zone five to ten times the width of mineralisation. The greater width of anomalous arsenic values in the oxide zones makes arsenic soil geochemistry a very useful tool for locating gold mineralisation.

Geochemical studies (Arne and House, 2009) also found discernible Fe or Mn oxide minerals scavenging of Au, As or Sb in the weathered zone and that raw concentrations of Au, As and Sb may be used for defining secondary dispersion (with allowance made for the rock type for Sb).

Resources and Reserves

The Fosterville sulphide project feasibility was based on extraction of reserves over almost 7.5 year life, but with the potential to convert inferred resources to reserve status in future years to extend the mine life a further 5 years. Sulphide gold production commenced in 2005 and resources and reserves at Fosterville have varied over time due to reserve depletion and exploration successes (Figure 6).

Since 2004 Exploration activities focussed on growing the resource base by drilling along-strike from known resources and exploring for new mineralised structures. Before 2008, underground resources were reported above a 2g/t Au lower cut-off and Fosterville resources steadily increased due to sustained exploration drilling of relatively shallow targets. However, after the change in ownership from PSV to Northgate in early 2008, underground resources were reported above a 3g/t Au lower cut-off to reflect gold grades closer to those used for reserve status. The combination of an elevated resource cut-off grade, the greater depth of exploration targets and mixed exploration drill results lead to decreasing overall resource ounces between 2008 and 2010. However, with continued exploration successes down-plunge on the Harrier and Phoenix mineralised systems and the use of underground drill platforms, resources have steadily increased and by the end of 2012 total sulphide resources (exclusive of ore reserves) were ~1.54Moz of gold (Table 1).

Ore reserves at Fosterville declined more quickly between 2006 and 2008, than after 2008, owing to limited availability of underground drilling platforms and exploration focussing on project scoping rather than reserve status drilling in earlier years. The Fosterville ore reserve gold ounces (305koz) as of December 2012 (Table 2) are approximately a third of those published in 2003, but still represent almost a three-year life of mine.
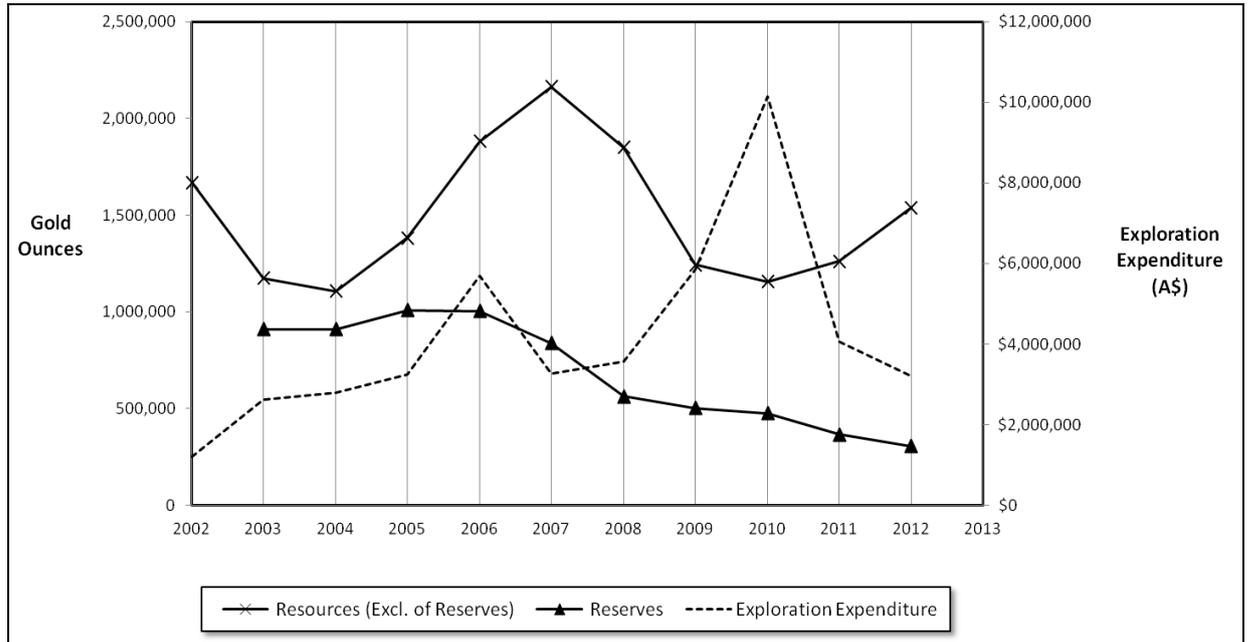
Figure 6. **Fosterville Sulphide gold resources and reserves over time. Data compiled from Perseverance, Northgate and Crocodile Gold Annual and Quarterly reports and internal company expenditure information.**

Table 1: Summarised Fosterville Mineral Resources at 31st December 2012

Classification	Measured			Indicated			Inferred		
	Tonnes (kt)	Gold Grade (g/t)	Insitu Gold (koz)	Tonnes (kt)	Gold Grade (g/t)	Insitu Gold (koz)	Tonnes (kt)	Gold Grade (g/t)	Insitu Gold (koz)
Total Oxide	**310**	**1.39**	**14**	**2,446**	**1.15**	**91**	**504**	**1.15**	**19**
Sulphide - Upper	1,717	**2.38**	131	3,666	1.84	217	1,943	1.58	99
Sulphide - Lower	29	**5.17**	5	4,486	5.42	782	1,823	5.20	305
Total Sulphide	**1,746**	**2.42**	**136**	**8,152**	**3.81**	**999**	**3,766**	**3.33**	**403**
Total Oxide & Sulphide	**2,056**	**2.27**	**150**	**10,598**	**3.20**	**1,089**	**4,270**	**3.07**	**422**

Notes:

Mineral Resources are reported exclusive of Mineral Reserves.

The lower cut-off grades applied are 0.5g/t Au for oxide, 0.8g/t Au for near-surface sulphide mineralisation above 5050mRL (approximately 100m below surface), which is considered to be potentially open-pittable. Below 5050mRL a lower cut-off grade of 3.0 g/t Au is applied.

Mineral resources are rounded to 1,000 tonnes, 0.01g/ t Au and 1,000 ounces. Minor discrepancies in summation may occur due to rounding.

Table 2:   Summarised Fosterville Ore Reserves at December 2012

Classification	Proven			Probable			Total		
	Tonnes (kt)	Gold Grade (g/t)	Insitu Gold (koz)	Tonnes (kt)	Gold Grade (g/t)	Insitu Gold (koz)	Tonnes (kt)	Gold Grade (g/t)	Insitu Gold (koz)
Underground (UG)									
Phoenix	163	4.50	24	798	4.92	126	961	4.85	150
Harrier	81	4.73	12	317	4.39	45	398	4.46	57
Total Underground	244	4.59	36	1,115	4.77	171	1,359	4.74	207
Tailings									
CIL	343	8.90	98	0	0.00	0	343	8.90	98
Total UG & Tailings	**587**	**7.10**	**134**	**1,115**	**4.77**	**171**	**1,702**	**5.57**	**305**

Notes:

The Mineral Reserve estimate used a gold price of A$1450/ounce and cut-off grades applied varied depending upon width, mining method and ground conditions.

Dilution of 5%-30% and mining recovery of 70%-100% were applied, dependent upon mining method.

Mineral Reserves have been rounded to 1,000 tonnes, 0.01 g/t Au and 1,000 ounces. Minor discrepancies in summation may occur due to rounding.

CIL tailings are stated as contained ounces. Recoveries of 25% are expected and are based on laboratory test work and operating performances.

Future Exploration

The Fosterville mine lease has significant gold resources (1.54Moz) and there are abundant exploration opportunities, both on lease and in the district that could potentially supply mill feed to the current operation in the future.

On the mine lease the Harrier and Phoenix mineralised systems are open down plunge and both offer exploration opportunities. The changing Phoenix system down-plunge geometry highlights the need for future geological work to recognise variations in fault architecture and positions of mineralisation that might exist within multiple segments of a fault. The recent understanding of the Benu resource area, down dip of Phoenix, indicates exploration potential exists up-plunge of this area. One of the future challenges, and no different to many underground mines, will be to create suitable and timely underground drill platforms to ensure drilling to mineralised structure angles are favourable.

Within the Fosterville mine lease there is also potential to deepen parts of existing oxide pits for sulphide hosted gold in the Robbin's Hill - O'Dwyer's area as well to explore for extensions and new trends of gold mineralisation beneath the cover sediments. The Robbin's Hill - O'Dwyer's area was significant during the oxide gold production phase, contributing approximately 134koz of gold, which was almost half of all the oxide gold produced from the entire Fosterville area.

In the Fosterville district and within exploration licences held by Fosterville Gold Mine, there are several interpreted and mapped faults that occur in hangingwall of the Redesdale Fault, with trends that are similar to the Fosterville Fault and have isolated Fosterville-style gold occurrences close to them (Figure 2). Portions of several faults are highlighted by existing surface geochemistry, whilst other parts are masked by shallow cover. In areas of Murray Basin Sediments cover there is potential in the future to use ground geophysical (IP) and soil geochemical techniques to focus exploration drilling towards discover of new trends of Fosterville-style gold mineralisation.

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The author acknowledges the past contributions of many Geologists and other technical disciplines who have worked at Fosterville under varied corporate ownerships of the Fosterville Gold project. The maintaining of a concerted multidisciplinary approach, encompassing exploration, mining and processing aspects will be important to ensure the Fosterville mining project continues well into the future.

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METALLOGENESIS IN NEW SOUTH WALES: NEW (AND OLD) INSIGHTS FROM SPATIAL AND TEMPORAL VARIATIONS IN RADIOGENIC ISOTOPES

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Abstract

Analysis of the distribution patterns of Pb isotope data from mineralised samples using the plumbotectonic model of Carr et al. (1995) indicates systematic patterns that reflect major metallogenic and tectonic boundaries in the Lachlan and Delamerian orogens in New South Wales and Victoria. This distribution pattern accurately maps the boundary between the Central and Eastern Lachlan. The Central Lachlan is characterised by Pb isotope characteristics with a strong crustal signature, whereas the Eastern Lachlan is characterised by a variable signature. The Macquarie Arc is dominated by Pb with a mantle signature: known porphyry Cu-Au and epithermal Au-Cu deposits in the arc are associated with a zone characterised by the strongest mantle signatures. In contrast, granite-related Sn deposits in the Central Lachlan are characterised by the strongest crustal signatures. The Pb isotope patterns are broadly similar to Nd isotope model age patterns derived from felsic magmatic rocks, although a lower density of Nd isotope analyses makes direct comparison problematic.

Comparison of Pb isotope data from the Girilambone district (e.g., Tritton, Murrawombie and Avoca Tank deposits) with that from the Cobar district in north central New South Wales indicates a less radiogenic signature, and probably older age, for deposits in the Girilambone district. Hence, a syngenetic volcanic-hosted massive sulphide origin for these deposits is preferred over a syn-tectonic origin. The data are also consistent with formation of the Girilambone district in a back-arc basin inboard from the earliest phase of the Macquarie Arc.

Introduction

Although radiogenic isotope systems are most widely used as geochronometers, several of these systems can also be used to trace tectonic and metallogenic processes. For example, the Rb-Sr, Sm-Nd and U-Pb systems have been used to map the extent of Proterozoic crust in western North America (Kistler and Peterman, 1973; Bennett and DePaolo, 1987; Wooden and DeWitt, 1990), and in the Yilgarn Craton of Western Australia, Champion and Cassidy (2008) used Nd isotope model ages to map the distribution of major crustal boundaries as well as internal domains of relatively juvenile crust. Huston et al. (2013) have shown that Nd model age maps and analogous maps showing variations in μ ($^{238}U/^{204}Pb$: a parameter calculated from Pb isotope data) can be used to define more prospective zones for volcanic-hosted massive sulphide (VHMS: juvenile zones) and komatiite-associated nickel sulphide deposits (more evolved zones) in Archean provinces. More recently, Champion (2013) used Nd data from granites and felsic volcanic rocks to create a national-scale Nd model age map for Australia, which images fundamental boundaries of crustal blocks that make up the continent.

Given the utility of radiogenic isotopes in identifying different crustal domains and, in some cases, discriminating zones of higher metallogenic endowment in some terranes, this contribution presents a Pb isotope map for the Lachlan and Delamerian orogens in New South Wales and Victoria. Additionally, we compare this map to the existing national-scale Nd model age map and with the distribution and metallogeny of major mineral deposits.

In addition to tracing tectonic and metallogenic processes, Pb isotope data can also assist in resolving specific questions related to ore genesis. An example of this is the origin of Cu deposits in the Girilambone district (e.g., Tritton project) in north-central New South Wales. Initially, these deposits were interpreted as syngenetic VHMS deposits (Carr et al., 1995), but Fogarty (1998) reinterpreted the origin as syn-tectonic, using the nearby Cobar district as an analogue. Since then, Jones (2012) has re-invigorated the VHMS interpretation, using geological relationships to (re)propose a VHMS origin. This contribution presents new, high precision lead isotope data from both the Cobar and Girilambone districts, and then uses these data, along with geological observations, to distinguish between the two alternative interpretations of mineralisation in the Girilambone district.
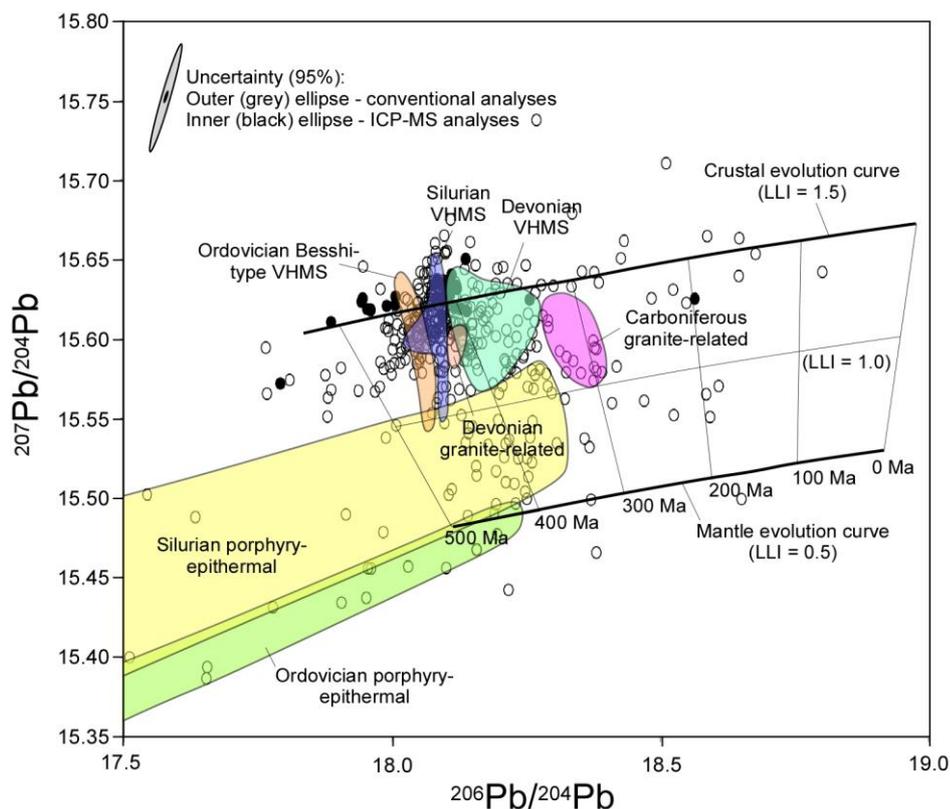
Figure 1. ^{206}Pb/^{204}Pb versus ^{207}Pb/^{204}Pb diagram showing representative lead isotope compositions of mineral occurrences and deposits in the Lachlan and Delamerian orogens of southeastern Australia. Criteria used for selecting representative samples are described in the text. Errors associated with conventional and higher precision ICP-MS analyses are shown in the upper left.

A lead isotope map of the Lachlan and Delamerian orogens

In a landmark paper, Carr et al. (1995) demonstrated that the evolution of Pb isotopes in the Lachlan Orogen can be modelled as mixing between mantle and crustal Pb sources (Figure 1). Model ages calculated from this Pb evolution model closely match (within 15 million years) mineralisation ages established using independent geochronometers (Carr et al., 1995). Given the success in using Pb isotopes to map major crustal boundaries and define mineral potential, we have used the Carr et al. (1995) evolution model, the extensive CSIRO Pb isotope database and new high precision Pb isotope analyses to produce a map showing geographical changes in Pb isotope characteristics (Figure 2).

Methods of data analysis

The CSIRO Pb isotope database contains thousands of individual analyses from mineralised rocks, with multiple analyses from most deposits. To select the best representative analysis for each deposit, the CSIRO database and the more recent high-precision analyses were culled using the following rules:

> (1) higher precision ICP-MS data were preferred over lower precision conventional data,
> (2) high-lead analyses (i.e., galena-rich or >1000 ppm Pb) were preferred over low-lead analyses as they are more likely to indicate initial ratios, and
> (3) least radiogenic analyses were preferred.

This resulted in 438 different sample points for possible inclusion in the regional Pb isotope map.

Because the Pb evolution in the Lachlan and Delamerian orogens is the result of mixing from two Pb sources (Carr et al., 1995), the method of calculating variations in μ, as used in Archean terranes, is not appropriate. Rather, the model must incorporate mixing between the mantle and crustal evolution curves. Mernagh (2008) and Mernagh and Glen (2008) used a graphical method of estimating the relative proportion of mixing between the two lead sources, assigning samples along the mantle growth curve a value of zero and samples along the crustal growth curve a value of one (see Figure 1), with other samples having values of between 0.0 and 1.2, depending on their relative position to these curves (samples with values above 1.0 plotted above the crustal growth curve). Because of the labour intensity of graphically estimating this parameter, Mernagh (2008) and Mernagh and Glen (2008) determined the mixing ratio for a limited number of samples.

We have modified the approach of Mernagh (2008) and Mernagh and Glen (2008) slightly. First of all, we assigned samples along the mantle curve values of 0.5 and samples along the crustal growth curve values of 1.5. Values of other points were calculated by interpolation between the curves and extrapolations outside the bounds of the curves. This method removed (with one exception) negative values, which were possible using the Mernagh method as a number of analyses fall below the mantle growth curve. In addition, we developed a digital method of calculating these values, which we term the Lachlan lead index (LLI). With the exception of one negative value of -2.43 and three undefined results, the LLI ranged from 0.01 to 2.27. When invalid points and points lacking location information were excluded (leaving a total of 414 valid points), LLI values were contoured using ArcMap®. Because in areas of low sample density, the contouring package in ArcMap® can produce artefacts, a mask was applied over areas lacking data points.

Results

Figure 2 shows the spatial distribution of the LLI. High values (>1) indicate a dominant crustal contribution, whereas low values (<1) indicate a significant mantle contribution. The LLI shows a number of consistent patterns, many of which relate to known metallogenic and tectonic features:

> (1) A gradient in LLI values closely corresponds to the boundary between the Eastern Lachlan and Central Lachlan domains (c.f., Glen, 2013). The Central Lachlan is characterised by higher LLI, indicative of a greater crustal component. The Eastern Lachlan is characterised by lower, but more variable LLI.
> (2) Within the Eastern Lachlan, the lowest LLI values are associated with the Ordovician Macquarie Arc. This is consistent with a significant mantle component for these rocks (c.f., Crawford et al., 2007; Glen et al., 2007). However, the very easternmost parts of the Macquarie Arc are characterised by Pb with a crustal signature.
> (3) Late Ordovician to early Silurian aged porphyry Cu-Au (Northparkes, Cadia and Copper Hill) and temporally-related epigenetic Au deposits (Gidginbung and Cowal) are spatially associated with zones of lowest LLI, as is the slightly younger

Mineral Hill deposit. This indicates a mantle-like Pb source, consistent with the results of Carr et al. (1995). The Pb isotope map has identified a small zone of very low LLI at coordinates 148.2°, -34.6° that is well removed from known exposures of Macquarie Arc rocks, although ultramafic to intermediate volcanic rocks of Ordovician age or older are known in the area.

(4) Granite-related Sn deposits of different ages (e.g. Ardlethan and Doradilla) appear to be associated with a zone with crust-dominated Pb that largely corresponds with the Central Lachlan (Wagga-Omeo Zone). This zone extends southward into east-central Victoria.

(5) Volcanic-hosted massive sulphide deposits and lode gold deposits do not appear to have a consistent pattern relative to the distribution of LLI. If anything, the VHMS deposits seem to be associated with zones characterised by higher LLI and, therefore, more crustal Pb. This differs to the Archean, where VHMS-rich provinces are more closely associated with more juvenile Pb (Huston et al., 2013).

(6) Lead isotope data from Cambrian VHMS and Devonian granite-related deposits in western Tasmania are significantly more radiogenic than data from equivalent aged rocks in the Delamerian Orogen (e.g., Stavely and Koonenberry belts), which has implications to proposed correlations of western Tasmania with the western Tasman Element on mainland Australia.

(7) Comparison of the LLI map with the Nd model age map of Champion (2013) indicates a broad correspondence, although the lower sample density in the latter map makes detailed comparison difficult.
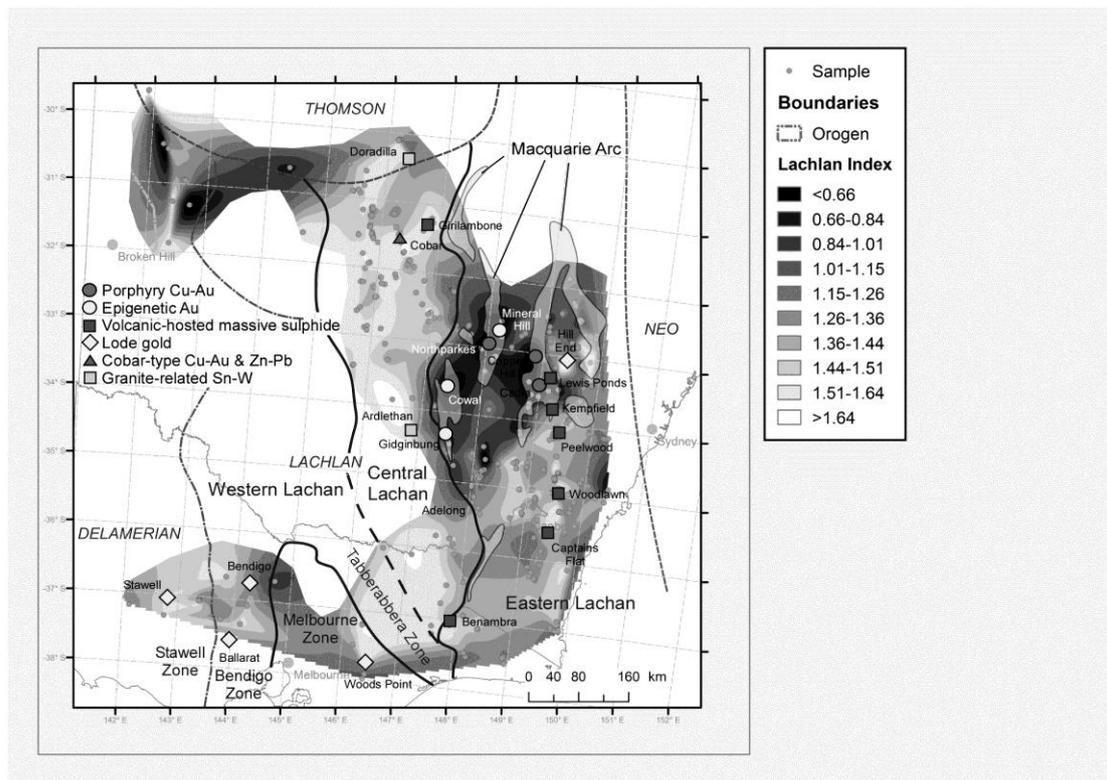
Figure 2. Map showing variations in the Lachlan lead index in the Lachlan and Delamerian orogens of southeastern Australia. The definition of the LLI is discussed in the text, as well as the method used to calculated it from Pb isotope data. The diagram also shows major orogen and zone boundaries as well as the location of important mineral deposits discussed in the text. NEO indicates the New England Orogen.

The origin of copper-rich massive sulphide deposits in the Girilambone district

As discussed in the introduction, the origin of deposits in the Girilambone district to the east of Cobar in north-central New South Wales is controversial, with some workers advocating a syngenetic, VHMS origin (Carr et al., 1995; Jones, 2012), and others advocating a syn-tectonic origin (Fogarty, 1998; Erceg, 2008) consistent with that proposed for the nearby Cobar district (see Figure 2 for locations). The deposits, of which Tritton is the most significant, consist of semi-massive to massive, pyrite-rich bodies hosted by the Ordovician, turbidite-dominated, Girilambone Group. In detail, the deposits are spatially associated with basaltic volcanic rocks with MORB-like geochemical signatures (Burton, 2011). Paleontological data from the Girilambone Group (Iwata et al., 1995) suggests an Early Ordovician age, which is consistent with the youngest detrital zircon ages from this unit of ~480 Ma (Fraser et al., in prep.). This age is supported by more recent conodont biozonation data collected as part of the ongoing Geological Survey of New South Wales Cobar Region Geological Mapping Project (P. Gilmore, pers. com., 2013).

As the Pb isotope evolution of the Lachlan Orogen is well modelled using the evolution model of Carr et al. (1995), a series of Pb-rich (i.e., > 1000 ppm Pb) samples from the Tritton, Murrawombie, Avoca Tank and nearby prospects were collected for high precision Pb isotope analysis using ICP-MS methods. These data are compared with high precision analyses of Pb-rich material from the Cobar district. As only Pb-rich (and U-poor) samples were analysed, the resulting data should indicate initial ratios. In addition to showing the comparison between the two districts, Figure 3 shows a modified Cumming and Richards (1975) Pb evolution model pinned to the least radiogenic Endeavour (previously named Elura) analysis. Based on ^{40}Ar-^{39}Ar analysis of muscovite associated with ore-related alteration zones, the Endeavour deposit is thought to have an age of ~384 Ma (Glen et al., 1992; Perkins et al., 1994), which was used as the age pinning point.
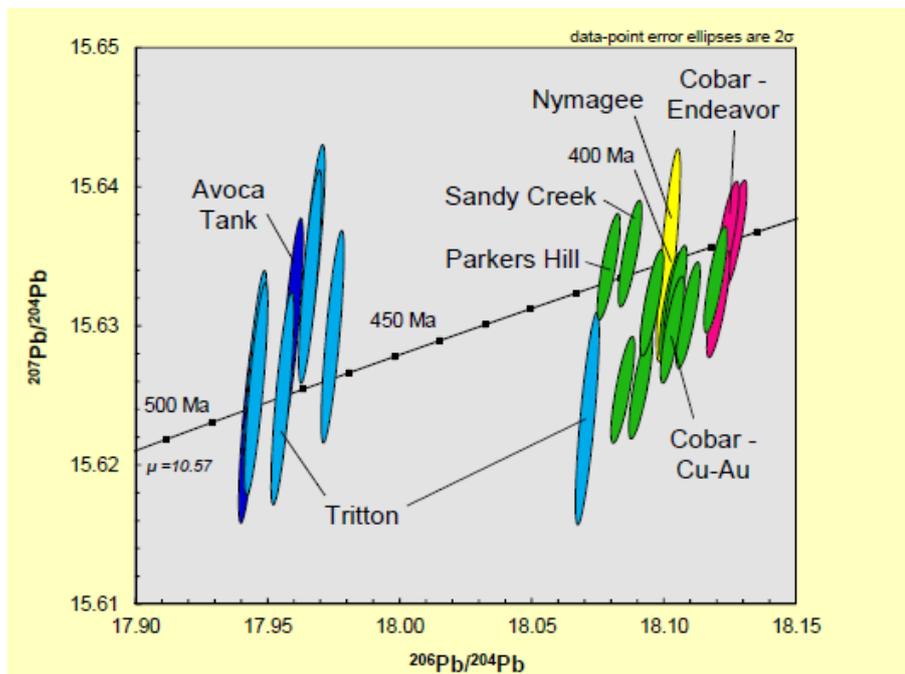
Figure 3. ^{206}Pb/^{204}Pb versus ^{207}Pb/^{204}Pb diagram showing variations in high precision ICP-MS analyses of Pb-rich samples from the Cobar and Girilambone districts. The ellipses indicate the 95% confidence errors associated with the analyses. The diagram also shows a modified Cumming and Richards (1975) Pb evolution model (ε = 0.046035 × 10^{-9}; μ = 10.57) from which model ages of mineralisation were estimated (see text for discussion).

The resulting Pb isotope evolution model gives ages of between 410 and 390 Ma (Figure 3) for Cu-rich deposits in the main Cobar field, consistent with independent [40]Ar-[39]Ar ages from ore-related mica of 405-400 Ma (Glen et al., 1992; Perkins et al., 1994). Lead isotope model ages for Pb-rich samples from the Tritton and Avoca Tank deposits range from 490 to 470 Ma, which overlaps the age of the Girilambone Group as determined from fossil assemblages and from detrital zircon maximum depositional ages.

Based on the Pb isotope data, our favoured interpretation for the age of the Tritton and Avoca Tank deposits is ~480 Ma, and, therefore, we interpret a syngenetic VHMS origin for the deposits, although it is likely that there has been remobilisation of the ore constituents during later deformational events. Evidence for such remobilisation is present in one analysis from the Tritton deposit (Figure 3), which has similarities to Cobar data. A primary syngenetic interpretation is also consistent with the recognition of massive sulphide clasts in conglomeratic facies of the Girilambone Group (Jones, 2012; Gilmore et al., in prep.), the observation that the Tritton ores have a similar deformation history to the surrounding sedimentary rocks, and similarities between the trace element composition of Tritton pyrite and pyrite from VHMS deposits from the Mount Windsor volcanic belt (Gilmore et al., in prep.).

The ~480 Ma age is similar to the age of VHMS deposits in the Mount Windsor volcanic belt and the Balcooma Metamorphics in north Queensland (c.f., Champion et al., 2009). It is possible that the Girilambone deposits formed in an inboard back-arc basin during the early development of Macquarie Arc. This interpretation is consistent with the association of the interpreted VHMS deposits with MORB-like basalt (Burton, 2011) and the presence of detrital zircons in the Girilambone Group with ages similar to the first phase of magmatism in the Macquarie Arc (cf., Glen et al., 2007).

Conclusions

Lead isotope data from mineral deposits in the Lachlan and Delamerian orogenies have been used to generate a map showing the relative importance of mantle versus crustal sources for the Pb using the Pb evolution model developed by Carr et al. (1995). Systematic patterns in the data are present that can be related to tectonic and metallogenic features:

(1) Lead isotopes effectively map the boundary between the Eastern and Central Lachlan.
(2) Lead in the Macquarie Arc is has a major mantle component, whereas lead in the Central Lachlan is crust dominant.
(3) Ordovician-Silurian porphyry Cu-Au and epithermal Au-Cu deposits are spatially associated with the most mantle-dominant lead, whereas granite-related Sn deposits of various ages are spatially associated with the crust-dominated Central Lachlan (Wagga-Omeo Zone). Other types of deposits do not have a specific association with lead isotope characteristics, although VHMS deposits tend to be associated with crust-dominated zones.
(4) Although there is a broad correlation between the Pb isotope data and Nd model ages established from magmatic rocks, the low data density for the Nd map makes direct comparison problematic.

New high precision Pb isotope data suggest that Cu-Au massive sulphide deposits in the Girilambone district (e.g., Tritton, Murrawombie and Avoca Tank) have a similar age to the enclosing Girilambone Group, and, therefore, are interpreted as VHMS deposits. These deposits are similar in age to VHMS deposits in north Queensland. The Girilambone deposits may have formed in a back-arc basin associated with the early evolution of the Macquarie Arc.

Acknowledgements

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MODELS AND EXPLORATION METHODS FOR OROGENIC DEPOSITS IN THE GIRILAMBONE BASIN

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Key Words: Gold, Arsenic, Antimony, Copper, Girilambone Project, Canbelego Copper Mine, Caballero Prospect, Battery Tank Goldfield, Sunrise Prospect, Good Friday Prospect, Boundary Prospect, Amity's Reward Prospect.

Abstract

The Girilambone Project (GP) covers ~2,963km^2 of granted exploration tenure in two corridors. The Western Girilambone Project (WGP) extends for ~50km along the Kopyje Shelf immediately east of the Cobar Basin. The Eastern Girilambone Project (EGP) comprises a series of semi-contiguous tenements covering Early Ordovician Girilambone Group rocks from north of Girilambone and south of the Barrier Highway toward the township of Tottenham (**Figure 1**).

GIRILAMBONE PROJECT (Figure 1)
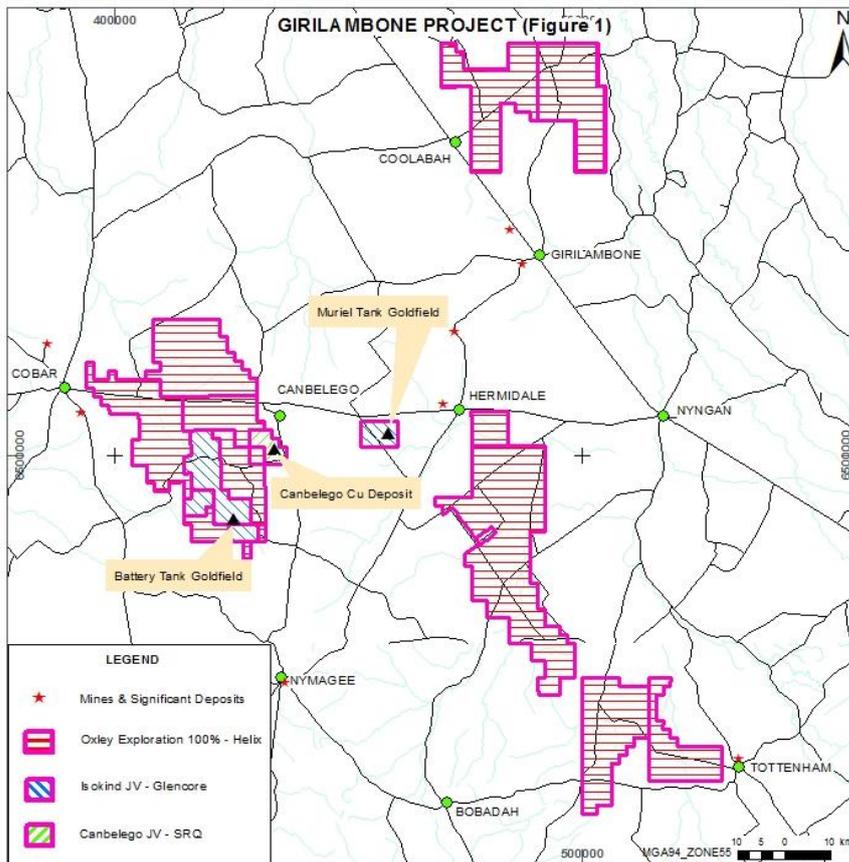
Helix have developed exploration methods specific to mineralisation models for Copper and Gold in the Cobar District. In three years Helix have defined two maiden JORC inferred mineral resources on the WGP; Canbelego Copper Prospect (1.5Mt @ 1.2% Cu) and Sunrise/Good Friday Gold Prospects (2.6Mt @ 1.2g/t Au) and identified numerous new prospects over the wider GP. The prospects are green-field discoveries often with no clear evidence for historical or more modern exploration activity in their vicinity.

Sub-crop and proximal float samples from the new prospects yield anomalous to highly mineralised surface samples including results of >10g/t Au and >0.4% Cu in rock chips and >0.3% Cu and >0.5g/t Au in soil samples.

Gold and copper mineralised areas identified on the GP display geological characteristics consistent with early low sulphidation epithermal and VMS mineralising environments. Late-stage mineralisation and associated overprinting structural fabrics, alteration and sulphide mineralisation styles are more typical of settings transitional between low sulphidation epithermal and orogenic styles. Structural features which characterise the identified areas of mineralisation are evident on regional to detailed magnetic imagery as an association of faults and shear zones. Localising controls are represented by the intersection and reactivation of these structures. This setting has resulted in pipe-like shoot controls common in "lode" Au/Cu mineralised districts. In the Cobar district much mineralisation of this character is commonly referred to as "Cobar-Style".

Historical mining and prospecting activity on the WGP has tended to concentrate on the Silurian to Devonian rocks of the Meryula Syncline for "Cobar Style" copper+/-gold mineralisation. Modern exploration has also taken place in the more immediate area of historical workings on the Battery Tank Goldfield, Canbelego Copper Deposit and the Muriel Tank Goldfield which are all hosted in inferred Ordovician Girilambone Group rocks.

Minimal on-ground historical exploration has taken place on the EGP as a result of the presence of more variable thicknesses and types of transported regolith cover which obscures most traces of sub-cropping copper mineralisation such as that which attracted historical prospectors to the areas currently or historically mined along strike at Girilambone, Tritton, Budgery and Tottenham.

Helix has succeeded in locating several new, green-field prospects relatively quickly, benefited by the "orientation" opportunity provided by initial work on the Battery Tank Goldfield and the Canbelego Copper Mine Prospect.
Combined with a regional exploration skill-set this has focussed area selection outside of the more common historical prospect focussed approach using target appropriate sampling and assessment methods transferred from the initial "orientation" areas.

Exploration Models and Mineralisation Characteristics

Copper Mineralisation
The Canbelego Copper Mine Prospect (1.5Mt @ 1.2% Cu – 18,000t) and the nearby Caballero Prospect are hosted in turbidite sediments inferred to be Ordovician Girilambone Group rocks. The rocks contain a substantial volcanogenic component and the bulk composition of the rocks suggests a likely acid (dacite to rhyolite) source (Cowan, 1977, Woodland, 1978). Rare rhyo-dacite tuff beds are found in sediments in the mineralised corridor (Mason, 2012). Differentiated mafic to ultramafic intrusive occurs as dyke-like and more commonly pipe-like bodies at numerous sites along the strike of the prospective sequence. Although inferred to be hosted in Ordovician in age rocks, the structural setting, bulk composition of the volcanogenic facies (includes emergent to sub-aerial volcaniclastics along strike to the north), along with a close proximity to rocks of the Canbelego-Mineral Hill Synclinorial Zone suggests that the sequence could represent a remnant of Silurian volcanic derived facies.

Eleven diamond core holes completed at Canbelego Copper Mine during the 1970's are stored at the W B Clarke Core Library. Descriptions of the core note multiple cycles of coarse clastics (tuffaceous sandstone/wacke) to fine grained epiclastics (siltstones and carbonaceous shales) as debris/turbidite flows (Cotton & Pyper., 1977, Woodland, 1978). Numerous units, particularly the finer grained intervals, contain abundant leucoxene and disseminated sulphide (py +/- cpy, po, sp, ga).

These units may provide a localised source of both sulphur and metals to be remobilised into the base-metal rich sulphide matrix breccia lodes during later deformation. Early alteration associated with the mineralised sequence is rich in dark (Fe?) chlorite with a well-developed enveloping zone of silicification. Silicification is also a common feature of the more intensely copper mineralised zones. The historically mined copper mineralisation is hosted in shear and breccia lodes focussed in zones of ~340°G striking continuous cleavage which dip steeply to the west and are surrounded by disseminated, stringer "knotty" shear hosted mineralisation on reactivations of the more widely prevalent 320°-330°G foliation trend. Mineralisation is preferentially hosted in tuffaceous chloritic shales and along shale contacts transitioning into sandstone/wacke (Woodland, 1978). Quartz/chlorite/calcite alteration is well developed in association with the sulphide matrix breccia veins. The main historical lode position has marked asymmetric development of chlorite alteration suggestive of this hosting structure being a basal failure structure with historical workings and "mine type" alteration being more widely developed to the west (hanging-wall) of this feature. Quartz/albite tension veins with pyrite, chalcopyrite, ankerite and rare iron poor sphalerite as selvages and as disseminations within the veins are common over a wide area peripheral to the mineralisation. These veins are often transposed by later shears which are defined by sericite alteration on shear planes with pervasive sericite halos where most strongly developed. Traces of crustiform and colloform quartz/sulphide/carbonate breccia veins have been noted at Canbelego Copper Mine Prospect and at the Epithermal Vein Prospect approximately 6km along strike to the north-west.

The Caballero Prospect is located 2.4km to the south of the Canbelego Copper Mine Prospect. The poorly exposed mineralisation is analogous to Canbelego with respect to lithotypes, structural setting and mineralisation styles. The peak of soil anomalism (0.3% Cu) is six times higher than the maximum Cu in soils result returned at the Canbelego Copper Mine Prospect. A fixed-loop EM conductor plate modelled at Caballero covers twice the strike length at a higher EM model conductance (50S) than at the Canbelego Copper Mine Prospect (30S). End-of-hole soil auger rock chips indicate the presence of micro-gabbro intrusive to the immediate east and chlorite altered volcanogenic sediments which contain iron oxide along foliation and as disseminations after sulphide. Drill testing and down-hole EM surveying is underway at the Caballero Prospect.

Gold Mineralisation
The Battery Tank Goldfield (Sunrise/Good Friday Resource 2.6Mt @ 1.2g/t Au – 100,000Ozs) is hosted within turbidite sequence. Sub-vertical and shallow dipping strataform components are present in the gold mineralisation. Mineralisation is best developed in the silicified siltstone and sandstone dominant components within a broader turbidite sequence which transitions from carbonaceous shales to coarse grained wacke (**Figure 2**).

(Figure 2)

Sunrise Prospect
Section 13150N

Sst/Slt = Inter-bedded sandstones and siltstones
Sh/Slt = Inter-bedded shales and siltstones
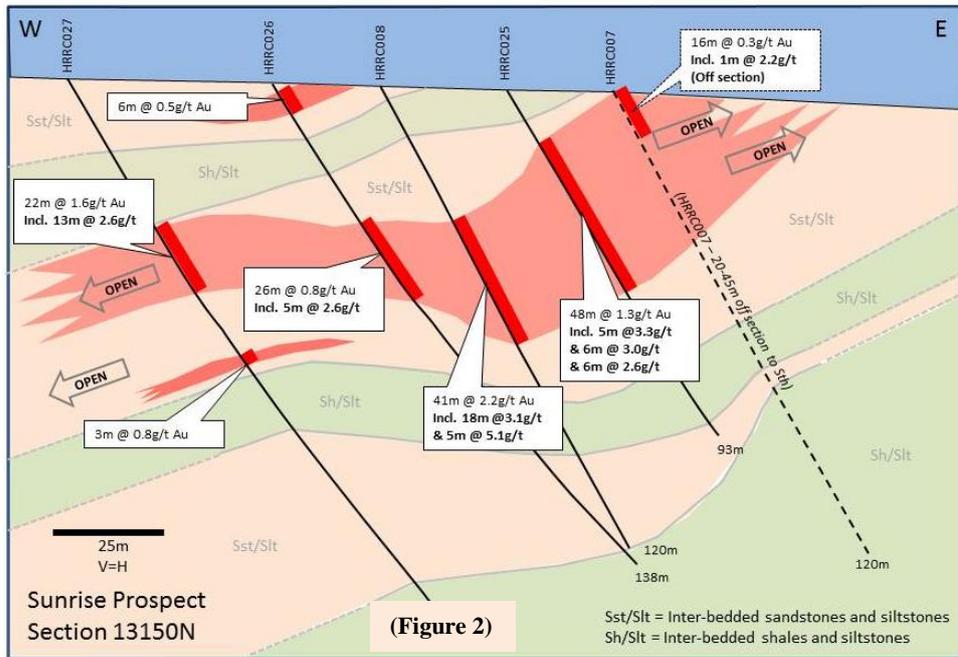
Silcification is early relative to the apparent gold mineralising phase but is a consistent feature at all prospects.

Niche sampling results indicate an association of gold mineralisation with clay/sericite/pyrite alteration on shear planes/slickenside steps, fractures, crackle veins and as disseminations surrounded by a sericite outward to clay alteration selvage within the broader silicified zones rather than with quartz veining or selvages associated with the quartz veins. This correlation is supported by assays and logged alteration and veining in drilling.

The mineralisation may have similar character to that identified at the Pearse and Pearse North Prospects at Mineral Hill (Johnston, pers comm, 2012, Johnston, 2013). Trace crustiform quartz sulphide veins have been noted as lag and drill chips in the south of the Sunrise Prospect.

The Battery Tank Goldfield mineralisation is silver and base metal poor, although local weakly anomalous lead and zinc have been detected in some areas. Drilling to date has largely been in the oxide to transitional zone. Weathering may have resulted in redistribution of some primary element associations such as silver.

Gold assays of drilling samples are routinely repeated by screen fire assay (75um mesh) for any fire assay result >/= 5g/t. Analysis of the screen fire assay work indicates that there is a low nuggety gold effect for the Battery Tank Goldfield Prospects. A comparison between 75um and 100um mesh for screen fire assays suggests a more consistent repeatability relative to fire assay results using a 75um mesh and indicates that larger gold particles are commonly between 75um and 100um in size. By comparison, historical explorer reports of poor gold assay repeatability on the Muriel Tank Goldfield suggest the presence of considerable nuggety gold. This conclusion is supported by the presence of visible gold in hand samples and is compatible with the quartz vein and selvage hosted mineralisation styles historically mined on the Muriel Tank Goldfield.

Gold mineralisation at Battery Tank Goldfield has a strong Au/As/Sb association. Antimony geochemistry in particular, is very effective at identifying areas of hydrothermal sulphide associated with the development of the silica/clay/sericite alteration within and surrounding shears over a much wider area than the potentially economic Au mineralisation. Despite the strong geochemical associations, domaining of geochemistry by the underlying geology is an important targeting step.

The effect of volcanism and hydrothermal remobilisation of disseminated volcanogenic mineralisation in the Silurian-Devonian rocks typically presents a substantially higher geochemical background for elements such as Sb, Bi, Cu, Pb, Zn and Ag with respect to the Ordovician rocks on the WGP. Hydrothermal remobilisation of sulphide with increasing proximity to the Silurian-Devonian rocks of the Meryula Syncline (100's of metres) is inferred to be the cause of an increase in background for the above elements in association with mineralisation around the Amity's Reward Prospect.

Historical mining at the Battery Tank Goldfield focussed on fold culminations, particularly antiforms, at the intersection of ~340˚G-350˚G reactivated cleavage with the 320˚G-330˚G dominant foliation. Overprinting foliation and faulting on ~060˚G strike is evident particularly at the Good Friday Prospect. The gold mineralisation is not consistent with quartz vein occurrence or density but does often coincide with 340˚G/350˚G structure containing multi-generation quartz tension veins that correspond with the larger of the historical workings within the Battery Tank Gold Field. Mining of silicified rock down fold limbs as opposed to quartz veins has occurred in historical workings at the Reward Prospect. Some suggestion of a gentle northerly plunge to mineralisation at the Reward Prospect is indicated by the historical mining development at that site.

Regional cues to mineralisation are the presence of local 340˚G to 010˚G cleavages and shears within the broader regional 310˚G to 330˚G foliation fabric. Northeast trending faults/shears result in zones of locally developed crenulation cleavage (chevrons) axis striking 010˚G to 060˚G and are diagnostic of areas where various earlier fabrics have been reactivated by compression from the E and SE at the regional scale localising the shear hosted mineralisation particularly where earlier structure has been compartmentalised or bracketed by several of these shears in close proximity. An association of mineralisation with early, deep tapping structure on a ~290˚G (Lachlan Traverse Zone and equivalent structure) is visible in magnetic imagery and presents circumstantial evidence supporting the development of zones of pipe like fluid flow propagating vertically through the sedimentary pile over several periods of deformation.

Within the Silurian-Devonian volcanogenic systems (including the surrounding re-sedimented debris), Antimony geochemistry is extremely effective for locating the fringing deposits of re-sedimented tuffaceous sediments, marls and exhalative facies in zones which are often a focus for later structure development and reactivation around the rigid blocks presented by the coherent volcanic facies and temporally associated alteration. Hydrothermal sulphide deposited in the sediment apron along with hydrothermally supported biogenic sulphur metabolising activity provide a very fertile metal source for the development of a host of proximal to distal gold/base-metals mineralisation styles (Mason, 2012). Within and proximal to tuffaceous and marly units, fold culminations and re-orientations of structure have a range of tensional quartz vein array and sulphide matrix breccia styles of base metal mineralisation in the WGP (eg Canbelego Copper Mine Prospect, Caballero Prospect, The Lease Prospect, Black Range Mine Prospect) transitioning toward more "typical" Cobar Style mineralisation where in the right structural setting. Similar features are identified in the region of the EGP overprinting and surrounding the VMS systems (McQueen, 2008)

Mineralisation at the Muriel Tank Goldfield is of two general styles;

i: within, and as a laminated quartz vein selvage to blue-black vuggy quartz veins

ii: as silica/sericite/sulphide crackle veins in crenulated turbidite sequences.

Rocks at Muriel Tank comprise of turbidite sediments which grade from black shale and chert to quartz wacke and quartz-feldspar wackes. Leucoxene is abundant in mineralised rocks at Golden Horseshoe and Browns Hope Prospects suggesting a

possible distal volcanogenic input of pre-cursor minerals into the sediment pile. Chlorite alteration of wall-rocks is strongly developed peripheral to the more significant historical prospects such as Golden Horseshoe and Browns Hope.

The blue-black quartz veins often display polyphase laminated quartz vein development at their margins. Slivers of chloritised wall rock define the margins of the vein phases. A silica/chlorite altered wacke unit is evident in the inferred footwall to the Golden Horseshoe and Browns Hope Prospect areas with similar alteration also seen over a broad area in coarse grained units intersected at depth at the north end of the Sunrise Prospect on the Battery Tank Goldfield.

Well-developed linear fault/shear structures, splays and bends of this structure are evident as zones of de-magnetisation on aeromagnetic imagery in the area of the Muriel Tank Goldfield. Structural setting, mineralised vein morphology, alteration zoning and the nuggety distribution of gold in veins are features that are consistent with "classic" orogenic gold mineralisation models.

Local focus for mineralisation at Golden Horseshoe and particularly at the Browns Hope Prospect is evident as the convergence of regional shears horizontally and vertically around domains of rigid silica/chlorite altered sandstones and wackes near the inferred base of the folded local stratigraphic sequence.

Exploration Methodologies

The WGP has generally <1m of transported material on variable preserved weathering profiles which have a well-developed soil profile, making the area amenable to rapid collection of shallow geochemical samples (McQueen, 2008). As a result, surface/near surface geochemistry has proven very effective for identifying and defining primary gold and copper mineralisation and associated alteration halos. This success has enables a transition reliably targeted Reverse Circulation drilling at an early stage in prospect advancement.

Helix utilise a minus 40 mesh sample of the B-C soil profile transition where developed on bedrock. This horizon is recognisable where the profile colour changes from red (haematite dominated) to yellow (goethite/manganese dominated). The rationale behind this approach is;

i: Consistent sample media, results are comparable (represent a single population as best as possible) & allowed identification of different geochemical backgrounds between Ordovician and Silurian-Devonian

ii: The selection of a finer fraction removes coarse silicate, oxide and rock grains and fragments minimising anomaly dilution and nugget effects

iii: The fine fraction concentrates iron oxy-hydroxide and manganese oxides associated with vein, fracture & disseminated sulphide weathering and iron/manganese redox interface concentrating effects

iv: Low sample weight=lower transport and handling costs with no significant difference in sample collection   time

If transported material is sampled the result is likely to be less representative of the bedrock geochemistry than a whole soil or coarse screened soil sample may have been. To allow assessment of this situation, Helix collects a representative sample of the coarse fraction in catalogued chip trays during the process to provide a record of the material sampled with the ability to assess the effectiveness of sampling and the character of material at sample sites containing geochemical anomalism.

The soil sampling assay methodology incorporates Aqua Regia digest, ICP finish for Au and a 4 Acid digest, ICP finish for As, Bi, Cu, Co, Fe, Mn, Ni, Pb, Sb, Zn.

The rationale behind this methodology includes;

i: A further reduction of silicate sample matrix dilution for Au by strong but "partial" sample dissolution

ii: MAD method allows incorporation of some lithogeochemical signal whilst providing high quality low level detection for Sb which is critical for detecting favourable areas for mineralisation

To date the selected method for geochemical sampling has provided a good geochemical signal for early stage decision making on anomaly quality and vectoring to near surface mineralisation. The use of Au, As and Sb in the form of an anomaly index for has proven effective in identifying coherent footprints for follow-up work.

For the EGP, variability in cover and shallow hydrogeological/regolith processes mean that the correct media may not be consistently present. Assessment of this is progressing to allow modification of the procedure as appropriate.

Portable XRF systems are being considered to speed up the search for the copper rich mineralized systems, particularly for the EGP. (Note: PXRF is not amenable for the Battery Tank Au style due to the lower detection limits for Sb being too high).

Conclusions

The character of the gold mineralisation that has been identified by Helix on the Battery Tank Goldfield and over the broader WGP has been successfully mined by historical prospectors. The nature of the mineralisation, particularly the controls and the wider presence of this style of gold mineralisation, has gone largely unrecognised.

Gold mineralisation on the Battery Tank Goldfield is shear hosted and is developed in zones where multiple generations of structure intersect and are reactivated with propagation of structure vertically through the sediment pile inducing pipe-like flow of mineralising fluids within the dominant ~330˚G "backbone structure". The character of gold mineralisation has features consistent with both low-sulphidation epithermal and orogenic models.

At the Muriel Tank Goldfield, gold mineralisation styles are more in keeping with "typical" vein hosted orogenic gold styles.

Copper mineralisation in the WGP has features consistent with VMS, low-sulphidation epithermal mineralisation however a structural overprint consistent with "Cobar Style" base-metal mineralisation represents the likely "high-grading" feature for potential ore grade mineralisation.

Sericite/clay shears bound and partly cross-cut the chlorite alteration at the Canbelego Copper Mine Prospect and highlight the wider presence of gold mineralising structure for styles similar to the Battery Tank Goldfield mineralisation elsewhere within the GP.

Acknowledgements

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FOUR EAGLES GOLD PROJECT: A VIRGIN GOLD DISCOVERY IN VICTORIA

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Abstract

Drilling during the past three years by Catalyst Metals Ltd has confirmed a new discovery of gold mineralization at Four Eagles totally concealed beneath Murray Basin sediments about 60 kms north of Bendigo. The initial aircore holes were drilled by Tom Burrowes (Providence Gold & Minerals) in 2010 and one hole intersected high grade gold mineralization. The size of the gold footprint is now about 6kms long by 2.5 kms wide but is still only delineated by very broad spaced drilling with very few holes testing below the oxide zone. The depth of the Murray Basin sediments varies from about 10 metres to 120 metres and shows an undulating Ordovician surface beneath. Within this footprint, at least three north south trending gold zones can be defined (Eagle 2, Eagle 3and Eagle 4) each of which contains high grade gold intersections of >10g/t Au, with values up to 150g/t Au.

Although the broad gold footprint and the parallel north south trending "Lines of Lode" are similar in size and shape to those seen at the Bendigo Goldfield, the nature of the mineralization at Four Eagles seems to be quite different. Four Eagles gold mineralization shows good sample repeatability suggesting that the gold is much more finely dispersed compared to the spectacular nugget gold at Bendigo. Even when high grades are encountered at Four Eagles, both coarse grained and fine grained gold is observed. The two areas however do lie in the same structural position west of the regional Whitelaw fault, which seems to have been very important in the formation of the large gold deposits at Bendigo (>22 million ounces of gold at ± 15g/tAu).

Within the gold trends, three prospects (Discovery, Hayanmi and Boyd's Dam) have been identified for further work and other areas west of the Whitelaw Fault will also require reconnaissance drilling. A very large programme of angled aircore, RC and diamond drilling will be necessary in the next few years to determine if continuous high grade gold resources can be established in these zones. Areas where the basement is less than 50 metres deep provide the greatest potential for open pittable reserves.

Much of the credit for this discovery can be attributed to Tom Burrowes (Providence) who explored with his own funds for 7 years before achieving success and Geoff Turner (EMS) who generated the structural targets that lead to the first gold intersections.

INTRODUCTION AND HISTORY

The Four Eagles Gold Project is located in Victoria about 60kms north of Bendigo between the towns of Mitiamo and Pyramid Hill. The area is held under exploration licence as a joint venture between Catalyst Metals Ltd ("Catalyst") and Providence Gold and Minerals Pty Ltd ("Providence"). The Principal of Providence, Tom Burrowes had commenced exploration in the area in 2003 but had little success until 2010, even though about 280 holes had been completed. The prospective Ordovician sequence at the Four Eagles Gold Project area is totally concealed by younger Murray Basin sedimentary rocks and has therefore had no prior mining or prospecting. In 2008, the Victorian Government published the gravity survey (Haydon, 2008) for the area which enabled the identification of the interpreted location of the regional Whitelaw Fault which appears to control the location of the Bendigo Goldfield, the source of 22 million ounces of historic gold production. This enabled the Project Geologist, Geoff Turner (EMS Consultants) to generate new targets just west of the Whitelaw Fault. Subsequent drilling in 2009 intersected several zones of low grade gold mineralization in the 0.2 to 1.0g/t Au range which on follow-up in 2010 produced a spectacular intersection of 6 metres @ 82.7g/t Au with abundant visible gold from 123 metres in drillhole FE328.

The joint venture was established with Catalyst in late 2010 and in the past three years, the size of the gold system has increased significantly and now contains at least three parallel ore zones up to six kilometres long. High grade gold intersections have now been recorded in three different prospect areas.

GEOLOGY

Surface geology at Four Eagles is essentially Late Tertiary to Quaternary Shepparton Formation, being a mottled grey (+brown, yellow, cream, orange) clay. The thickness of the Shepparton Formation is around 35 metres, but has recorded a maximum depth of 113 metres (hole abandoned in sands) in the western part of the tenement. Dirty yellow to orange quartz sands of the Calivil Sand have been noted in areas of thicker cover. The Shepparton Formation and Calivil Sand together comprise terrestrial (possibly estuarine) upper units of the Murray Basin sediments (Lawrence, 1975).

Basement lithologies form part of the Ordovician Castlemaine Group, being essentially sandstones and siltstones (or shales) of a regional turbidite sequence. Sandstones are generally medium grained, part micaceous (detrital mica) and massive. Bedding is rare, but measurable where observed in larger core pieces. The finer grained sediments (siltstone to shale) often present a strong cleavage. Regionally, the basement lithologies have been folded along a NNW trending fold axis (Cherry and Wilkinson, 1994).

The depth to the top of the Ordovician section is quite variable and ranges from about 10 metres in the north east to about 120 metres in the south. It is an undulating surface and is often dissected by Tertiary paleo-channels. The top of the basement section is generally weathered to a "saprolite" zone of bleached clay which can be up to 30 metres thick.

The Late Devonian Pyramid Hill Granite lies just outside the licence area north of Mitiamo. Ordovician turbidites have been metamorphosed to andalusite-muscovite-biotite schist for up to 5 km from the granite.

MINERALISATION

Over 27,000 metres of aircore, RC and diamond drilling have been carried out on the Four Eagles Gold Project and have broadly defined a "footprint" of gold mineralization about 6km long by 2.5km wide (Figure 2). Within this footprint, linear north south trending gold zones have been defined with Eagle 2, Eagle 3 and Eagle 4 being the most prominent. Mineralisation on Eagle 3 has been traced for over 6 kms in length as shown on Figure 2 and includes high grade intersections of 3 metres @ 14.7g/t Au, 3 metres @ 20.5 g/tAu, 3 metres @ 9.1 g/t Au and 1.5 metres @ 12.9 g/t Au. Further reconnaissance drilling will be necessary to test if these gold zones extend further north where basement depths are mostly less than 50 metres (Figure 3). Most drilling has been vertical aircore drilling which has limited penetration and provides little information on the structure and nature of the mineralization which is also mostly vertical. A small number of diamond drillholes have been completed on the Discovery Prospect within the Eagle 2 trend and these suggest that gold mineralization is associated with quartz veinlets and clay alteration within sub vertical shear zones, possibly associated with the limbs of anticlines. There seems to be a broad association between gold and anomalous arsenic within the regional gold trends but high arsenic values are rare and tend to be in the <500ppm As range.
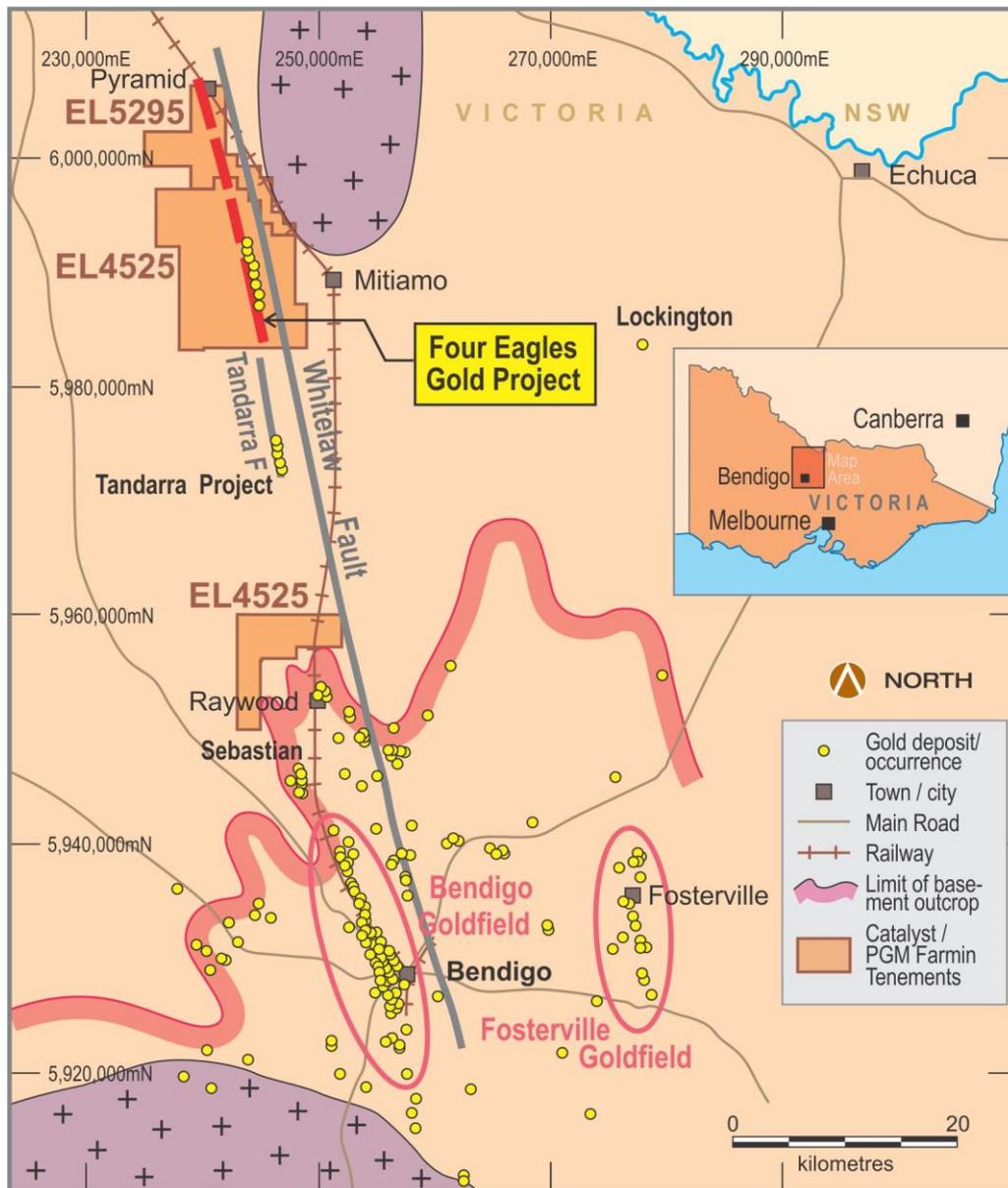
Figure 1 Location Map showing Four Eagles Gold Project

Although the Ordovician host rocks at Four Eagles are similar to those at Bendigo, the mineralization at Four Eagles appears to much more finely divided with minimal nugget effect. This is shown on Figure 4 by comparative data between 30 gram gold assays and 2kg bulk Leachwell assays which have a correlation of about 80%.   There are almost no instances where a high grade value in a small sample totally disappears in the bulk analysis. This is very significant and suggests that a reliable ore resource could be estimated from drillhole data.

Drillhole Intersections (>0.7g/t Au)

FEDD001		3.7m @ 4.7g/t Au from 170m
	inc.	0.8m @ 17.5g/t Au from 173m
FEDD007		0.4m @ 8.4g/t Au from 168m
	and	0.75m @ 15.3g/t Au from 170m
FEDD008		0.4m @ 152g/t Au from 150m
FERC002		2m @ 1.8g/t Au from 67m
	and	1m @ 18.3g/t Au from 127m
FERC003		2m @ 6.2g/t Au from 49m
FE326		1.5m @ 1.81g/t Au from 114m
FE328		6m @ 82.7g/t Au from 123m
FE343		3m @ 3.34g/t Au from 111m
FE380		3m @ 9.71g/t Au from 120m
FE399		3.0m @ 1.42g/t Au from 66m
FE402		3.0m @ 0.8g/t Au from 90m
FE415		6.0m @ 2.6g/t Au from 45m
	and	3.0m @ 36.6g/t Au from 57m
FE469		3.0m @ 1.23g/t Au from 36m
FE471		3.0m @ 5.96g/t Au from 75m
	and	3.0m @ 1.33g/t Au from 81m
FE472		3.0m @ 1.2g/t Au from 45m
	and	3.0m @ 2.32g/t Au from 63m
FE492		3.0m @ 1.2g/t Au from 75m
FE509		3.0m @ 0.7g/t Au from 84m
FE532		3.0m @ 2.1g/t Au from 96m
FE535		3.0m @ 1.37g/t Au from 63m
FE572A		3.0m @ 1.74g/t Au from 51m
FE575		3.0m @ 4.9g/t Au from 66m
FE578		3.0m @ 1.14g/t Au from 60m
FE579		9.0m @ 2.33g/t Au from 48m
	and	3.0m @ 1.23g/t Au from 78m
FE584		3.0m @ 0.88g/t Au from 117m
FE591		3.0m @ 14.7g/t Au from 87m
FE592		9.0m @ 7.9g/t Au from 87m
	incl.	3.0m @ 1.26g/t Au from 87m
	incl.	3.0m @ 20.5g/t Au from 90m
	and	3.0m @ 1.94g/t Au from 93m
FE595		3.0m @ 2.33g/t Au from 126m
FE606		3.0m @ 1.39g/t Au from 102m
FE608		3.0m @ 9.1g/t Au from 108m
FE619		3.0m @ 0.8g/t Au from 45m
FE623		3.0m @ 0.83g/t Au from 33m
FE626		1.5m @ 12.9g/t Au from 52.5m
FE648		1.5m @ 1.0g/t Au from 82.5m
FE649		4.5m @ 1.0g/t Au from 97.5m

Legend:
- Drillholes
- Au Zone
- As Zone

Drillhole grades:
- 0.1 to 0.2 g/t Au
- 0.2 to 0.5 g/t Au
- 0.5 to 1.0 g/t Au
- 1.0 to 5.0 g/t Au
- > 5.0 g/t Au

Map labels: 316 (3.85km north), 619, Projected Tandarra Fault, Whitelaw Fault, Bendigo Pyramid Road, 5,992,000mN, 469 623, 446 648 649, Boyd's Dam, 343 626, 326, 399 471, D005 592, 591 595, 578, 5,990,000mN, Hayanmi, 492, 608, 579 572A, 402, 575, 415 R002, 472 R003, 584, D001, 328 D007, 509, D008, EAGLE 4 ZONE, EAGLE 5 TARGET, Discovery, 380, Bendigo Pyramid Road, EAGLE 1 TARGET, NORTH, 0 1 kilometre, 5,988,000mN, EAGLE 2, EAGLE 3, 242,000mE, 244,000mE, 246,000mE

Figure 2 Four Eagles Drill Plan showing interpreted gold arsenic trends

CONCLUSION

Exploration by Providence and Catalyst at Four Eagles has confirmed a new gold discovery north of Bendigo in Victoria but considerable drilling will be necessary before a decision on future mining can be made. The deposits are totally concealed by younger sediments of the Murray Basin so virtually no exploration has been previously undertaken. Basement depths vary from 10 metres to 120 metres and indicate potential for open pit gold deposits.

Gold mineralization is hosted by the Ordovician Castlemaine Group which hosts the Bendigo Goldfield and appears to be present in sub-vertical shear zones with quartz veinlets, clay rich zones and minor sulphides. Gold mineralization seems to lie within north south trending corridors up to 50 metres thick and up to six kilometres long, probably associated with the limbs or hinges of tight anticlinal structures. The continuity and nature of the gold mineralization within these corridors is not well understood and will require a large programme of angled drilling. These corridors are parallel to and west of the regional Whitelaw Fault and are situated between the Tandarra Fault and the Whitelaw Fault. Gold mineralization is present adjacent to the Tandarra Fault on Navarre's Tandarra Project about 15 kms south of Four Eagles.
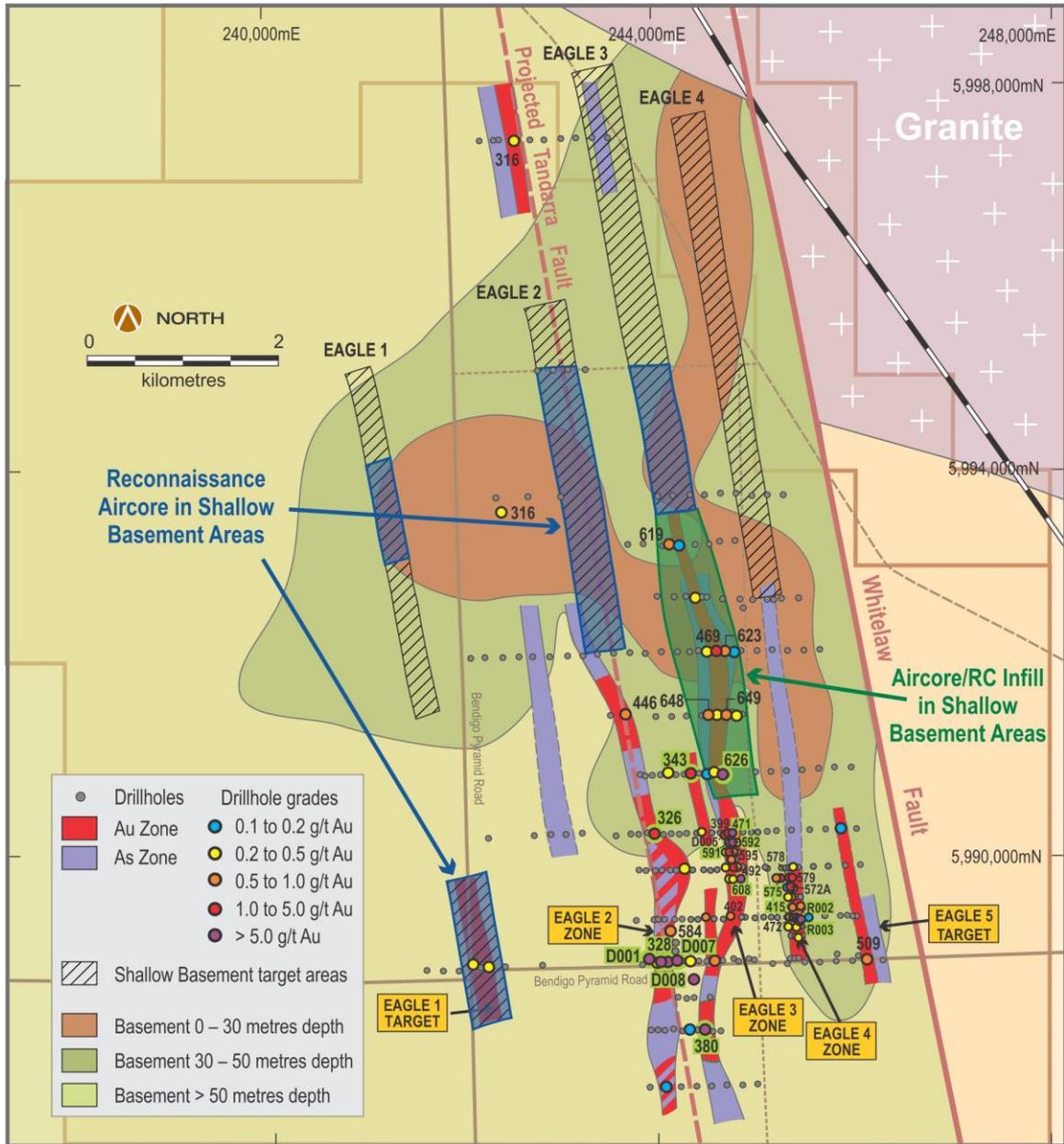
Figure 3   Four Eagles gold target areas and interpreted depth to basement
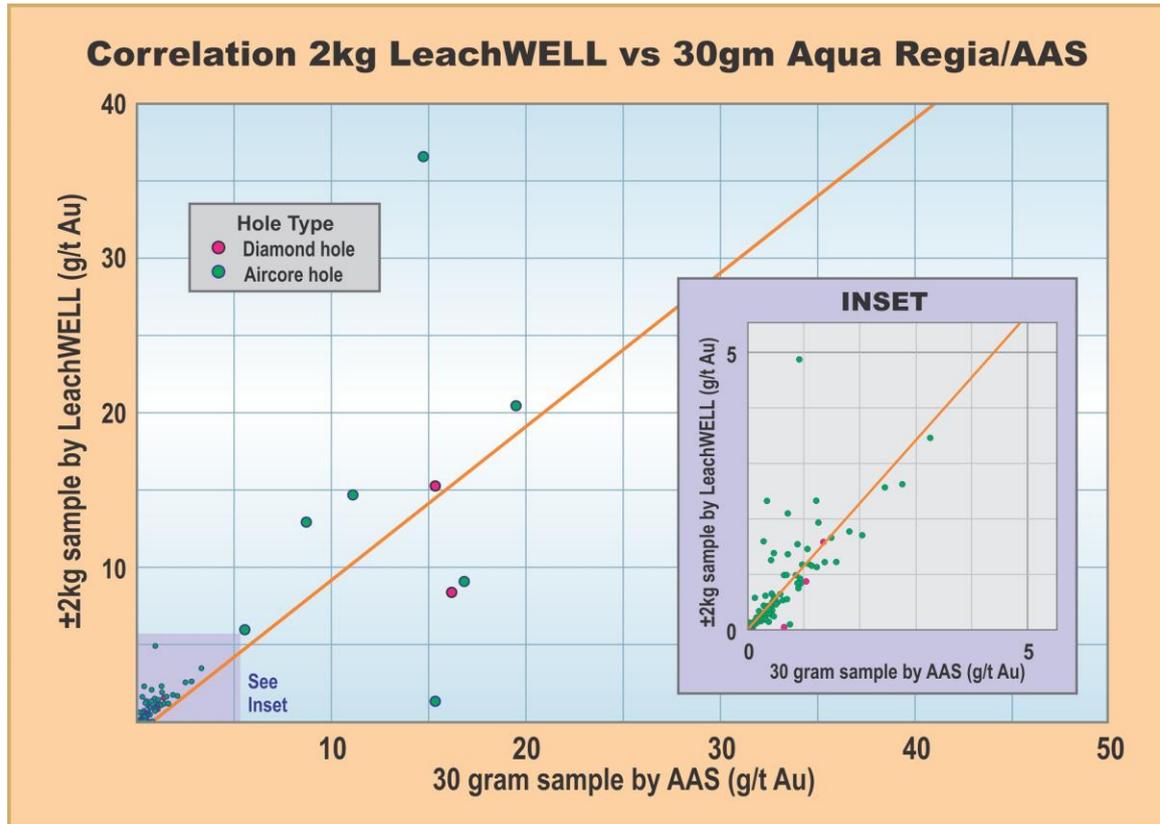
Figure 4   Comparative drillhole assay data showing correlation between 30 gram Aqua Regia/AAS and 2kg bulk leach (Leachwell)

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OROGENIC GOLD DEPOSITS THROUGH TIME: A TWO-STAGE PROCESS

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The formation of orogenic gold deposits is a two-stage process. The first stage involves pre-concentration of gold in a suitable source rock, such as carbonaceous black shales, felsic volcaniclastics or komatiitic volcanics. The second stage involves the release of gold (commonly with arsenic and/or tellurium) from the source rocks, during metamorphism or magmatic intrusive events, accompanied by the replacement of source rock pyrite by pyrrhotite. Recent research suggests that syn-sedimentary gold, trapped in the structure of diagenetic arsenian pyrite in reduced carbonaceous facies of continental margin sedimentary basins is an ideal source of gold for many orogenic and Carlin style gold deposits. The conversion of diagenetic arsenian pyrite to pyrrhotite, during greenschist facies metamorphism is the key process releasing gold and arsenic to the metamorphic fluid, with metal deposition in structural trap sites to form the deposits.

Orogenic gold deposits are spread periodically through earth history, with fertile source rocks developed in the Archean (3.0 to 2.5 Ga), Paleoproterozoic (2.2 to 1.7 Ga) and the Phanerozoic (0.6 to 0.1 Ga). Our research suggests that the major control on the fertile gold periods relates to pulses or cycles of oxygenation in the Earths atmosphere – ocean system. Increased oxygenation leads to more active continental erosion and increased supply of gold to the oceans, consequently producing higher levels of gold pre-concentration in the carbonaceous shale source rocks.
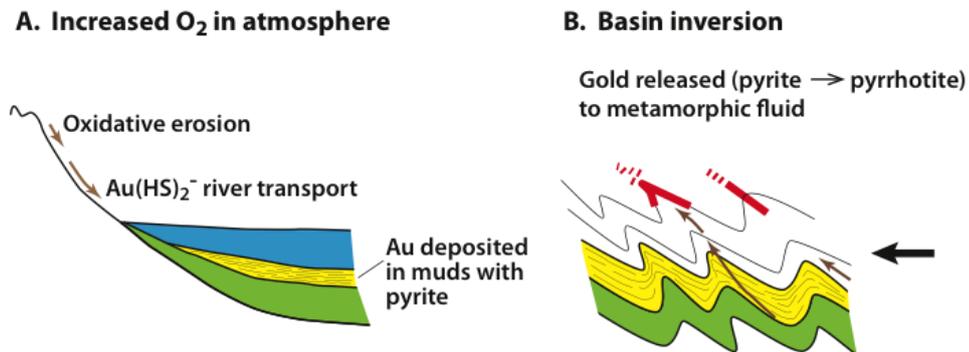
Figure 1: cartoon of the two-stage process in the formation of orogenic gold deposits. A: oxidative erosion of gold from continents, transport via river systems and deposition in marine carbonaceous mudstones. B: Basin inversion and metamorphism converts gold-bearing diagenetic pyrite to pyrrhotite with release of Au, As and Te to ore fluid.

EXPLORATION FOR BRECCIA HOSTED GOLD DEPOSITS IN NORTH EAST QUEENSLAND

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Introduction

Several significant gold deposits in north east Queensland are associated with or hosted in hydrothermal/magmatic breccia pipes, including Kidston (5Moz), Mt Leyshon (3Moz) and Mt Wright (1Moz). Over one hundred breccia systems have been identified by numerous explorers in the north-east Queensland region (Figure 1), although most have either been determined to be barren or weakly anomalous for gold. Identifying the systems that are likely to contain ore-grade mineralisation and understanding that the breccia is just a component of the overall hydrothermal-magmatic system is the key to exploration success. The known deposits have a wide range of characteristics but still share some similarities that can be used as guide to assess the prospectivity of other systems. This paper reviews the exploration models derived from these relatively well-known breccia hosted gold deposits in north east Queensland and includes details of the recently discovered Welcome breccia hosted gold system in the Ravenswood area.
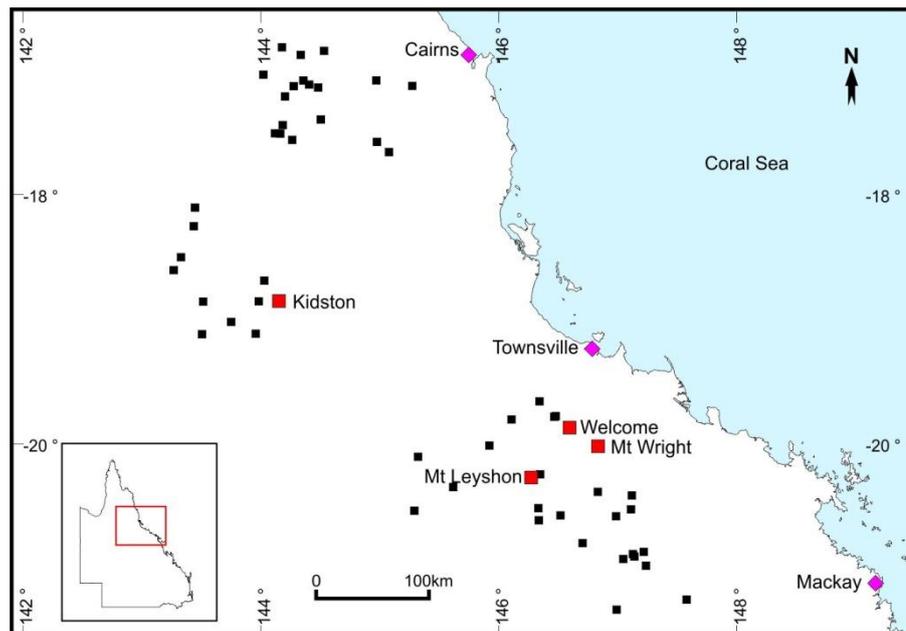
Figure 1. Collation (non exhaustive) of hydrothermal/magmatic breccia systems between Cairns and Mackay in north east Queensland, with locations of Kidston, Mt Leyshon, Mt Wright and Welcome marked.

Background

The 5Moz Kidston deposit (280 km NW of Townsville) was discovered in the early 1980's and was mined from 1984 to 2000 by Kidston Gold Mines Ltd (subsidiary or Placer Dome Inc). The deposit is hosted within a breccia pipe with dimensions of 1100m x 900m at surface and at least 1300m deep. The breccia is related to the intrusion of Carboniferous aged rhyolite dykes and plugs, adjacent to the contact of middle Proterozoic metamorphics and Silurian-Devonian granodiorite (Morrison, 2007a).

The 3Moz Mt Leyshon deposits (130km SW of Townsville) was also discovered in the early 1980's and was mined via open-cut methods from 1987-2001 by Mt Leyshon Gold Mines Ltd (subsidiary of Normandy Mining Ltd). The ore body is approx 500x500m across and occupies the NW corner of a sub-circular breccia complex, approximately 1.5km in diameter. The breccia complex is related to a suite of early dacite and rhyolite to late trachytes and trachy-andesite intrusions of Late Carboniferous to Early Permian age and is located on the contact between Cambrian meta-sediments and Ordovician granite of the Ravenswood Batholith (Morrison, 2007b).

The Mt Wright deposit (85km south of Townsville) was discovered in 1992, with mining commencing in 2006. The deposit is currently being mined by sub-level caving methods by Carpentaria Gold Pty Ltd (subsidiary of Resolute Mining Ltd), with production forecast to continue until 2015. The deposit is hosted within a Carboniferous-Permian aged rhyolite spine approximately 200 x 60m across and at least 1200m deep, within a larger breccia complex approximately 250 x 250m across at surface (Morrison, et al., 2013). The breccia complex is hosted within Ordovician-aged granite of the Ravenswood Batholith.

The upper portion of the Welcome deposit (75km SW of Townsville) was discovered in 1980's, with a small open pit in operation for three months in 1994, producing 65,208t @ 1.87g/t Au (3,915 oz). Carpentaria Gold signed a JV with the previous holder in 2009, and commenced drilling in 2010, with the third and final hole of initial program (WED003) returning 113m @ 7.7g/t Au from 316m. Subsequent drilling outlined a total resource of 2.04Mt @ 3.2g/t (210,000 oz). A scoping study conducted in 2011 indicated a marginal underground operation was possible, with haulage of the ore to the Carpentaria Gold processing plant in Ravenswood (40km to SE). Carpentaria Gold obtained 100% interest in the project in 2011, although further work was put on hold as the company focussed on the feasibility study for an expanded open pit operation in Ravenswood (Sarsfield). The deposit is hosted within a breccia pipe approximately 50 x 20m across, and adjacent quartz-sulphide vein array that extends up to 30m from the breccia. The breccia system is at least 600m deep and hosted within Ordovician granodiorite of the Ravenswood Batholith (Lisowiec et al., 2013).

Outcropping mineralisation occurs at all four locations and was intermittently worked for around 100 years, prior to discovery of the larger ore body and modern mining. At Kidston and Mt Leyshon, parts of the main ore body outcrop and extend approximately 250-400m below the surface. At Mt Wright a small satellite ore body outcrops within granite-dominant breccia, but the main ore body is hosted within a separate unit (rhyolite), with ore extending from 150 to 800m below the surface. At Welcome, the top 50-100m of the breccia and the adjacent quartz sulphide vein array is mineralised. However, from approximately 100m to 350m depth, the breccia is generally barren, although mineralisation continues within the adjacent veins (albeit patchy). From approximately 350-500m depth, the breccia is again mineralised, with mineralisation in both the breccia and veins decreasing with increasing depth.

Exploration Model

1. Topography.

Kidston, Mt Leyshon and Mt Wright are/were distinct topographic features that rise around 100m above the surrounding terrain due to the hydrothermal quartz alteration within the breccia pipe being more resistant to erosion. Intrusions associated with the overall hydrothermal-magmatic system can also contribute to the topography. Reconnaissance airborne surveys were conducted by numerous companies in the 1980s-1990s and resulted in the identification of numerous topographically distinct breccias and other hydrothermal systems. In the case of Mt Leyshon, several hydrothermal-magmatic complexes were identified along a NE-orientated trend between Mt Leyshon and a NE-elongated intrusive complex of similar age (Carboniferous-Permian). Several of these complexes were subsequently drilled, and were discovered to have anomalous metal values. The Welcome breccia did not form an obvious hill, possibly due to the relatively small scale of the system, but possibly coincidently, the surface expression is located at the highest point in an area with

very subtle topographic relief. Obviously topography will have little assistance where systems are buried by late cover.

2. Magnetics

Aeromagnetic surveys can used to identify potential breccia systems, although the magnetic anomaly can be variable or non-existent. Within the known deposits, the ore stage alteration is sericitic and magnetite destructive, but the extent and magnitude of this alteration is variable and often complicated (or swamped) by more magnetic features such as intrusive plugs and dykes, pyrrhotite mineralisation and/or host rocks with low primary magnetic susceptibility, resulting in a poor contrast of the feature relative to the background.
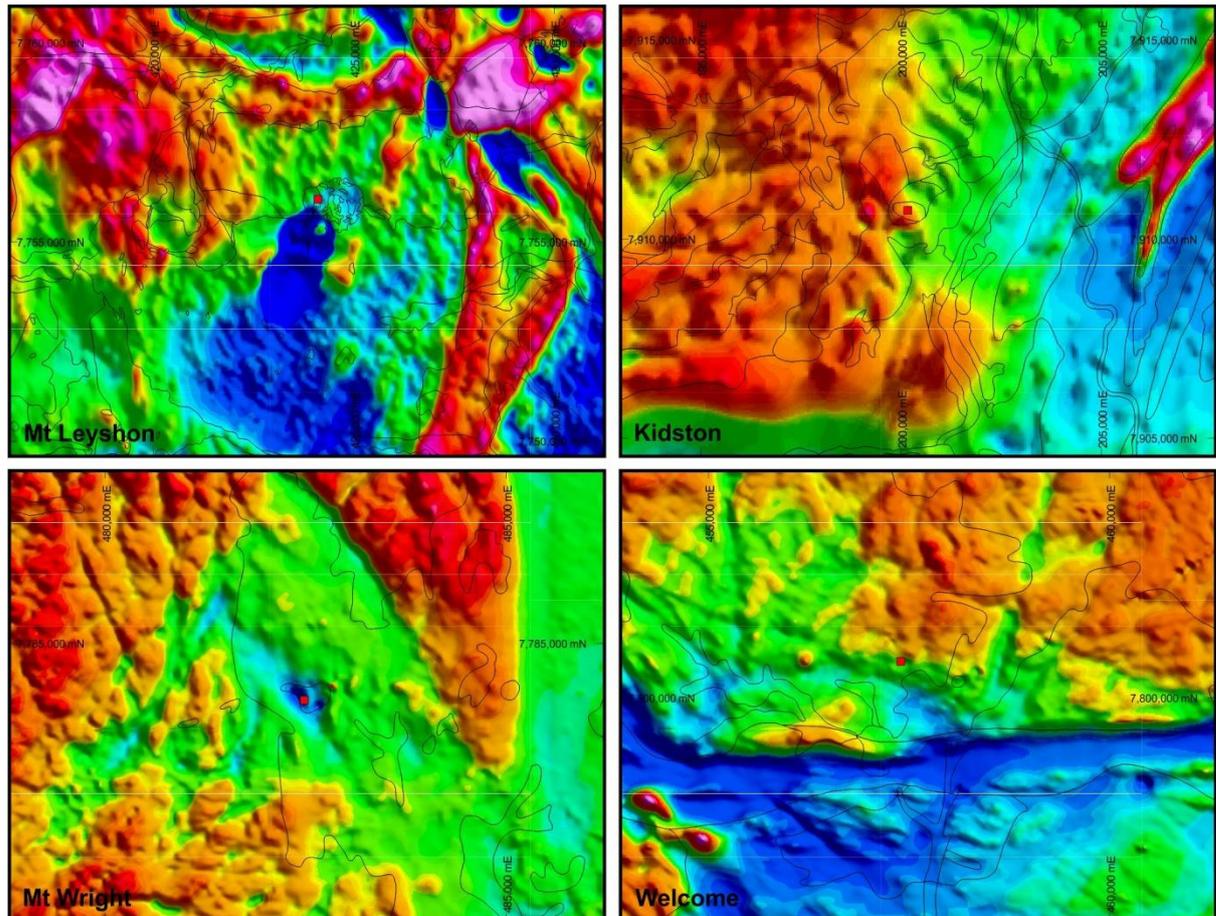
Figure 2. RTP Aeromagnetic images from the Mt Leyshon, Kidston, Mt Wright and Welcome areas, with deposit locations marked. Line work is regional scale (1:100,000) solid geology.

At Mt Leyshon, a strong, reversely polarised magnetic feature, related to biotite-magnetite alteration and hornfels is associated with a porphyry intrusion in the southern portion of the complex (Sexton et al, 1995). Whilst the anomaly is beneficial in highlighting the system, the gold ore is actually related to a subsequent event and off-set from the magnetic anomaly, within the north-west portion of the pipe (Figure 2). As such, the magnetic anomaly is highlighting a part of the intrusion-related hydrothermal system, but not the mineralisation stage. Mt Wright is also associated with a reversal polarised magnetic anomaly (Figure 2), which is still poorly understood, but could be related to dolerite dykes and/or early, high temperature potassic alteration within the breccia complex. This feature dominates the magnetic destructive alteration within the breccia/ore. At a regional scale, Kidston does not have an obvious magnetic anomaly due to poor contrast between the alteration and the host rocks, and the Welcome breccia is so small, the magnetite destructive alteration is barely visible in the 100m line spaced data collected over the region and would certainly be missed in regional magnetic interpretations.

3. Orebody relative to Breccia System

Regardless of the exact form of mineralisation within a breccia system, often the area of economic mineralisation is substantially less than the area of breccia. At Mt Leyshon, the ore pod occupies around one third of the near-surface area of the breccia complex (Figure 3). The finger-shaped orebody at Mt Wright also occupies about one third of the complex but is 400-700m below the surface, and surrounded by a mineralised envelope (Figure 3). On the other hand, the Kidston ore body, which is bowl-shaped, forms a ring that occupies less than 25% of the pipe near surface, but the majority of the area over a narrow depth range, approximately 200m below the surface (i.e. at the base of the bowl). The Welcome deposit is a series of stacked ore pods within the 50m diameter, 600m tall breccia pipe and a set of mineralised sheeted veins that locally extend another 50m beyond the pipe. The extent of ore relative to breccia therefore ranges from 0% to near 100%, depending on the RL.

There are numerous reasons why ore grade mineralisation only occupies a relatively small percentage of the overall breccia pipe both horizontally and vertically, some of which are outlined below. As such it is important to not prematurely dismiss a breccia system, when only a small portion can be observed. To some extent, smaller breccia systems are easier to assess, as the larger the system, the more "real estate" exists to host economic mineralisation, which in turn makes it more difficult to target via drilling. Either way, unless the ore body is outcropping, further criteria need to be assessed to evaluate the system.
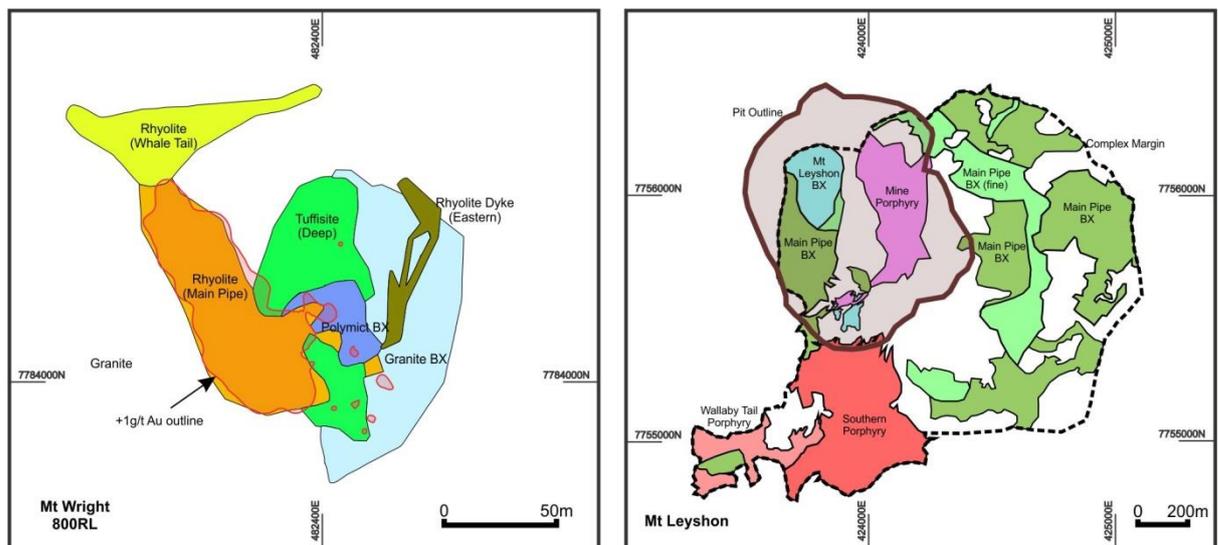
Figure 3. Simplified geological maps of the breccia complexes at Mt Wright (800RL = 540m below surface) and Mt Leyshon (surface). Location of ore within system can be inferred from +1g/t Au outline from Mt Wright and open pit outline from Mt Leyshon.

4. Preferred host –Breccia Facies

Even relatively simple, single stage breccia pipes have different breccia facies, usually ranging from shatter / stockwork breccias through clast-supported to matrix- supported and milled breccias. The mineralising fluid typically postdates the formation of the breccia and as such, the amount of open space is important to potentially obtaining economic grades. Coarse clast-supported breccias are the best host to mineralisation because they can sustain the largest cavities and hence have the most sulfide infill. However, most clast-supported breccias pre-date mineralisation and may have a matrix of fine clasts and rock flour that needs to be removed before sulfide-fill can take place. Since the mineralisation is often distributed by cross-cutting structures, the ore is often a combination of veins and adjacent cavities formed by localised replacement or excavation of breccia-matrix. At Kidston and

Welcome the ore is approximately half and half cavity fill and veins, whereas at Mt Leyshon the veins are subsidiary to the breccia cavity fill mineralisation, but are high-grade and at Mt Wright veins and networks are dominant because the bulk of the ore is in the intrusion rather than in the adjacent poorly mineralised clast-supported breccia.

5. Pressure release and trap

Although breccia systems can be efficient fluid pathways, the metals need to drop out of solution to form the ore. Geological observations suggest that both Mt Leyshon and Kidston probably formed as closed systems, with a roof to the breccia pipe, parts of which are still preserved. The roof acted as a trap to the fluids, preventing any significant leakage to the surface. In these systems, the metal precipitates out of solution via decompression boiling – possibly the result of gravitational collapse and/or magma retreat in the waning stages of the hydrothermal-magmatic system. This is particularly evident at Kidston, where a relatively flat lying sill, immediately below the ore zone is thought to have collapsed, resulting in a pressure release, from which the metals were precipitated. This is the piston-cylinder model of Morrison et al. (1996); (Figure 4).

The nature of the tops of the Mt Wright and Welcome breccia systems are less clear. At Welcome, silica cement that formed prior to the mineralisation phase may have acted as an impermeable barrier to the progress of Au bearing fluids within the breccia but diverted them into the adjacent veins. At Mt Wright, the mineralised breccia that outcropped and was mined in the 1990's also appears to have had a roof, as large granite blocks are still visible in the high wall of the pit. However, the rhyolite spine that hosts the majority of the ore, grades into a tuffisite (fine grained milled breccia) at the present surface, with no evidence that the pipe had a roof or if it extended to and breached the paleo-surface (e.g. as a diatreme). Therefore, there is no obvious physical trap specifically for the main gold orebody, but there is mineralisation that extends through all the breccias and into the wall rocks above and adjacent to the ore suggesting dispersion and cooling were maybe more important here.
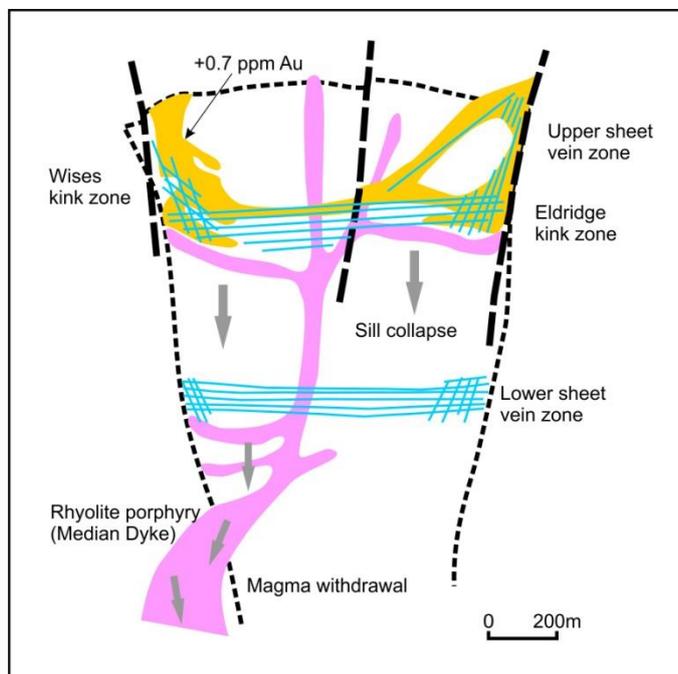
Figure 4. Kidston piston-cylinder model for gold mineralisation (Morrison et al., 1996), showing the sill-collapse mechanism for pressure release that resulted in the formation of the mineralised breccia and veins. The lower vein set are Mo-rich, with little Au, which reflects the metal zoning within the system.

6. Geochemistry - Metal Zoning

Understanding the potential metal zonation can be an important indicator in assessing the prospectivity of a system and what part to target by drilling. Different metals are precipitated out of solution at different stages, which is related to a combination of the initial fluid composition (source), reactions of the fluid with the wallrocks, and changing pressure, temperate and pH conditions. The relative abundance of certain metals can therefore be used as a guide to determine whether the exposed portion of a system is shallow or distal to the ore and/or too deep or proximal to the source or core of the system. Mt Leyshon, Kidston, Mt Wright and Welcome all have well defined metal distributions which are outlined in Table 1:

Table 1: Metal zonation of patterns of the Kidston, Mt Leyshon, Mt Wright and Welcome deposits. Selected mineral species shown in brackets.

Deposit	Distal	Intermediate (Au)	Proximal	Core
Kidston	(Ank-Py)	Zn-Cu-Pb-Bi-Te-Au	Cu-Bi-Te	Mo-W-Bi
Mt Leyshon	Zn	Zn-Cu-Pb-Ag-Bi-Te-Au	Py-Kspar	Cu-Mo
Mt Wright	Zn-Pb-Ag	Bi-Cu-Au-Te-Au (Py-Marc)	Fe-Cu(Po)	Mo-W-Te
Welcome	As-Sb-Zn (Ank)	Zn-Cu-Pb-Bi-Te-Au (Cal)	Fe(Py-Chl)	Mo-W?

Whilst each deposit is different, exposed at different levels and drilled to different depths, several patterns emerge that can be useful for assessing prospectivity. Deposits are broadly expected to have a far distal (marginal) As-Sb zone, often with Fe-Carbonate (e.g. ankerite); a near-distal base-metal zone (that overlaps into the Au zone); an intermediate base-metal zone with Au plus Bi-Te; a proximal zone with Fe +/- Cu and a core zone of Mo+/-Cu-W. Therefore a collection of samples from a prospect, analysed for a broad suite of elements, can be used to assess the broad location within the system. From this, inferences about the possible location of Au can then be made. This pattern of zoning is characteristic of gold-bearing hydrothermal systems in the Permo-Carboniferous of north Queensland whether they have developed into a breccia or not.

Summary

Both topography and magnetics can be useful for locating hydrothermal-magmatic systems, but provide little clues to whether the system is likely to host Au or not. The recognition that the ore body may only occupy a relatively small portion of the breccia system is important to keep in mind, as many systems may be easily dismissed based up the portion that is exposed or intercepted in drilling. Likewise, this does not provide direct evidence for mineralisation. The other observations of preferred host, traps and metal zoning can provide the important indicators to assess the prospectively of the system and potentially locate the ore. These are the tools that are routinely used to assess the breccia systems in the region. It is also important to note that these general principles can also be applied to other intrusion-related systems, which have not developed breccias (e.g. quartz stockworks etc.)

Conclusion

Breccia hosted deposits are an important sub-class of intrusion-related gold systems in NE Queensland, that include several world-class deposits. Understanding the key characteristics of the known deposits is extremely beneficial when exploring for this deposit style. It is quite likely that the hydrothermal-magmatic breccia system for the next major discovery has already been located, but not yet adequately tested for blind Au mineralisation somewhere within the pipe. The general strategy outlined above has been used to evaluate numerous breccia systems in the region, with the Welcome (deeps) deposit being one example of success.

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"HERE'S TO HENTY" A SPARKLING, FULL-BODIED MINE.

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Extended Abstract
The Henty gold mine is a high grade gold deposit, located in the Cambrian, Mount Read Volcanics in western Tasmania. The ore is hosted in highly deformed, sheared volcanics and sediments adjacent to the Henty Fault. The latter is a significant regional structure which bisects the Cambrian volcanics.

Bendigo Mining Limited (BML-later Unity Mining Limited) purchased the Henty Gold Mine from Barrick in 2009. At that time the mine was due to be closed at the end of that year.

BML commenced an aggressive exploration programme which almost immediately delivered results. Ore grade intersections were obtained in the Tyndall and Darwin Zones and shortly afterwards, the Newton and the Read Zones were both discovered. The Newton Zone was discovered in an area which had been deemed to be fully explored. Low grade gold intersections in some of the "sterilisation" holes were noticed and infill drilling around these delivered higher-grade gold intercepts which eventually became part of the Newton resource.

The Read Zone discovery resulted from the observation that the main Henty line of mineralisation continued, parallel to the Henty fault, "behind" or on the western side of, the South Darwin mineralisation. The latter was a significant producer for the mine but is located slightly east of the line of strike of the main Henty deposit and strikes at a low angle to the Henty Fault, where the rest of the mineralisation strikes parallel to the fault. This configuration of the known mineralisation resulted in an undrilled "gap" between the South Darwin Zone and the Henty Fault. Persistent drilling of this "gap" lead to discovery of the Read Zone and the publication of a maiden Resource in February 2013. The extent of this "resource building" is illustrated by contrasting the two long sections below in figures 1 and 2.
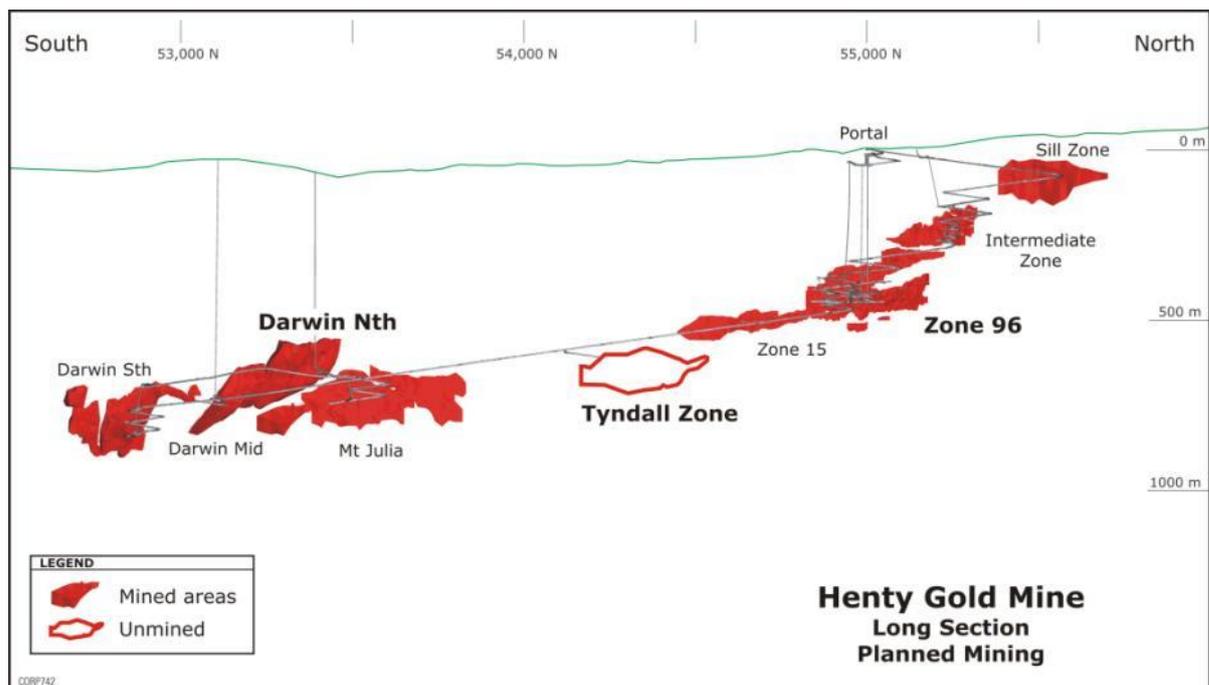
Figure 1. Resources and mined ore in 2009.
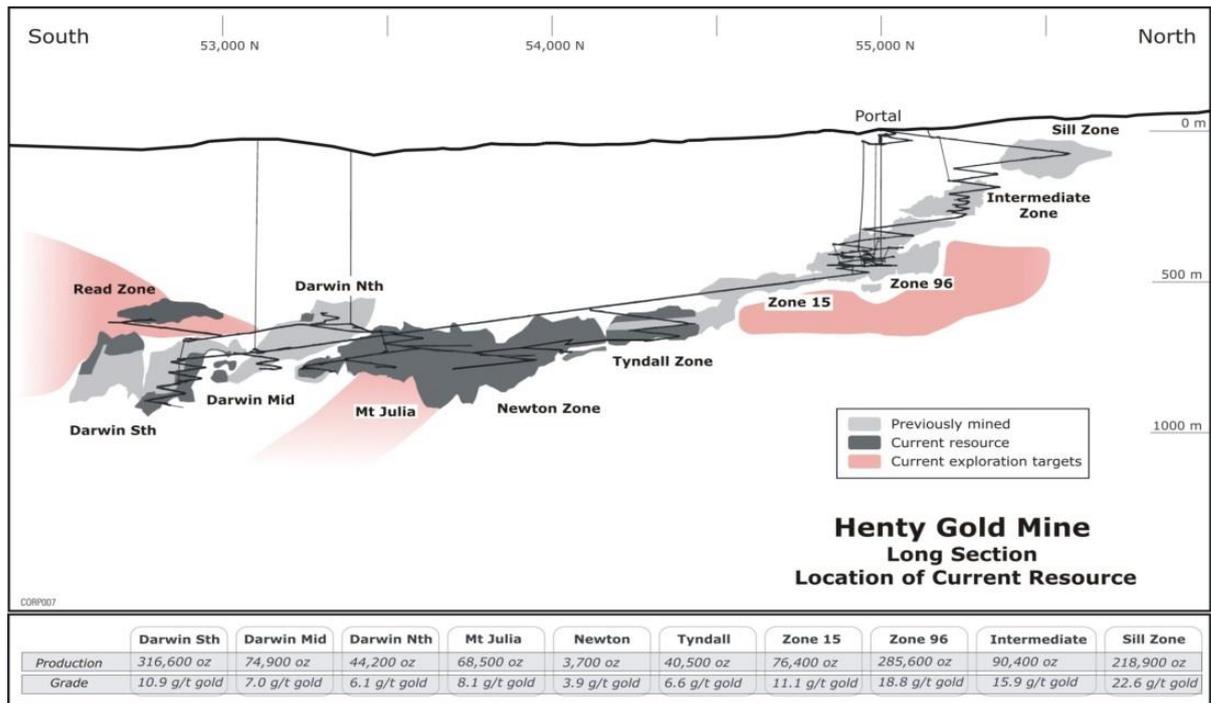
Figure 2. Resources and mined ore in 2013

The Read Zone discovery included some very high grade intersections and though its tonnage to date is not large it has already contributed significantly to the production of gold from site. Exploration at Henty has continued to expand the resource base and in total 220,000 oz of Reserve-category gold has been discovered since July 2009. 165,000 oz of these has been mined.

Lessons learnt from the Newton and Read discoveries have and are being applied to exploration in and around Henty mine. The most significant of these are:

1. Understanding the scale of the mineralisation and following-up on any gold intersections, even if they are deemed a "miss" at the time.

2. Recognising that the orientation of the lenses at Henty sometimes varies and that this creates opportunities for further discovery. This is being applied to the south of Henty now.

3. Persistent drilling pays off.

4. Appreciating that the Henty mineralisation occurs because of a particular combination of structures and stratigraphy and applying this to regional exploration.

5. Learning how to use elements other than gold to designate a prospective zone. Copper has proven to be the most useful element in this regard, though its efficacy varies throughout the deposit.

6. Unfortunately there is little physical contrast between the Henty mineralisation and the surrounding rocks, so geophysics is not an effective ore-finding tool, however it is useful for identifying the combination of components described in (4) above.

7.

These lessons are constantly applied to the generation of new targets at Henty. All to keep up the supply of high grade gold from a mine which is expected to become more "full-bodied" as time goes on.

TOMINGLEY GOLD PROJECT – GEOLOGICAL SETTING AND MINERALISATION UPDATED

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Abstract

This review of the Tomingley Gold Project provides an update from a presentation given at Mines & Wines in 2006. Seven years later, two additional deposits have been defined, namely Caloma (5.5 million tonnes grading 2.1g/t gold for 369,400 ounces of gold) and Caloma Two (resource calculation pending) forming a global resource of 12.6 million tonnes grading 2.0g/t gold (811,700 ounces). Development approval was given in February 2013, construction has commenced and first production is due in early 2014.

The project currently comprises the Wyoming One, Wyoming Three, Caloma and Caloma Two Deposits, the historic Myalls United Gold Mine and several tenements covering Ordo-Silurian volcanics and sedimentary rocks with minor intrusives. .

The eastern Lachlan Orogen in southeastern Australia is noted for its major porphyry-epithermal-skarn copper-gold deposits hosted in Late Ordovician volcanics. While many small quartz vein hosted or orogenic lode-type gold deposits are known in the region, the discovery of the Tomingley gold deposits has demonstrated the potential for larger lode-type mineralisation hosted within the same Ordovician volcanic stratigraphy.

Outcrop within the project area is limited with the Ordovician sequence obscured by up to 60 metres of clay-rich cover of probable Quaternary to Miocene age. Regional aeromagnetic data is obscured by the maghemite bearing cover sequence but still weakly defines a north-south trending linear belt interpreted to represent the Ordovician andesitic volcanic sequence within probable Silurian pelitic sediments.

Extensive drilling has identified economic mineralisation associated with sericite–carbonate (ankerite)-albite-quartz-(± chlorite ± pyrite ± arsenopyrite) alteration focused within feldspar ± augite phyric basaltic-andesite intrusions and adjacent volcaniclastic sediments. The Wyoming and Caloma deposits appear to have formed as the result of a rheological contrast between the porphyritic volcanic sill hosts and the surrounding volcaniclastic sediments, with the sills showing brittle fracture and the sediments ductile deformation, and many similarities to well documented lode-style gold deposits. East-west compression followed by a dextral transpression structural regime has been important in the formation of the mineralisation. The age of the alteration and mineralisation remain problematic but a relationship with the Middle Devonian Tabberabberan Orogeny is considered likely.

Regional Geological Setting

The Tomingley deposits are located near the eastern margin of the Junee-Narromine volcanic belt, just east of the interpreted Parkes Thrust. This structure separates the flat lying Ordovician Goonumbla volcanic complex from a thin slice of north-south trending andesitic volcanics identified by regional aeromagnetic data and interpreted to be the Late Ordovician Mingelo Volcanics. The Tomingley Gold Project covers the entirety of this interpreted north-south belt extending north approximately 25 kilometres from Trewilga to Tomingley and being about 2 kilometres in width. Drilling north of Tomingley has not identified any Ordovician volcanics and is interpreted to be either distal to the intrusive centre or faulted out along a major northwest structure.

The Goonumbla volcanics are overlain by sediments thought to be equivalents of the Ordo-Silurian Cotton Formation. Although Sherwin (1996) suggest that the Cotton Formation may have been contemporaneous with deposition of the Goonumbla Volcanics, Squire et al (2006) suggest that differences in detrital composition and biostratigraphy mean the units are

distinctly separate, and are perhaps part of the Silurian Forbes group. Drilling data at Tomingley supports Squire et al with an observed angular unconformable contact and the sediments consist of well-bedded fine quartzose sandstone and laminated siltstone with a diagnostic basal quartz rich conglomerate.

The Ordovician rocks west of the Parkes thrust are weakly deformed, with broad open folds and sub-greenschist metamorphic assemblages (Sherwin, 1996). In contrast, the Ordo-Silurian sequences east of the fault, including the rocks hosting the Tomingley deposits, exhibit tight to isoclinal folding, strong axial planar cleavage with greenschist metamorphic assemblages.

Northwest trending transverse structures are also evident in regional magnetic and gravity data, and rarely as faults mappable in outcrop. These structures appear to be long lived fundamental crustal breaks that were irregularly reactivated throughout the geological development of the Eastern Belt. They also show a relationship to intrusive centres and mineralisation where the structures intersect and occasionally offset the arc parallel structures (Squire et al., 2003).

Tomingley Geology and Structure

The Tomingley deposit area is almost entirely covered by alluvial sequences of clays, sand and gravel up to 60 metres thick. The transported regolith sediments are thought to have been deposited and weathered at different times, with the lower clayey unit representing a wetter climate, probably during the Middle Miocene to Middle Pliocene, and the upper sandy units indicating drier conditions beginning from the Middle Pliocene to the present (Mann 2009). The maghemite bearing cover sequence has made exploration using geophysical techniques problematic and exploration has been primarily completed through drilling and geochemistry.

The gold mineralisation is hosted within volcaniclastic sediments, rare lavas and shallow intrusive porphyritic rocks. The volcanic units are of trachy-andesite to basaltic trachy-andesite composition. The volcaniclastic rocks, which contain very rare detrital quartz, are dominated by well bedded sandstones and siltstones with minor breccias, lithic conglomerates and black mudstones centred at the Wyoming One and Myalls United area, reducing in grainsize to dominantly peperitic graphitic mudstones north at Wyoming Three and the Caloma deposits. The volcanics appear to terminate further north at the historic Tomingley workings within the township.

The volcaniclastic units are intruded by numerous coarse feldspar ± augite porphyritic bodies which commonly show peperitic contacts and are interpreted as shallowly emplaced sills. Wyoming Three, Caloma and Caloma Two sills that host mineralisation are all correlative but are chemically distinct from Wyoming One and Myalls United mineralised sills (Mesthos, 2012).

A narrow, marginally discordant, chlorite-talc schist has also been located by drilling just to the east of the sills at Wyoming One. This likely represents a mafic-ultramafic precursor, similar to olivine rich lavas (picrites) described in the Molong Belt (Crawford, 2003).

To the west, the andesitic volcanic sequence is in sharp contact with well foliated fine grained sediments that are interpreted to correlate with rocks of either the Ordo-Silurian Cotton formation or the Silurian Forbes Group. The contact is an angular unconformity and Tomingley styled gold mineralisation is not apparent within this formation. The eastern margin of the volcanic sequence is uncertain.

Narrow tholeiitic dolerite dykes, of slightly differing ages, crosscut the whole sequence and postdate mineralisation. The timings are possibly as early as Early Silurian and may have intruded as part of an early phase of extension of the Cowra Trough (Crawford, 2003). Other dolerite intrusions crosscut thin quartz-kspar phyric rhyolitic feeder dykes which were zircon dated as the same age as the Middle Devonian Dulladerry Volcanics (Watkins pers com., 2010).

A deformational history of the Tomingley deposits has been developed from empirical observations recorded from orientated drill core with 3D modelling of structural data and gold assay values. This was combined with 3D numerical modelling which tested the effects of

east-west compression, dextral transpression and sinistral transpression (Schaubs et al., 2013).

The Tomingley area was subject to east-west compression which is expressed as a regional foliation, dominantly north-north-west striking stratigraphy and minor folds. Reverse sense of movement in shears and vertical fibres in the mineralised veins give support to east-west compression controlling the formation of mineralised veins. Subsequent major dextral wrenching caused further realignment of stratigraphy including a one kilometre southeast offset to the volcanic belt. Regional north-north-west striking, steeply east dipping stratigraphic orientation has been realigned to moderately west dipping stratigraphy on the eastern side of this major dextral strike slip structure. At Wyoming Three and Caloma Two significant folding has realigned stratigraphy and existing mineralisation with the orientation of the strike slip dextral structure. Synformal folding at Caloma Two has resulted from the compression of stratigraphy along with the possible development of reverse saddle reef lodes. An antithetic Riedel shear (sinistral) and associated folding may have developed locally at Wyoming One. Intermittent periods of extension from the Early Silurian to at least the Middle Devonian led to the whole sequence being intruded by various episodes of dykes.

Work by Downes (2009) on sulphur and lead isotopes on the eastern Lachlan found the large Wyoming One–Myalls United system has ^{34}S values significantly below 0‰, with the data implying that sulphur was sourced from a fractionated magmatic reservoir. The presence of primitive mantle-derived lead-isotope values at Wyoming One supports this interpretation. Orogenic mineralisation in the Parkes district in similar stratigraphic and structural settings as Tomingley were dated as the Middle Devonian Tabberabberan Orogeny and therefore considered likely for Tomingley, although the Early Devonian Bindian Orogeny should also be considered.

Mineralisation

Mineralisation has been identified at a number of locations within the volcanic belt but to date evaluation of deposits has focused on the Tomingley area where four deposits (Wyoming One, Wyoming Three, Caloma and Caloma Two) have been identified (Figure 1), three of which are in the current mine schedule.

Global resources (excluding Caloma Two) total 12.6 million tonnes grading 2.0g/t gold for 811,700 ounces of gold. The current open pit and underground mining inventory is 7.38 million tonnes grading 1.96g/t gold.

Each of the deposits has its own structural nuances however all are characterised by:

- being hosted within feldspar ± augite phyric sub-volcanic intrusions and along immediate contacts of volcaniclastic sediments;

- intense sericite–carbonate (ankerite)–albite–quartz-(± chlorite ± pyrite ± arsenopyrite) alteration of the hosts; and

- strong quartz ± carbonate (ankerite) ± albite ± pyrite ± arsenopyrite veining.

Wyoming One

Gold mineralisation at Wyoming One is distributed both around and within a small (40 metres by 100 metres near surface (200mRL) broadening at depth), roughly elliptical, sub-vertical, south plunging, feldspar ± augite phyric sill. The deposit has been separated into distinct mineralised zones: the 'porphyry' zone; contact zone; hangingwall zone; the '376' zone; and the '831' zone (Figure 2a).

The hangingwall zone appears stratigraphically controlled by a thin fine-grained carbonaceous mudstone, parallels the contact zone and stratigraphy striking north-northwest and is the only defined mineralisation not having a spatial relationship with a porphyritic host. The zone appears to have been a focus for shearing and is a possible linking conduit with the Myalls United lodes, 500 metres to the south.

The '376' and '831' zones are high grade east-west zones truncating and transecting the sill. The 'porphyry' zone of mineralisation is dominated by a stockwork-like vein system of irregular silicification (locally described as 'mushy quartz') however planar veins have a pervasive shallow north dip with a west-northwest to east-northeast strike.

Wyoming Three

Alteration at Wyoming Three is much less pervasive than at other deposits with mineralisation associated with discrete sub-vertical veining striking about 105° thought to be associated with the major north-west trending structure (Figure 2b).

Caloma

The Caloma deposit is hosted within a moderately to steeply west dipping basaltic-andesite unit. Gold mineralisation is focused within a shallow to moderate west dipping sheeted vein system that approximately parallels the strike of local stratigraphy (Figure 2c). To date 9 vein sets have been identified. Each of these typically pinches and swells, both along strike and down dip, is terminated at the Cotton Formation contact in the west and tends to 'horse-tail' when in contact with the volcaniclastic sediments in the east.

Caloma Two

Stratigraphy at Caloma Two has a distinctive east-west orientation in contrast to the north-north-west orientation at the adjacent Caloma deposit. This dramatic change in trend is interpreted to be associated with parasitic folding along the major northwest trending fault which dislocates stratigraphy from Wyoming Three to Caloma Two. The linking stratigraphy between Caloma and Caloma Two dips steeply to the southwest aligning itself with this major structure to the south. There is some evidence for possible synformal folding.

The mineralisation at Caloma Two is constrained by flat to moderate north dipping en echelon vein sets (Figure 2d). Mineralisation appears to dilate when in contact with a northern bounding volcaniclastic sediment unit. At depth there is evidence for potential reverse saddle reef like structures associated with the closure of the possible synform. Mineralisation linking Caloma with Caloma Two appears to be restricted within or adjacent to a narrow, steeply dipping volcaniclastic sediment unit.

Myalls United

The Myalls United mine is situated 500 metres south of the Wyoming One deposit and has only recently been drill tested. The two parallel quartz reefs hosted in sheared porphyritic andesite were mined to a depth of 200 metres over a strike length of 700 metres between 1883 and 1912 with 70,000 ounces of gold produced (Clarke, 1986). Recent drilling beneath the workings intersected two broad zones of low grade gold mineralisation with higher grade shoots within strong quartz veining and alteration hosted in and along contacts of sheared feldspar porphyry. Litho-geochemical studies suggest the Myalls United sill has affinities to the Wyoming One sill (Mesthos, 2012). Best intersections were 34 metres grading 0.51g/t gold from 294 metres including 4 metres grading 2.98g/t gold from 294 metres and 17 metres grading 0.75g/t gold from 439 metres including 2 metres grading 3.47g/t gold from 442 metres. The grades of the shoots were lower than what was historically mined and further work is planned to better define the high grade shoots.

Conclusions

The mineralisation at Tomingley has few documented affinities with the typical Ordovician hosted magmatically derived deposits identified elsewhere in the Lachlan Orogen in New South Wales. The style of mineralisation and associated sericite-carbonate-albite-quartz alteration assemblage is more typical of orogenic lode style gold deposits. Many smaller orogenic quartz vein lode type occurrences are known to exist in the region, including the Parkes-Forbes district, however the discovery of the Tomingley deposits proves economically significant mineralisation of this style exist within the Ordovician of the eastern Lachlan Orogen. Sulphur isotope work characterising Tomingley with a light sulphur isotope signature compared to heavy sulphur signatures of various orogenic mineralisation in the Parkes-Forbes district may be a factor.

At all four Tomingley deposits, the mineralised fluids are interpreted to have been focused by differential strain in and around the feldspar-pyroxene porphyritic sills due to the rheological competency contrast between the sills and the bounding volcaniclastic sediments. The brittle nature of the sills often leads to the development of shear hosted sheeted vein deposits. Regional east-west compression followed by a major local dextral transpression event has structurally prepared the Tomingley area for significant orogenic gold mineralisation. The

hangingwall zone at Wyoming One is the only economic stratabound lode at Tomingley and the thin graphitic mudstone strata appears to have been a focus for shearing and is a possible linking conduit with the Myalls United lodes.

Acknowledgements

The petrology of Tony Crawford has provided valuable insight into the mineralogy and alteration that are an important part of the understanding of the Tomingley deposits. Core logging and numerical modelling by Peter Schaubs (pmd*CRC) has added significantly to the understanding of the structural setting of the Tomingley deposits. Honours theses by Bamford and Mann have aided characterisation of the overburden within the project area. An honours thesis by Mesthos on geochemistry of the host volcanics has defined and characterised three groups of porphyritic intrusions within the belt hosting mineralisation.

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Figure 1
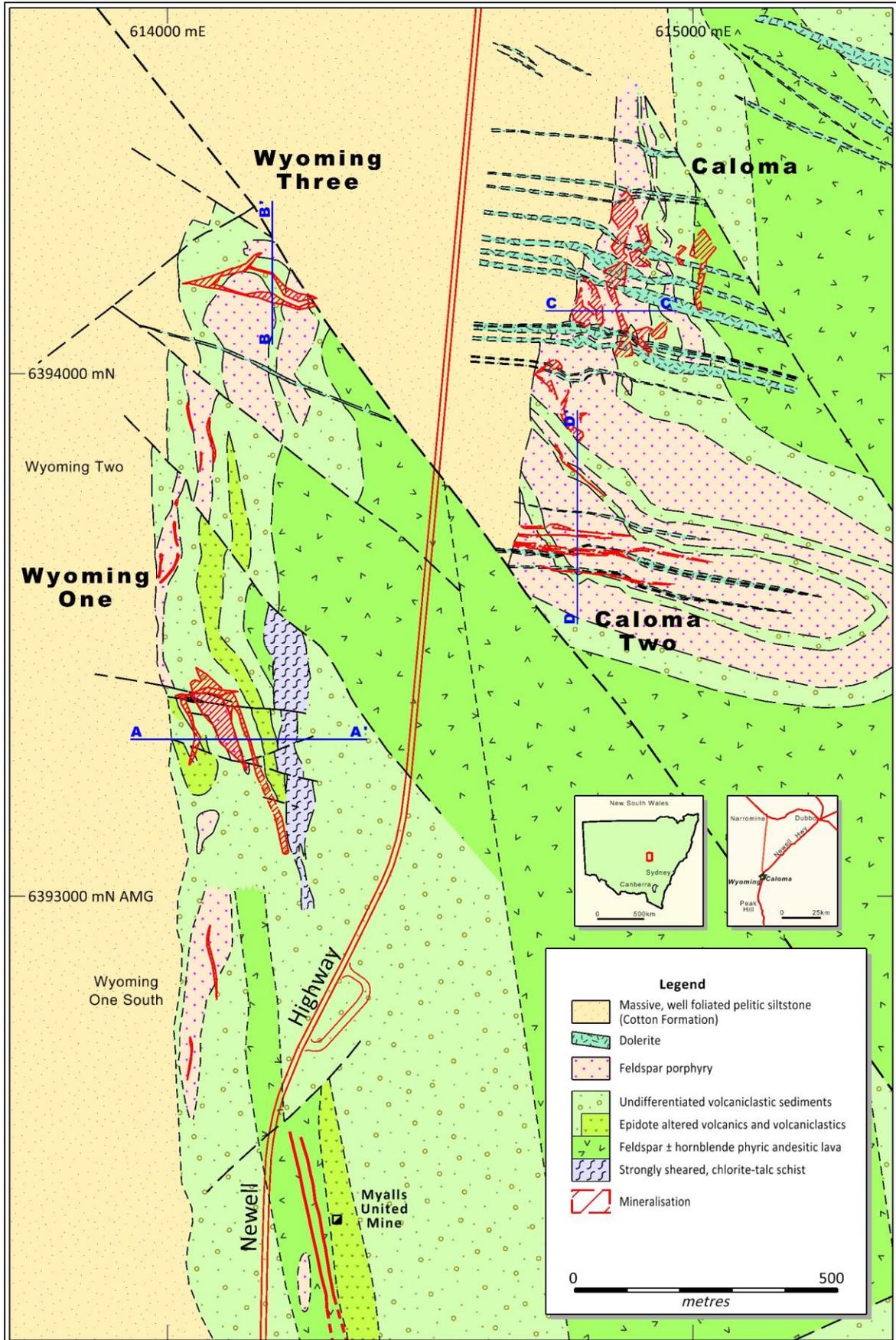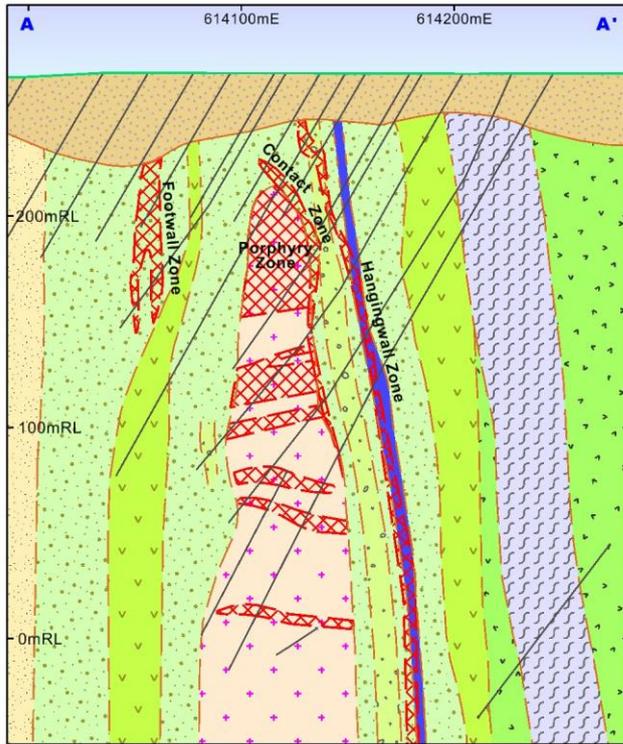
Figure 2a: Wyoming One cross section 6393300mN
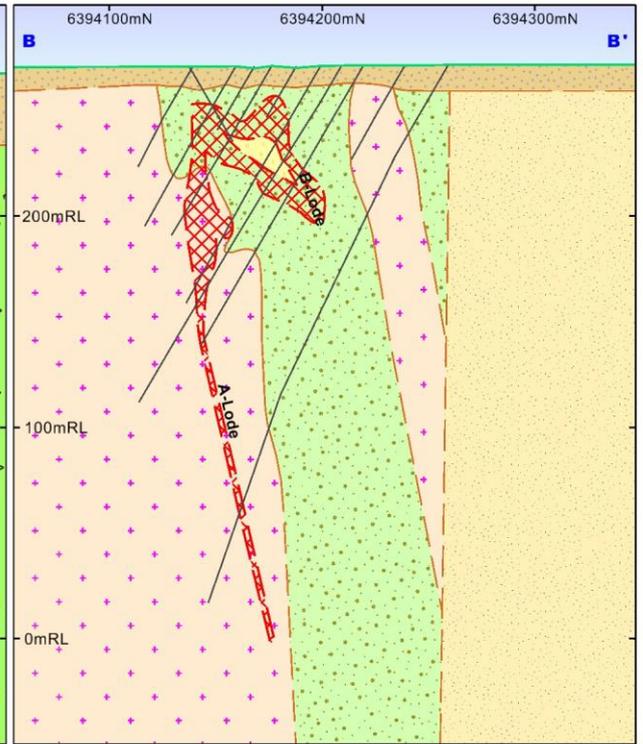
Figure 2b: Wyoming Three cross section 614200mE
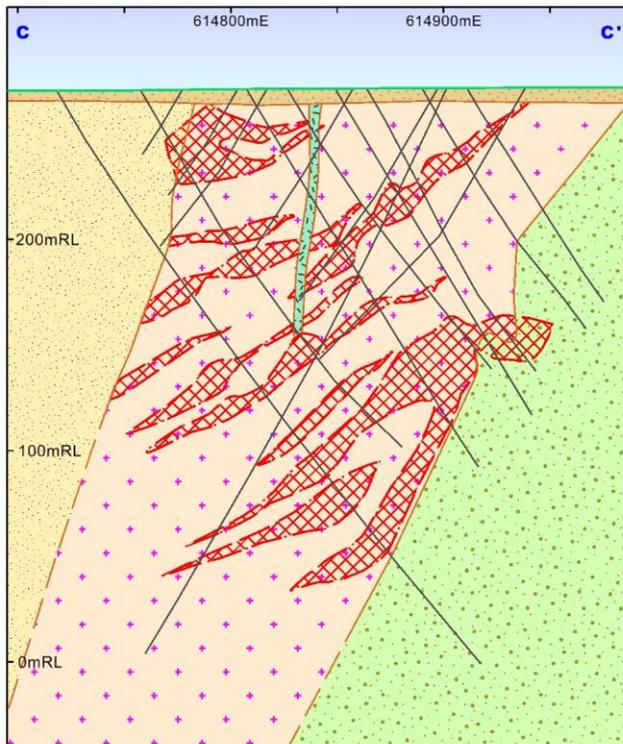
Figure 2c: Caloma cross section 6394120mN
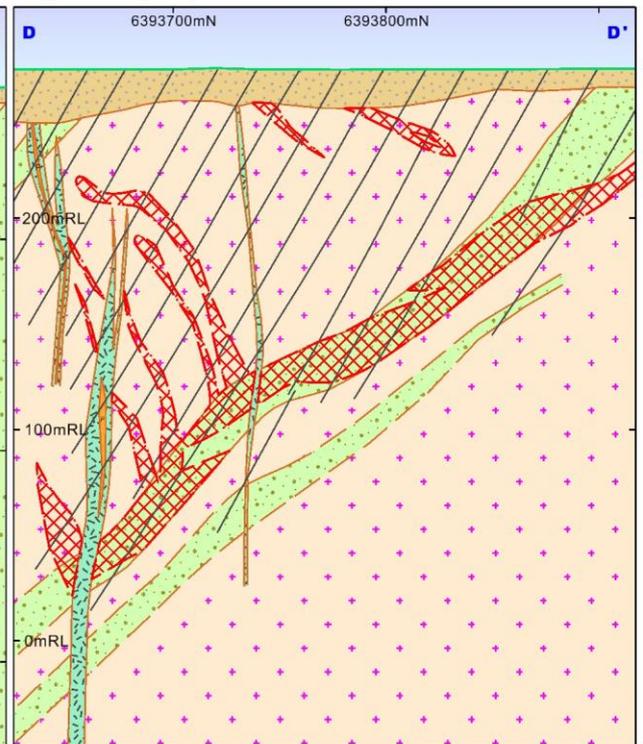
Figure 2d: Caloma Two cross section 614780mE

Legend

Alluvium	Feldspar porphyry
Quartz	Undiff volcaniclastic seds
Siltstone (Cotton Formation)	Black graphitic shales
Dolerite	Volcaniclastic conglomerate
Pegmatite	Epidote altered volcanics
	Chlorite-talc schist
	Andesitic volcanics

Mineralisation

Drill hole trace
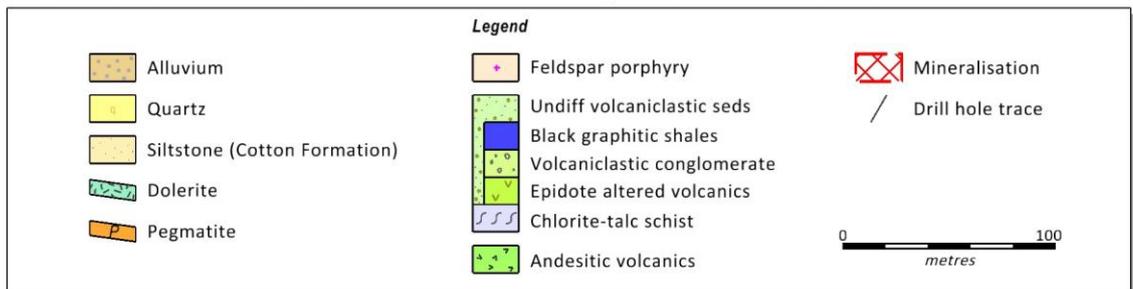
THE COPPER CHERT DISCOVERY, MOUNT LYELL MINERAL FIELD TASMANIA

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Abstract

The Copper Chert deposit is a new discovery located in the Comstock Valley on the northern end of the Mount Lyell mineral field, Queenstown Tasmania. The deposit is part of the large Cambrian hybrid volcanogenic-magmatic Cu-Au-Ag system at Mount Lyell, which has been exploited for approximately 120 years from 22 separate mine workings. The Mount Lyell mineral field occupies the southern end of a belt of polymetallic base and precious metal deposits within the late Middle Cambrian Mount Read Volcanics (MRV) succession of western Tasmania.

The Copper Chert deposit is considered to represent a new style of volcanic hosted, copper rich polymetallic mineralisation for the Mount Lyell mineral field. The mineralisation is largely Cu-Au-Ag but also contains significant intersections of Pb-Zn-Ag. The deposit is hosted in an intense microcrystalline silica alteration package known locally as the Comstock Chert. It also has a stratigraphic control within the lower Tyndall Group and across the underlying contact with the Central Volcanic Complex, within the MRV.

The discovery can be attributed to drilling a zone of anomalous conductivity generated by both Down Hole Electro Magnetics (DHEM) and surface surveys of Controlled-Source Audio-Frequency Magneto-Tellurics (CSAMT).

A maiden Inferred Resource of 4 MT @ 1.36% Cu, 0.81 g/t Au and 40 g/t Ag was estimated in March 2013, based on 27 drill holes for 10,216 metres of diamond drill core. An on-going exploration program includes infill and extension to upgrade the resource confidence level, and applying the successful strategy to search for a repeat deposit within the prospective stratigraphy.

Geological Setting

The Mount Lyell field and the Henty-Mount Julia-Darwin trend of gold deposits are located in the southern half of the MRV, an established world class province of late Middle Cambrian polymetallic VHMS deposits (Figure 1). The host geology of the southern MRV is dominated by mainly calc-alkaline submarine rhyo-dacitic and minor andesitic volcanics, resedimented volcaniclastics and marine sediments. These rocks comprise the central belt within a Middle Cambrian post collisional tectonic domain called the Dundas Trough. Mineral deposits in the southern MRV are mainly synvolcanic Cu-Au-Ag and Au-Ag-Cu systems with both near sea floor massive sulphide and deeper high sulphidation, possibly intrusion-related, affinities.
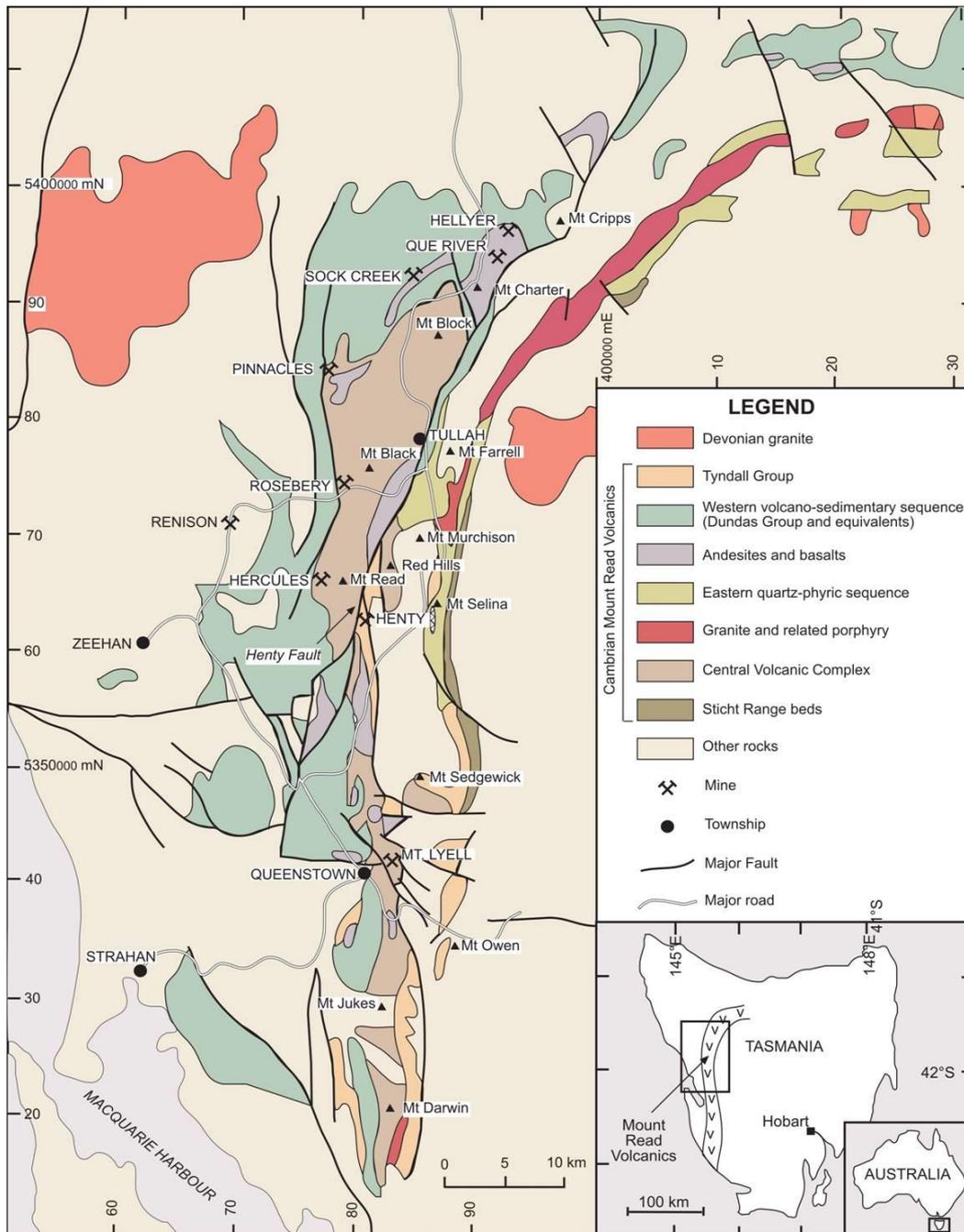
Figure 1: Mount Read Volcanics Regional Geology Map (from Gifkins et al, 2005)

The Copper Chert deposit at Comstock (Figure 2) is hosted in a body of intense microcrystalline silica surrounded by a zone of schistose sericite-silica-pyrite alteration, which replaces andesites and polymict epiclastic style lithic volcaniclastic breccias and conglomerates. The chert varies in texture from massive to network fractured to brecciated. The brecciated chert appears to show at least two generations of silicification. The main body of copper mineralization occurs as a relatively high grade core association of coarser grained chalcopyrite-pyrite-bornite-chalcocite-mawsonite, with characteristic breccia infill and lacey network overprint textures. Lower grade copper +/- lead-zinc mineralisation occurs outside the high grade core (Figure 3).

Stratigraphically the deposit is restricted to the base of the Tyndall Group, which is the uppermost sub division of the MRV. The deposit is roughly stratiform and stratabound, with all significant alteration and mineralisation encountered to date occurring stratigraphically beneath a Lower Tyndall Group unit of soft sediment deformed hematitic limestone and

calcareous sandstone and conglomerate, patchily interfingered with coherent and fragmental andesite. The hematite appears to represent the outer-most zone of hydrothermal alteration in the hanging wall but the carbonate is interpreted as biogenic/sedimentary in origin.

There is a degree of structural control as well as stratigraphic and alteration facies control on the deposit. Copper Chert (and all other primary deposits at Mount Lyell) sits in the immediate hanging wall of the Great Lyell Fault, a Middle-Late Cambrian synvolcanic growth fault which marks the boundary between the hydrothermally altered Middle Cambrian volcanics and the unaltered Late Cambrian sequence of siliciclastic conglomerates, sandstone and minor lutites, known as the Owen Conglomerate. The Great Lyell Fault was probably a graben forming normal fault ~500Ma but is now a west-northwest dipping reverse fault, due to compressional shortening and inversion during Devonian orogenic deformation. The mineralisation tends to be restricted to one side of the host chert body, suggesting that prospect scale faulting also imposed some control on fluid focus, however to date no direct evidence of such structures has been detected.
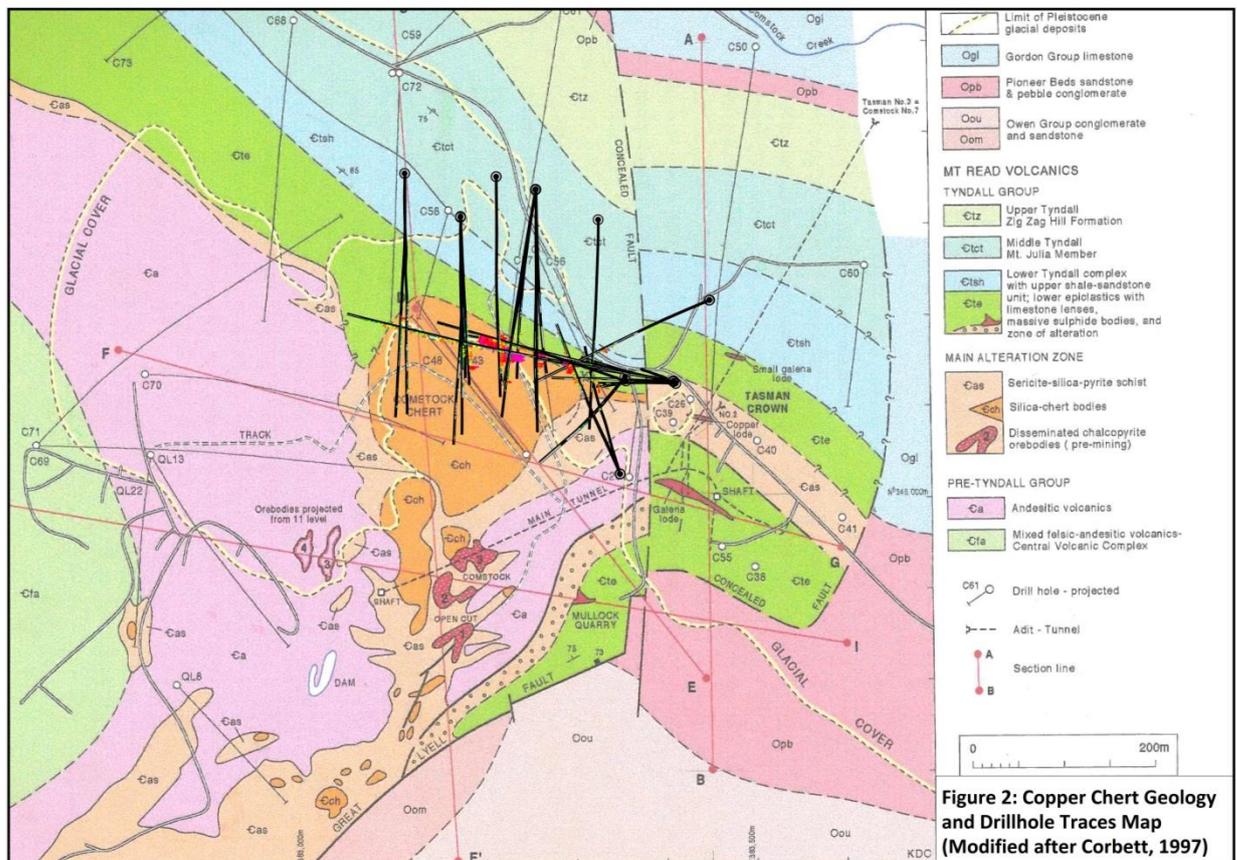
Figure 2: Copper Chert Geology and Drillhole Traces Map (Modified after Corbett, 1997)

The Copper Chert Discovery

Copper Chert was discovered in 2008 by an intersection of 22 metres @ 1.9% Cu in a diamond drill hole which passed midway between the modelled positions of a surface grid line based CSAMT conductive anomaly and an off-hole DHEM conductor from an earlier drill hole testing a prospective stratigraphic position. At the time surface exploration drilling had a lower priority than expenditure within the operating Prince Lyell mine and consequently it was not until 2011 that follow-up drilling confirmed that a significant deposit had been discovered.

Systematic drilling through 2012-2013 on north-south fences, with approximately 50 metre spacing, showed that the earlier holes had been drilled essentially down plunge and parallel to the strike of the deposit.   No potentially ore grade copper mineralisation occurs outside the chert alteration facies but patchy lead-zinc +/- gold intersections have been achieved in both

chert and schist alteration host rocks, particularly immediately west of the main copper mineralisation.

Ground based and down hole electrical geophysics, combined with 3D modelling of targets based on a combination of conductors and the results of previous drilling, are proving to be the most effective exploration methods for siting drill holes. Outcrop mapping in the area is considered adequately covered and soil and stream sediment geochemistry are unreliable due to the prevalence of glacial sediment cover and ground disturbance from historic mining and infrastructure. Orientation scale lithogeochemistry on drill core has provided no evidence of vectors to ore. Current drilling is designed to extend and close the resource in both the up-dip and, especially, the down dip directions.

Figure 3: Copper Chert Long Section
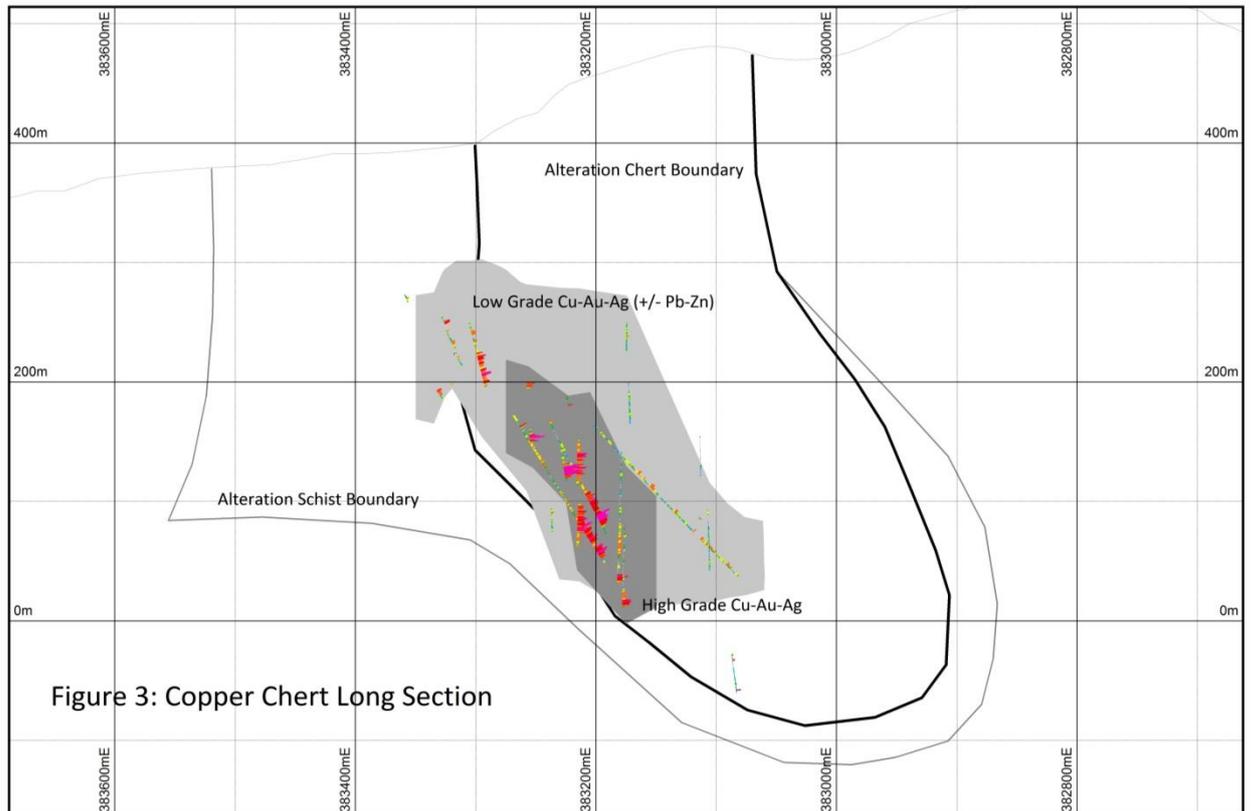
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A NEW INTRUSION-RELATED GOLD FIELD IN THE THOMSON FOLD BELT, NSW

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Key Words: copper, gold, lead, zinc, silver, bismuth, tungsten, IRG

Abstract

Thomson Resources has drilled eight magnetic anomalies in the southern Thomson Fold Belt, NSW. Large silica-carbonate alteration zones with quartz-carbonate-pyrrhotite veining have been intersected at all eight. The mineralised systems share a common metal association, viz. Au, As, Bi, Cu, Zn, Pb, W and Mo. Felsic intrusions have been intersected at Cut A, Cut Ac, F3 and, now, F1. Intersected granodiorite is a reduced peraluminous I-type, a chemistry commonly associated with Intrusion-related gold (IRG) deposits worldwide. Age dating of one of the intrusions has ruled out Thomson's previous deposit model (Cobar-type). The metal association, alteration, and intrusive chemistry all support an IRG model for this mineral system. Thomson Resources has clearly discovered an IRG mineral province in the Thomson Fold Belt.

Introduction

The Thomson Fold Belt is a major geological province covering a large area of south-east Queensland and north-western NSW. As originally defined (Kirkegaard 1974) it was thought to be of Palaeozoic age, predating Mesozoic cover, although Neoproterozoic rocks are known to occur in the Anakie inlier of northeast Queensland. Its southeastern boundary has been controversial – placed on the Darling River lineament by Kirkegaard (1974), it was proposed much further north by Murray and Kirkegaard (1978), and has been moved to several other positions by later authors (e.g. compare positions in Hill et al 2008, Glen et al 2007, Glen et al 2013). Recent work has cast doubt on any particular structure as forming such a boundary (Burton 2010). However, the southwestern boundary of the Thomson Fold Belt is marked by a major structure – the Olepoloko Fault (Figure 1).
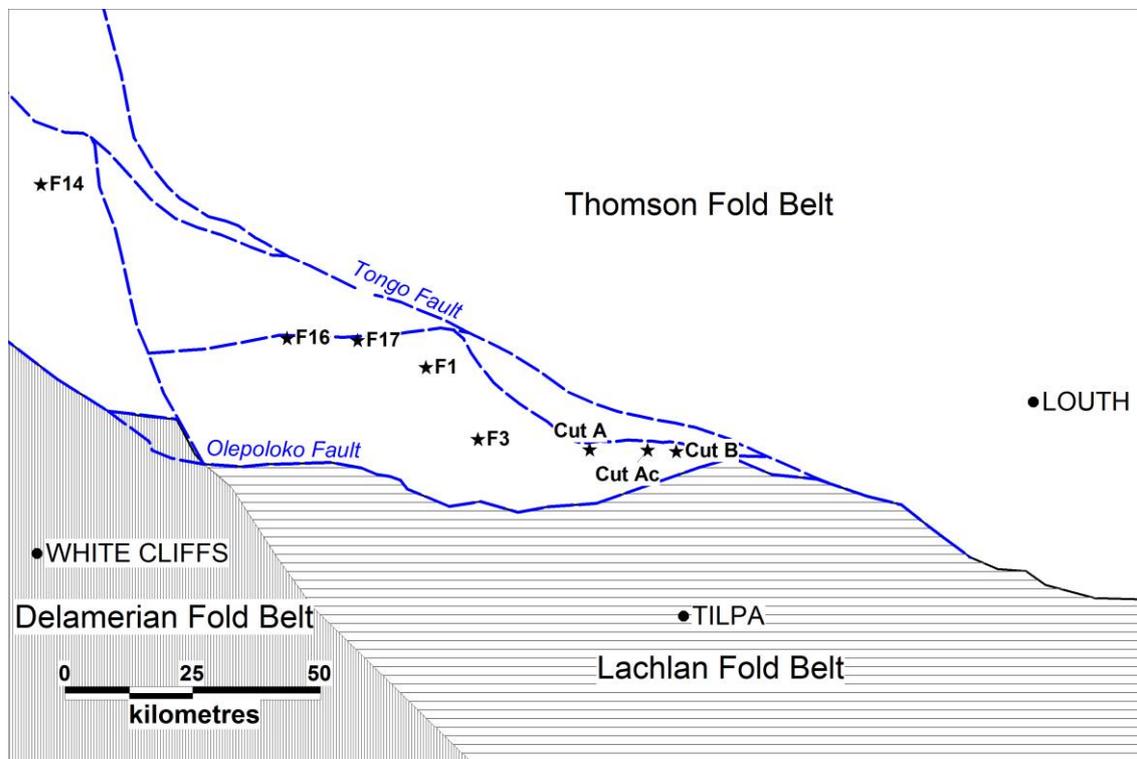
Figure 1. Location Map.

Cover Rocks

Late Jurassic to Cretaceous Eromanga Basin sedimentary rocks unconformably overly Thomson Fold Belt basement. Sediments within the Eromanga Basin include a lower package of non-marine, sand-dominated, braided fluvial systems separated by a marine package with thick mudstones from an upper non-marine package indicative of meandering fluvial systems traversing a flood basin dominated by coal swamps and lakes (Alexander and Sansome 1996). This sequence is host to oil and gas reserves in Queensland and South Australia. Evidence of hydrocarbon movement has been detected by Thomson Resources east of Bourke where a thick sequence of pyrite-cemented sandstones was encountered in drilling. These rocks probably developed by bacterial and/or thermochemical reduction of formation water sulphate and the resultant production of hydrogen sulphide at palaeo-oil/water contacts (Ellis 2006).

Regional Setting

The Thomson and Lachlan Fold Belts form part of the Tasmanides of Eastern Australia, a collage of deformed and intruded Palaeozoic rocks formed as result of repeated collisional tectonic events. The Lachlan Fold Belt in NSW is one of the world's great metallogenic provinces. It hosts at least two giant porphyry copper/gold systems (Cadia/Ridgeway and North-Parkes) as well as the giant Endeavor lead/zinc/silver deposit in the Cobar Basin, the large Woodlawn VHMS copper/lead/zinc deposit and many other smaller deposits. Just 20km to the north of Endeavour in the Cobar Basin, the Lachlan Fold Belt goes undercover and the Thomson Fold Belt appears. New data acquired by the NSW Government under the "Exploration NSW" and "New Frontiers" initiatives have confirmed many distinct similarities between the Thomson and Lachlan Fold Belts and provided strong encouragement that major new deposits are present in the Thomson.

Regional Geophysics

Airborne magnetic surveys commissioned by the NSW Government highlighted widespread magnetic signatures in the Thomson that mirror the kind of magnetic responses in the Palaeozoic rocks of the exposed Lachlan Fold Belt to the southeast. The Palaeozoic can be "seen" through the non-magnetic Mesozoic rocks and a deformed volcano-sedimentary sequence with multiple igneous intrusions can be inferred.

A similar picture emerges from the seismic reflection survey (Glen et al. 2013), which imaged sediments and volcanic rocks against the major north-dipping Olepoloko Fault located near Tilpa (Figure 2). The Olepoloko Fault forms the southern and southwestern boundary of the Thomson Fold Belt from Milparinka to Tilpa, separating it from the Delamerian Orogen and Lachlan Fold Belt (Figure 1). Reverse movement on the Olepoloko Fault of at least 5km is needed to juxtapose the Late Devonian sediments (Mulga Downs Group) of the Nelyambo Trough (which is inferred to rest upon Lachlan Fold Belt) against older sediments of the Thomson. This movement, possibly of Kanimblan (Carboniferous) age, is likely to have been accompanied by other compressional structures, such as the fold structures evident in the seismic data. Although the Olepoloko Fault is clearly a major structure at this point, it is difficult to trace much further east of Tilpa and as Burton (2010) suggests it may not in any case delineate a Thomson-Lachlan Fold Belt boundary.

Target Prospectivity

Initially, the targets for exploration in this area were the discrete magnetic anomalies with similar characteristics to the magnetic responses of the Cobar deposits. Many of the Cobar basin deposits are associated with "bulls-eye" magnetic anomalies (the giant ore deposit Endeavor being the best example, Lawrie and Hinman 1998) associated with extensive magnetic pyrrhotite envelopes which surround the main deposits. Within the Thomson, about twenty high priority targets with similar magnetic expressions to the Cobar deposits were identified. However, the intrusive granite age obtained (see below) rules out a Cobar-type occurrence in this area. Instead, a new model of an intrusion-related gold (IRG) mineral system is applicable.

The Intrusion-related gold model was developed relatively recently (Thompson et al. 1999, Lang et al. 2000, Lang and Baker 2001) and shares a pipe-like geometry with Cobar-type

deposits. However, the granites that have been recorded near Cobar-type deposits are thought to predate mineralisation (Lawrie and Hinman 1998). Various aspects of the new model (Figure 2) were reviewed to compare to features seen in core drilling.
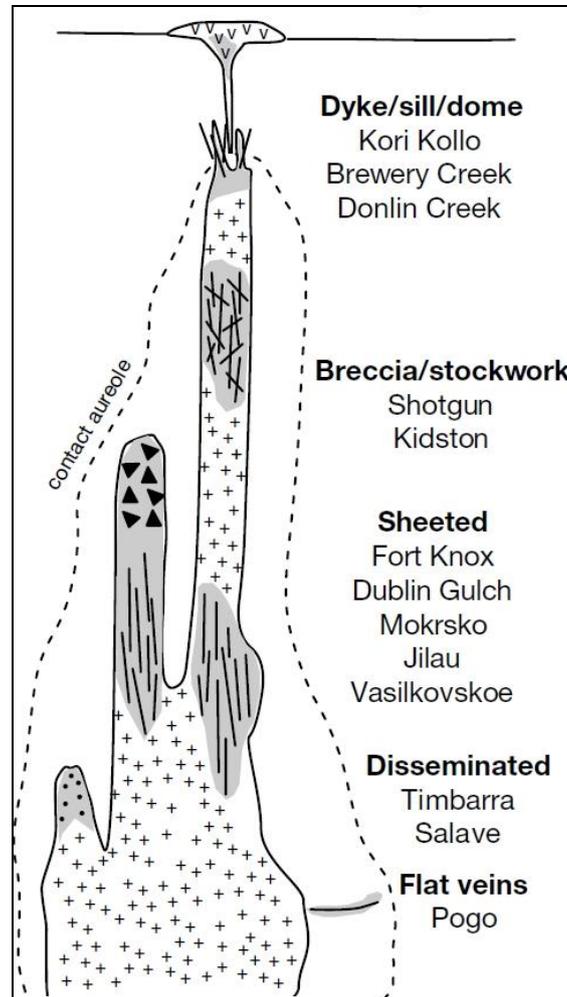
Figure 2. Intrusion-related gold model – from Baker (2000).

Target Geology

Basement rocks in the NSW portion of the Thomson Fold Belt have been assigned various ages from Neoproterozoic through Cambrian, Ordovician, to early Devonian (Glen et al 2013) extending for about 450km from near Tibooburra to east of Bourke. The focus of this paper is on that area of the Thomson between the Olepoloko and Tongo Faults (Figure 1), where there is no outcrop and the geology is known only from 15 mineral exploration holes drilled to basement between 2007 and 2013.

Most holes intersected a turbiditic sedimentary sequence dominated by siltstone with minor sandstone horizons. One hole intersected a thick sequence of pyritic, graphitic black shale. Several of the later holes drilled intersected granite, granodiorite and tonalite. Cleavage is moderately well developed in the siltstone.

Some zircon provenance work has been done on sandstone samples from this drill core (Glen et al. 2010, 2013). Results from the Cuttaburra area (Figure 1, Cut B) revealed a provenance minimum age of 501 Ma. From drilling at F16, 80km west, a sample of sandstone yielded a minimum age of 508 Ma. These results are similar, in minimum ages and in the overall zircon probability patterns to results from the Cobar Basin – a sample from the Alley Sandstone

Member yielded a minimum age of 500 Ma. This sample is from outcrop, and the same bed contains Early Devonian brachiopods. So, all three areas appear to have Cambrian highland areas as sediment sources. Glen et al (2010) infer that "*the Thomson Orogen possessed a shared history of ... deposition of the Cobar Supergroup with the Lachlan Orogen*". However Glen et al (2013) prefer a correlation with the Cambrian Warrata Group to the west.

More definitively, a SHRIMP age was derived from magmatic zircons in the granodiorite intersected at Cut A (Figure 1). This was a U/Pb magmatic crystallisation age of 428.3 ± 2.8 Ma (Emma Chisholm pers. comm. 2012). The granodiorite does appear to have an intrusive contact; this was measured in orientated core as dipping 85° towards 169° (southeast).

144 measurements of bedding down hole from 181m to 597m showed a reasonably consistent strike and dip (Figure 3) of about 125°, dipping 75° towards 215° (mean measured at 63° to 210°).
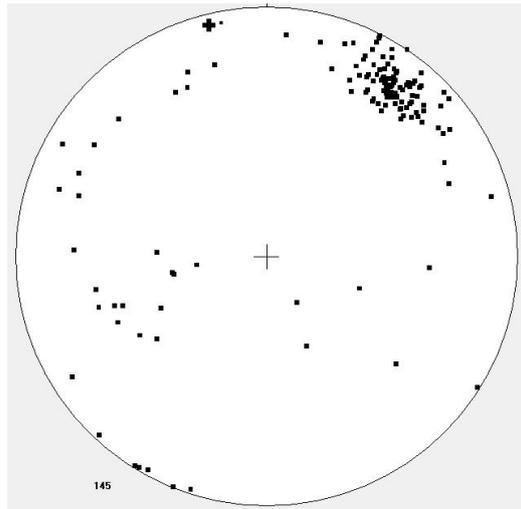
Figure 3. Bedding measured in CutAD01, n=145. Granite contact measurement shown as cross.

So, with the intrusion dated as Early to Middle Silurian, the likely age of the host sediments appears to be constrained between Late Cambrian to Early Silurian; in any case older than the Cobar Basin sediments.
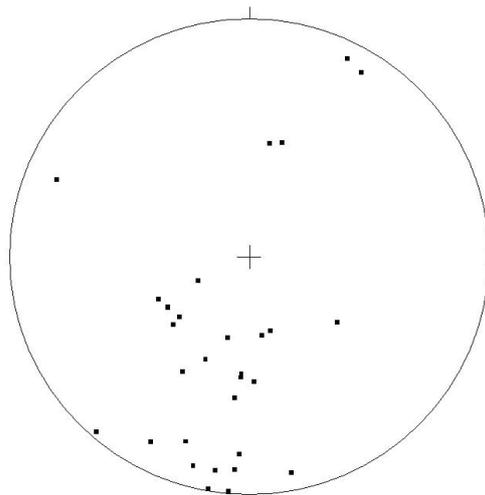
Figure 4. Orientation of mineralized veins in drilling at Cut A (n=31).

Measurements of veins in orientated core at Cuttaburra A show that the veins have a high angle to bedding and the granite contact (compare Figures 3 and 4). Measured veins dip towards the NE and appear to cluster around either moderate (35° to 25°) or steep (80° to 15°) dips with angles of 75° or 35° with bedding. Similar but more complex relationships are

observed at Cuttaburra B (bedding folded, but there is a cluster at about 80˚ to 040˚, veins cluster at 60˚ to 180˚, angle between the two 55˚).

Alteration

Pervasive silica alteration with a minor carbonate component and crackle quartz-carbonate-pyrrhotite veining alteration occurs in all holes drilled to date, bar CutBD03 which was targeted at an IP anomaly rather than the magnetic. These alteration systems have large footprints – at F3 the alteration extended from where basement was intersected at 264m downhole to the termination at 716m – a downhole width of 452m. Similarly at Cut A a downhole width of 506m of alteration was intersected from base of cover at 135m to end of hole at 641m. At Cut B and F16, Hylogger analysis confirms the presence of significant ankerite and siderite, as well as muscovite – iron and potassic alteration. This assemblage is common to IRG deposits (Maloof et al. 2001, Hart 2007).

Note that no other basement drilling has been carried out in the area, making the success rate 100% - all magnetic anomalies tested to date are represented by large alteration systems.

Geochemistry

Sulphur isotope analyses have been obtained from galena and pyrite from four of the drilled targets. All results are moderately positive and relatively consistent within anomalies, but there is a weak trend from higher values in the west to lower values in the east (F14 $\delta^{34}S‰$ = 10.2, F16 11.1-12.6, Cut Ac 6.6-9.1 and Cut B 5.1-7.8). These values are all consistent with the action of hydrothermal fluids (Mernagh 2007), perhaps with more oxidized fluids in the Falcon region versus reduced fluids in the Cuttaburra region. However, they are markedly different from the values obtained at the Donlin Creek IRG which were strongly negative (-16 to -10, Goldfarb et al. 2004), as well as from other NSW granites (for example -2 to +2 at Ardlethan, Ren et al. 1995). They are also a little higher than that calculated for early IRG models (0-5, Lang et al. 2000).

Limited isotopic analysis has also been undertaken. Lead isotope analysis was carried out on galena from drill holes at F14, F16, Cut Ac and Cut B (Figure1, Table 1). The $^{206}Pb/^{204}Pb$ ratios vary from 18.02 to 18.12 suggesting at least some basement fluid involvement (Mernagh 2007).

Table 1 Results of galena Pb isotope analysis

Sample No	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
CutAcD02 398-398.2m	18.118	15.637	38.282
CutAcD02 398-398.2m	18.117	15.636	38.282
CutBD02 134m	18.096	15.630	38.249
F14D01: 308.4m	18.050	15.638	38.237
F16D02: 331.7-331.8m	18.025	15.622	38.216
F16D02: 336.3-336.5m	18.020	15.620	38.203

Whole-rock geochemical analysis was carried out on two of the granite samples (Cut A and Cut Ac). The chemistry of both samples appears to be consistent with I-type, rather than S-type affinity, although they appear somewhat peraluminous as calculated from their CIPW norms (Phil Blevin, unpublished internal report). The main argument for them being I-type is that the less felsic sample has an SiO2 content that is too low for normal S-types and the trace element contents are more typical of I-types in the granodiorite to granite range. Alteration in the samples has probably served to make them more peraluminous, presumably through the loss of alkalis, especially Na. There is no evidence for extended fractional crystallisation to more evolved compositions, and these granitoids would not be expected to be associated with "tin granites" in the sense of being centres to highly fractionated Sn W-centred zoned mineral systems. More likely, they may represent mildly reduced (to mildly oxidised) I-type granites typical of those associated with W skarns and granite related gold

deposits. Reduced I-type granites are characteristically hosts for Intrusion-related gold systems (Thompson et al. 1999).

Mineralisation

The metal suite associated with IRG deposits is characteristic - Au, As, Bi, Cu, Zn, Pb, W, Mo, Sb, Te (Thompson and Newberry 2000; Thompson et al. 1999; Lang and Baker 2001). Most of these show marked anomalism at the various places drilled to date (Table 2).

Tungsten in particular is characteristic. Five of the eight anomalies show anomalous tungsten in assays with extensive scheelite recorded in the Cut A granodiorite and an assay of 0.6% W in a vein at Cut B.

Table 2: Drilling Results from the Thomson Tenements

Anomaly	Comments	Au (g/t)	Ag (g/t)	As (%)	Cu (%)	Zn (%)	Bi (%)	Mo (ppm)	Sn (%)	W (%)
All drilling to 2010	Various anomalies – Cut B, F3, F14, F16, F17	0.1	71	0.4	0.1	0.2	0.1	23	-	0.4
Cut A	Veined, altered turbiditic sediments	3.7	58	1.0	0.2	1.0	0.1	105	0	0
Cut B	Strong mineralisation in quartz-pyrrhotite vein	0.5	113	3.1	0.5	4.2	0.4	171	0.8	0.6
F1	Veined granite; first granite-hosted anomalies	0.2	13	1.0	0.2	0.1	0.002	1580	-	0.3

Note – *all values quoted are of the maximum value seen per drill hole in >0.5m half-core cuts. Samples were analysed by ALS laboratories in Orange, NSW. Gold was analysed by Au-AA26: Fire Assay Fusion and Atomic Absorption Spectroscopy. Other elements were analysed by ME-ICP61: 4 acid digestion, HCl leach and inductively coupled plasma-atomic emission spectrometry. Tin was analysed by ME-XRF15b: XRF Fusion. Note- Te not analysed for, Sb elevated but not shown.*

Target Geophysics

Several geophysical techniques were applied to try and identify the source of the aeromagnetic anomalies and to identify potential mineralised bodies. To date, none of the techniques trialled has proven to be particularly useful.

Magnetic modelling
Extensive modelling of the magnetic anomalies has been carried out at various prospects with differing interpretations; broadly speaking, models demand either deep (below drilling), small, strongly magnetic (SI of 0.05 or greater) bodies or large weakly magnetic bodies (SI 0.01 or less). In most drilling to date, the material intersected has low magnetic susceptibility, or has very narrow intervals of moderate susceptibility disseminated or massive pyrrhotite e.g. CutBD02 average SI of 0.02, CutAD01 average SI of 0.0016. This favours the second alternative which seems at odds with the discrete bulls-eye nature of the anomalies. Recent drilling at F1 has yielded magnetic susceptibility readings with averages over the hole closer to those in the stronger models (SI of 0.06 for F1DD01).

Remanence
The magnetic mineral pyrrhotite has some unusual characteristics. Monoclinic forms of pyrrhotite are in general more defect-rich than the more symmetrical hexagonal forms, and thus are more magnetic. It also is capable of carrying remanent magnetizations of thermal, chemical or detrital origin, meaning it retains an original magnetisation which may differ substantially from todays (for example from a time when the Earth's magnetic poles were reversed). This can greatly increase or distort the magnetic response we see today; for instance, pyrrhotite is known to cause "magnetic low" anomalies.

Petrology was done on a sample which it was thought might contain non-magnetic pyrrhotite – this turned out to be melnikovite, a form of pyrite often formed by in-situ supergene alteration of pre-existing pyrrhotite.

Remanence was identified in testing of magnetic pyrrhotite elsewhere. Results were variable; pyrrhotite from anomaly Cut B had K values that ranged from 6 to 63 whereas at F3 the K values were from 0.4 to 6. Modelling at Cut B predicted that the remanent magnetization direction is approximately 5 degrees steeper than the geomagnetic field. This is not considered particularly significant, however the measured remanence could greatly increase the apparent magnetic anomaly.

Gravity
A detailed surface gravity survey was carried out at the Cut B anomaly. The effect of basement topography was considered low as all three drill holes at the prospect encountered basement at about the same downhole depth (90m). The gravity anomaly was significant and generally co-incident with the magnetic anomaly. The centre of both geophysical anomalies lies about 200m of the section line of the three drill holes.

Specific gravity measurements using a compact balance were taken from CutBD02 core; the average SG of sedimentary samples was 2.77. This value is quite high and probably reflects the siliceous alteration seen in core. In turn, this could account for the surface anomaly.

The fact that the gravity anomaly is coincident with the aeromagnetic anomaly reduces its usefulness as it is a much more expensive technique.

IP
Several dipole-dipole IP lines were recorded over the Cuttaburra prospects, with strong anomalies showing up at most. Drill hole CutBD03 was specifically targeted at an IP anomaly and intersected thick black shale with disseminated pyrite, thus explaining the anomaly. The anomalous material is sedimentary in origin and has nothing to do with the mineralising process.

EM
Both surface (SIROTEM) and downhole EM surveys have been carried out. No off-hole anomalies were seen in either form of the surveys, probably indicating that either there are no conductive bodies present or that the technique is not appropriate. It would be expected that EM surveys would be highly affected by the conductive overburden of flat lying mudrock, which would reduce the transmitted EM field at depth, making it difficult to detect off-hole conductors. There was a minor in-hole response measured at a depth of 410m in CutBD02, corresponding to a 20cm pyrrhotite vein.   Modelling suggests that this conductor does not increase in size away from the hole.

Downhole Magnetometry
Recently, 3-component Downhole Magnetic (DHMAG) surveying was completed at the Cuttaburra project. The DHMAG data were collected using a Crone RAD tool. The RAD tool uses 3 orthogonal fluxgate magnetometers and accelerometers to continuously record the magnetic field and orientation of the tool as it is raised or lowered in the drill hole, then into magnetic east, north and vertical components.

No off-hole magnetic anomalies were recorded in the 3 surveys conducted (Cut A, Cut B, Cut Ac).

Summary

The drilling conducted so far in the southern Thomson Fold Belt has tested eight magnetic anomalies. All have similar magnetic characteristics, being 1 to 3km across and bulls-eye or annular in shape. All drilling intersected similar basement geology, alteration and mineralisation with siliclastic sediments, extensively altered by siliceous and carbonate alteration, veined by quartz-carbonate-pyrrhotite veining, and with similar trace element (metal) signatures. Later drilling encountered similar felsic intrusions with affinities to peraluminous reduced I-type granites. Taken together these features strongly suggest that

the region hosts an Intrusion-related gold mineral field (Table 3). The very limited drilling that has taken place on the anomalies to date (1 to 3 holes each) has highlighted the potential but not fully tested the systems.

Table 3 Comparison of drilling results to the IRG model

Category	Characteristics of Intrusion-related gold deposits	Features observed in the southern Thomson Fold Belt
Tectonic setting	Youngest, furthest inboard, moderately reduced (ilmenite-series) plutonic suite that developed during weak post-collisional extension behind a thickened continental margin (Hart 2007)	Well inboard of Macquarie Arc; Lachlan Fold Belt represents thickened continental margin
Structural controls	Many aligned with the strike direction of extensional fractures that likely result from the same far-field stresses that controlled pluton emplacement and, therefore, may parallel the elongate direction of the pluton.	No deposit identified as yet. Mineralised veins are at high angle to bedding.
Host Rock	Siliclastic sediments in passive margin environments or back arc basins.	Siliclastic sediments – mixed turbiditic siltstones and sandstones with minor black shale
Associated Igneous Intrusion - Composition	Reduced, peraluminous, I-type granite/granodiorite	Mildly reduced, peraluminous, I-type granodiorite
Associated Igneous Intrusion – Geometry	Generally small and solitary, often elongate ($1-10km^2$)	Magnetic anomalies are discrete and similar in size ($1-10km^2$)
Alteration Minerals	Carbonate, Silica, Feldspathization, Sericitization, Biotite.	Silica, Carbonate, Sericitization, Muscovite. Biotite and Feldspars occur but have not been identified as alteration minerals.
Style of mineralisation and veining	Sheeted vein systems, Stockworks	Sheeted vein systems
Ore minerals	Pyrrhotite, Pyrite, Arsenopyrite, Chalcopyrite, Sphalerite, Scheelite, Galena, Molybdenite, Stibnite, Bismuthinite, Loellingite	Pyrrhotite, Pyrite, Arsenopyrite, Chalcopyrite, Sphalerite, Scheelite, Galena, Molybdenite, Cassiterite. Likely bismuth minerals identified in petrology.
Metal suite	Au, As, Bi, Cu, Zn, Pb, Mo, W, Sb, Te	Au, As, Bi, Cu, Zn, Pb, Mo, W, Sb,
Deposit Associations	No Porphyry-type deposits in the same belt	No Porphyry-type deposits known
Magnetic characteristics	Annular (ilmenite or minor magnetite, surrounded by pyrrhotite halo) or bulls-eye positive magnetic anomalies	Mostly bulls-eye positive magnetic anomalies; F1, Cut B are annular

Acknowledgements

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MINERS NEED DEEPER MAPS

Insights into deep exploration via district scale gradient array IP in the Orange Porphyry Region

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Gold and Copper Resources

Summary

The cost of exploration is rising, and the rate of new discovery is decreasing. The "easy pickings", which have sustained the exploration industry over the past decades, have been discovered. Explorers are required to look deeper into the ground to target mineralised systems. Deep drilling in areas with little outcrop to develop targets is expensive. Surface cover provides little reassurance that you are drilling in the right place. What is needed is the ability to see deeper into the ground, to produce deeper maps in order to eliminate wildcat drilling.

In the search for porphyry systems, IP (induced polarisation) has a long history of use, given its ability to detect large disseminated sulphide bodies that surround porphyry systems.

The discovery of Ridgeway under cover was the stimulus for Gold and Copper Resources (GCR) to initiate a substantial exploration strategy to look under cover for porphyry systems. GCR is undertaking a large-scale gradient array IP (or Super IP) survey, targeting copper-gold porphyries and related systems, which are blind at surface, or under cover. GCR have overcome many logistical challenges, and are now successfully deploying the Super IP survey across its exploration licences. The presence of porphyry-related alteration and mineralisation intersected in early drilling reinforced its decision.

Introduction

Since 2003, Gold and Copper Resources have put together a significant land package, with exploration licenses over approximately 1,500km^2 in the Central West of NSW (Figure 1). Exploration is focused on the discovery of economic copper-gold porphyry mineralisation, of similar scale and size to the currently mined porphyry systems at Cadia Valley. GCR believes there is a significant mineral endowment still to be found within the Orange region, but that future exploration successes are likely to be under cover or "blind" at surface.

To that end, GCR are in the process of conducting a large-scale gradient array IP survey across their licences. The aim of the survey is to create a regional resistivity map, and a regional chargeability map – a "sulphide map" of similar scale and importance to the regional magnetic maps, which have been commonly used throughout the industry. The sulphide map is an additional data layer which will be used together with existing data, and importantly drilling, to test for mineralised targets at depth.

In the Orange region, there has been a long history of exploration success through barren rock sequences and cover. At Newcrest's Cadia Valley Operation, while the Cadia Hill copper-gold porphyry system outcropped, both the Ridgeway and Cadia East deposits have been discovered through cover.

The Ridgeway orebody was discovered beneath 20 – 80m of Tertiary and 450m into the Ordovician host rock sequences. The Ridgeway orebody would not have been detectable from outcrop on the Ordovician surface (Holliday et al, 1999). At Cadia East, discovery was the result of "wildcat drilling and relatively deep drilling through 60 – 200m of post-mineral Silurian sedimentary rocks, in addition to barren Ordovician rocks thrust over the Silurian" (Wood, 2012). Exploration techniques that can locate potential mineralisation at depth, beneath cover and barren sequences, therefore provide an extra level of information to target drilling.

The completion of an early IP survey at Ridgeway was crucial in focusing exploration efforts into the area. While the survey is now known to have detected only the pyrite halo above the ore, the anomalous result provided a target for drilling, leading to Ridgeway's discovery (Holliday et al, 1999; Holliday and Cooke, 2007). GCR plans to use the results from the Super IP survey in a similar way, knowing that a strongly chargeable response doesn't mean copper or gold is present; rather it provides a target for further work.

While most IP surveys are carried out on a prospect scale - once a target has already been identified through geological mapping or sampling - GCR are using the IP survey to identify targets, and then refine them through mapping and sampling.
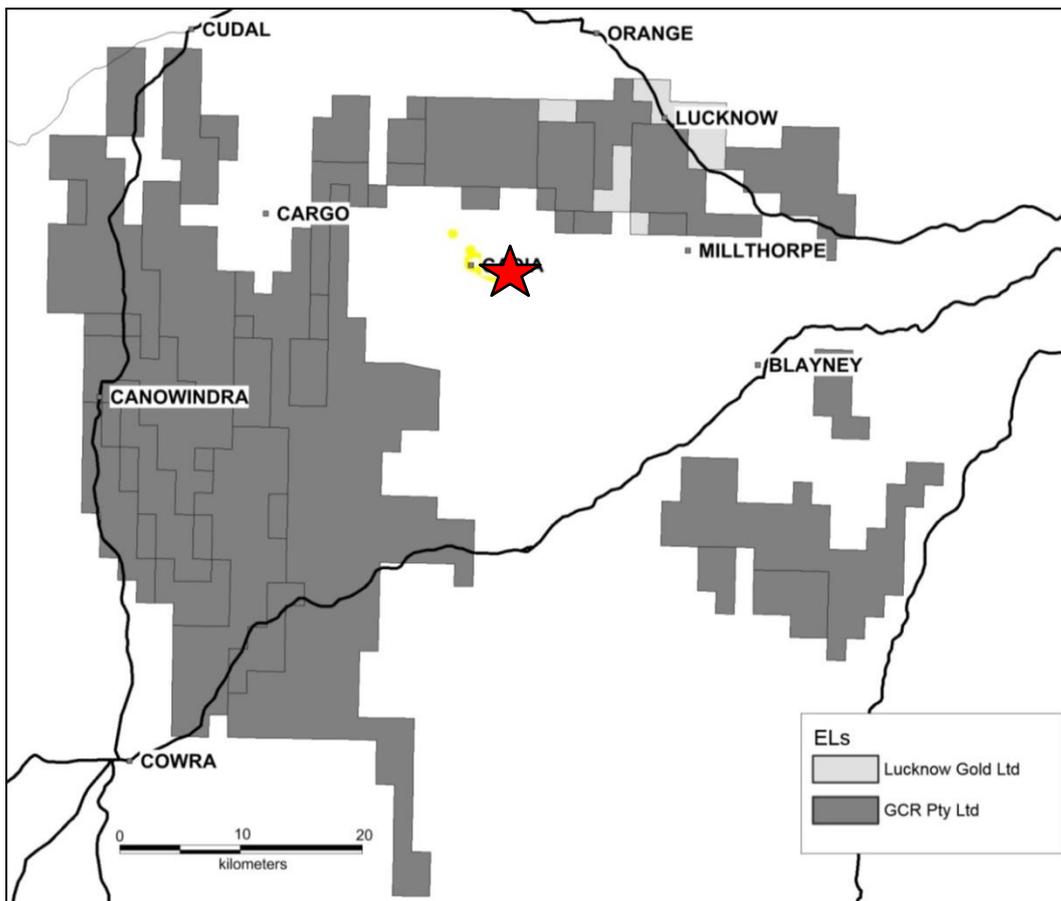
Figure 1: Gold and Copper Resources Exploration Licences, together with Lucknow Gold Ltd, shown with respect to the Cadia Valley mines.

Background

Gold and Copper Resources' exploration licences lie within the Molong Volcanic Belt, of the Ordovician Macquarie Arc. A large portion of the licence area is covered with basalts and trachytes from the Tertiary Mt Canobolas Complex, along with older Siluro-Devonian sequences. These cover rocks hide the prospective Ordovician rocks of the Macquarie Arc below. The licence areas have had a long history of "traditional" exploration, with little economic result. A technique is needed to see geology and importantly, the presence of sulphides, at depth through these cover sequences and barren zones.

Ivanhoe Mines Ltd has had extraordinary success at Oyu Tolgoi (O.T.), using large-scale gradient array IP to delineate and extend the known ore systems. A large-scale gradient array IP survey, using the proprietary "Zeus" transmitter has been successful in defining the extent of the known mineralisation at Oyu Tolgoi. Zeus has succeeded in further outlining the spatial extent of the ore bodies at O.T., and revealing previously undetected mineralisation to depths of up to 3,500m. The Heruga deposit, for example, was discovered through regional

gradient array IP, though it is buried under between 500 – 1000m of Devonian sediments and volcanics (Kirwin, 2006).   The Zeus system also showed that the main Hugo North Deposit had a depth extent at least 2.5 times greater than that which has been defined to date by drilling, and was increasing in size at depth.

The similar rocks and district-scale potential for porphyry deposits under cover, led GCR to believe that a regional gradient array IP survey was the appropriate tool to run in the Orange area.   As such, in 2007, GCR presented its exploration strategy to Robert Friedland, the CEO and Founder of Ivanhoe Mines Ltd. He immediately saw the potential of the Orange District in relation to the deployment of Super IP.   Further negotiation and innovation has led to the large-scale gradient array IP survey being deployed across GCR's ELs.

Logistics

The environment in the Orange region is very different to the deserts of Mongolia.   Many people believed an IP survey of this scale would not be possible, given the logistical challenges of running an electrical survey of this size through the densely populated Central West.   At Oyu Tolgoi, the high voltage transmission cables running between electrode points 10km apart, were run out along the ground. In Orange, across the same distance, the cable on the ground was likely to run through backyards, orchards, paddocks and vineyards. How do you lay out 12km or more of electric cable carrying 1000V+ in a populated area?

Gold and Copper Resources' innovative answer was to put the transmission line up on poles. This ensured that the integrity of the transmission line was maintained, and kept it clear from livestock, kangaroos and people.   The transmission line met all of the required safety regulations for a power line, with minimum clearances along roadsides, railway crossings and power lines. Additionally, the poles allow the transmission line to be left up for extended periods, allowing further research and development opportunities.

A further issue for GCR to overcome was the electrical resistance across 12km of transmission wire. To generate sufficient signals across such large distances, it may have been necessary to transmit above the Australian Standard definition of high voltage. However, because the transmission wire was up on poles, there was no need to use the insulated copper wire which traditional IP surveys use.   The traditional copper wire also did not have the ability to be tensioned between poles.   After exploring different options, a commercially available aluminium steel wire, known as "raisin", best met the required criteria. The raisin wire has 1/3 of the resistance of transmission wire used at O.T. and does not need to be insulated, being at least 5m off the ground. By lowering the resistance of the wire, less power is needed from the transmitter to get the required amount of amps into the ground. This means that high powered transmitters are not required for a survey of this scale and commercially available Australian transmitters can be used. This was a major breakthrough in the deployment of the IP survey.

The process for the IP survey starts with land access.   Against an increasingly difficult exploration environment, Gold and Copper Resources have had great success achieving land access agreements.   GCR have signed over 1,300 access agreements, and are yet to take any landholder to arbitration. The success of the land access team is due to a number of reasons; the low impact nature of the survey, the innate flexibility, and the chance for landholders to find out once and for all if anything of significance is below their land. For the vast majority of landholders, all the company is negotiating to do is walk across their property and take readings every 100m. This allows a good relationship to be founded and if further work is required, trust has already been established.   The regional scale of the survey means that GCR can schedule the survey activities around farming needs, moving into different agricultural, livestock or forestry areas depending on the season.

The IP survey began in July 2011, using the "Zeus" transmitter and a team of 30 Mongolian operators who had been working at Oyu Tolgoi. The survey was highly successful, and the team surveyed a large area in less than 2 months.   Once the contract ended, the survey continued using a Search transmitter and a team from Fender Geophysics. After comparison

of data across the same survey area, it was determined that the Zeus transmitter and the Search transmitter produced similar results.

The IP survey is carried out in 40km^2 survey blocks, which run 10km N-S and 4km E-W (Figure 2). The electrodes are spaced 12km apart, with the middle 4km block surveyed along 200m spaced lines. Once the survey block is complete, the whole system moves down the transmission line, ensuring that the whole area is systematically surveyed. The regional survey will take place across 9 transmission lines which are spaced approximately 10km apart (Figure 3). Currently there is more than 130km of transmission line which has been erected for the survey, the equivalent of a power line running between Sydney and Lithgow.
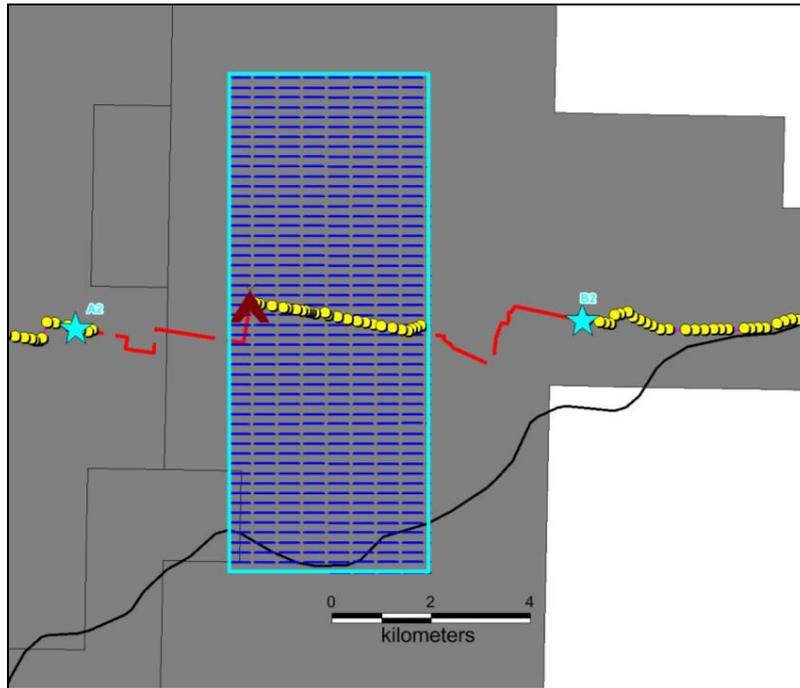
Figure 2: IP Survey block set up. The stars represent the electrode locations, which lie ~4km either side of the survey block. The block is surveyed along 200m spaced lines, 5km north and south of the transmission line.

Results

More than 500km^2 of IP survey has already been carried out; the data processed and follow up work begun. The IP survey data is processed and reviewed by GCR's consulting geophysicist Steve Collins and then further reviewed by company geologists.

The project is district wide and when complete will have covered over 1,500km^2 of ground with IP. The size of the survey is important, as it allows the company to distinguish "background" chargeability and resistivity values from those which are anomalous. The results need to be looked at in domains, as the results from different geological terrains have different IP characteristics. For example, the IP survey results across the Tertiary basalts will be attenuated from those across outcropping Ordovician rock units. Each domain is analysed for background chargeability values and then truly anomalous values marked for follow up work.
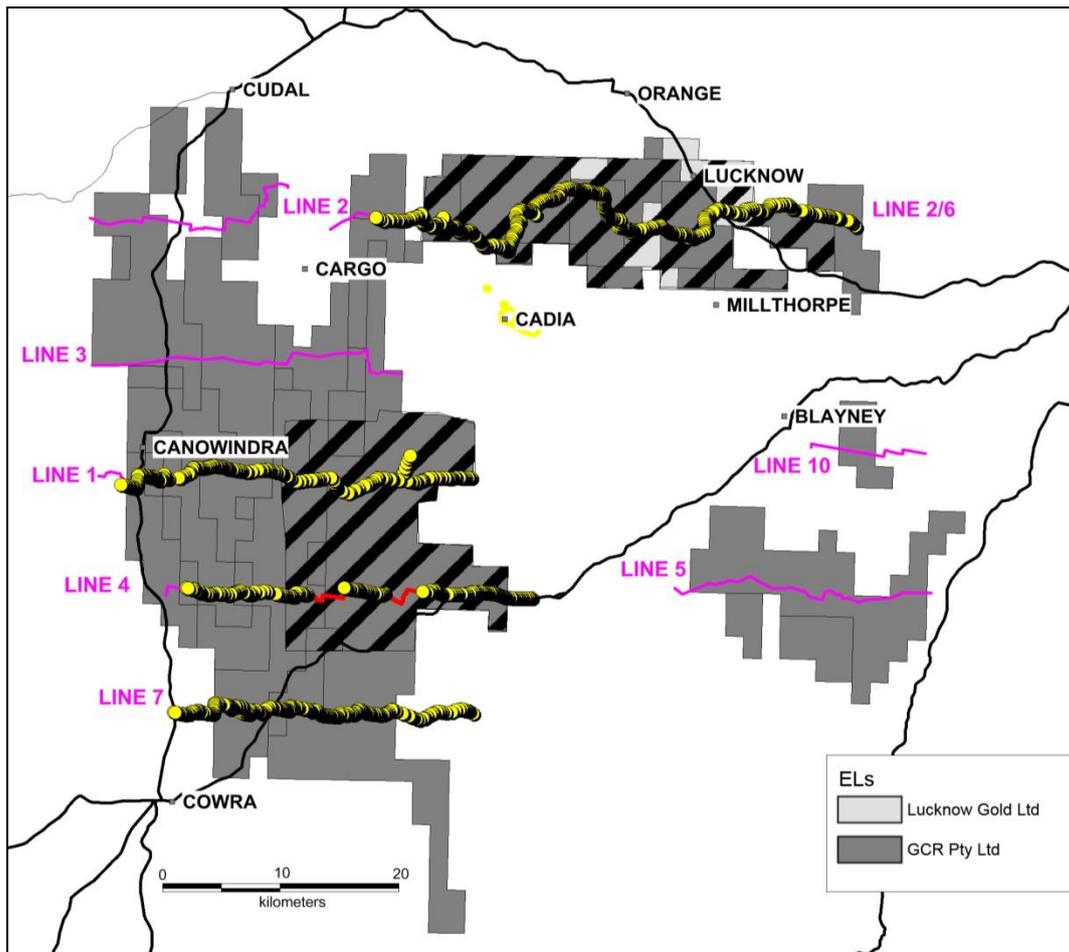
Figure 3: Regional IP survey design – circles are transmission line pole locations, with the planned lines. The striped area represents the area that has been surveyed as of June 2013.

An IP survey of this scale, through several geological domains, will no doubt throw up many "red herrings" and data needs to be field checked before too much emphasis is placed on the geophysics. For example, an isolated chargeable anomaly at Chinaman's Hill (Figure 4), which had values to 50mv/v became a high priority target almost instantaneously, as it appeared with a co-incident magnetic anomaly. An offset pole-dipole survey was commenced, along with a 3D inversion over the magnetics, and field mapping and sampling. Field checking showed that the anomaly occurred coincident with a topographic high, comprised of unaltered ultramafics. Geochemical sampling showed there was no anomalism. Further, the results from the 3D IP model and the magnetic modelling showed that the two responses correlated to one another to depths over 200m. Finally, petrophysical testing completed on samples returned to show that, unusually, very fine grained magnetite was responsible for the extremely high chargeability values. The importance of "old fashioned geology" is vital in validating and ground truthing the IP results.

Drilling has since begun to test the highest ranked chargeable anomalies, and to assist with reconciliation of the geophysical data.

The "Corrivale" anomaly (Figure 4) is a 2km by 3km complex anomaly, with chargeability values up to 46mv/v. Historic copper workings are present across the surface, with rock chip sampling returning 2% Cu. Results from an offset pole-dipole IP survey to the north of the main anomaly correlated well with the gradient array, so the decision was made to drill. A 750m drillhole was designed to intersect the strongest part of the gradient array IP anomaly. The drillhole encountered very fine grained chalcopyrite and pyrite visible from 80m within a volcanic breccia. The volcanic breccia showed a variety of altered clasts, including mineralised monzonites, providing evidence that a mineralised volcanic centre is likely

present within the Walli Volcanics. Samples of the sulphide bearing volcanic breccia were sent for petrophysical testing to determine if the drillhole had intersected the chargeable response; i.e. if the fine grained sulphides in the core were responsible for the anomaly. The results from the test work indicated that the samples submitted were not strongly chargeable, and therefore the drillhole had not effectively tested the IP anomaly.

The IP survey run across the Tertiary Volcanics has allowed effective targeting through the cover for the first time. The IP provides an extra layer of detail to the magnetics and radiometrics which have traditionally been used for drill targeting in the area. The survey through the North Cadia area produced 4 high priority targets; preliminary drilling has now been completed on two of these (Roxanne and Faith, Figure 4).

Three vector drill holes have been completed at Roxanne into a chargeable high, with anomalous surface geochemistry. Significant results from the drilling include 1.15m @ 0.58g/t Au, with anomalous arsenic, silver, moly and antimony, and 0.6m @ 1.29g/t Au with anomalous moly, lead and zinc. The gold is associated with hydrothermally altered dikes, which are in turn associated with anomalous As, Ag, Sb, Hg, Mo in disrupted quartz+carbonate veins and breccias. Drilling at the Faith IP anomaly also intersected significant metasomatic alteration adjacent to dikes and sills. The geochemical results from drilling at Roxanne confirm that we are looking at a high level porphyry system.

Drilling at both Faith and Roxanne has confirmed the presence of long lived structural features of favourable orientation for the emplacement of porphyry systems, parallel to the Lachlan Transverse Zone (LTZ), a major, arc-normal corridor which favoured emplacement of porphyries (Glen et al, 2007). The gold-bearing veins at Roxanne and the metasomatically altered dikes at both Faith and Roxanne align with this WNW orientation, increasing the prospectivity to the north of the Cadia Valley.

While only 3 IP anomalies have so far been drilled, GCR continues to develop other targets through analysis of historic data, comparison with other geophysical datasets, and geological mapping and sampling.

Conclusions

Through innovation and bold exploration, Gold and Copper Resources have begun the process of delivering a regional scale sulphide map. The IP survey has the ability to see through cover sequences, spanning large areas quickly with minimum surface disturbance. The discovery of Ridgeway underneath 500m of cover is proof that hidden mineralised systems are present in the area, and the potential remains to find other buried porphyry systems. GCR are the first explorer to regionally "look below" cover, and to prove that porphyry related mineralisation exists north of the Cadia Valley. The results from the Super IP survey will identify new anomalies, including buried sulphide systems which are blind at surface, and assist in targeting drilling of existing known prospects from surface geology.

The completed sulphide map will provide an accurate representation of the geology beneath cover, at an unprecedented scale. This map will have uses for strategic land use decisions by government, and provides certainty for local landholders with regards to future exploration activities on their properties. Several government and university project working groups such as UNCOVER have the task of determining ways of assisting industry with exploration undercover. A large scale gradient array is one of the methods that they should consider.
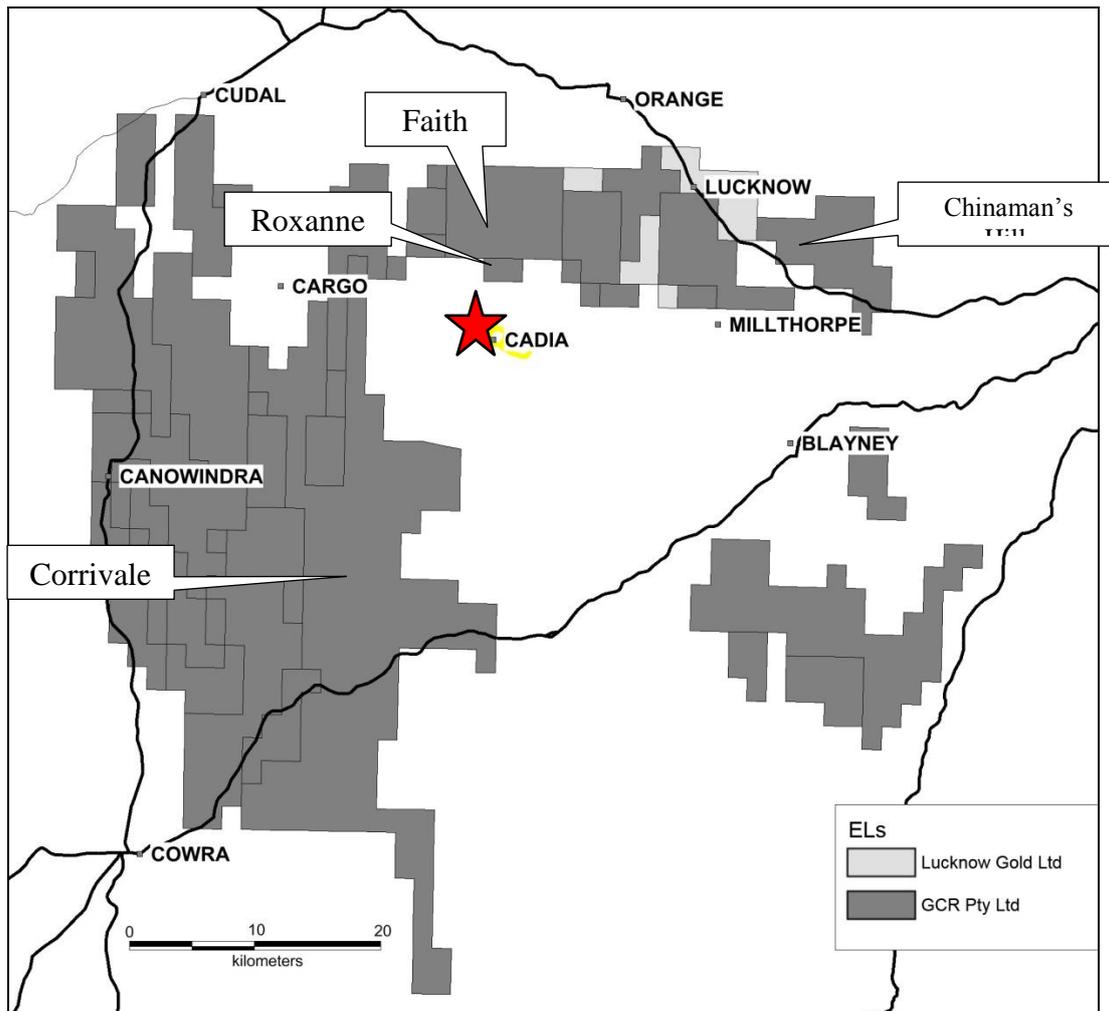
Figure 4: Location of a selection of Gold and Copper Resources active projects

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EXTENSION AND TELESCOPING OVERPRINTED BY INVERSION AND EROSION OF EPITHERMAL SYSTEMS IN THE DRUMMOND AND BOWEN BASINS

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Abstract

Epithermal Au-Ag deposits are hosted in the Devonian-Carboniferous Drummond Basin and the Late Permian-Middle Triassic Bowen Basin in Eastern Australia. These deposits owe their preservation and exhumation to regional-scale geologic processes that typically occur on continental crust inboard of active subduction zones. In both cases extension in back-arc basins controlled by large-scale listric normal faults control the basin geometry. Within these basins low-sulphidation epithermal vein mineralisation is hosted in syn-rift andesite in close proximity to the major listric faults. Deposition of additional syn and post-rift rocks resulted in the preservation of these ancient epithermal systems. In the case of Pajingo, the Stones Creek andesite that hosts the mineralisation was buried to a depth of five kilometres during formation of the Drummond Basin. At Pajingo there is now evidence to suggest that the epithermal veins have a vertical extent of some 1200m. Rocks that describe sinters are overprinted by both stratabound and vertical low-sulphidation veins/lodes. This suggests telescoped systems developed during ongoing andesitic volcanism in the back-arc.

The younger and in some cases almost co-axial compression during orogeny exploits the pre-existing listric normal faults, creating geometries and structures typical of basin inversion. It is this event that results in exhumation of the older epithermal systems. The resultant geologic complexity depends on the extent of the inversion. Recognition of the geologic effects ascribed to this event is critical for successful exploration. This includes rotation of the palaeo-horizontal which results in different levels of the epithermal system being preserved at the current erosion level. This is often further complicated by the propagation of inversion related thrusts that depending on their orientation may result in either duplication or loss of sequence or mineralised vein.

Many people exploring these systems have comprehensive understandings of the typical models that explain the different styles of epithermal mineralisation. The challenge is to integrate the models with what the geology maps tell us at different scales of observation. In areas of poor exposure and deep-weathering the use of high-resolution 2D and 3D seismic already provides valuable insights to better understand the cross-sectional geology and potentially directly target blind and deep vein systems.

THE HOBBS GOLD DEPOSIT AT MT ADRAH: SHAPING UP A MAJOR GOLD RESOURCE.

Andrew White
Sovereign Gold Company Ltd

Within the last fifteen years a new class of gold deposits has been recognised, the Intrusion Related Gold Deposits. In these, gold mineralisation is associated with bismuth, tungsten, arsenic, molybdenum, tellurium and antimony, and the deposits typically have low base metal content. Typically, intrusion-related gold systems may contain more than 3 million ounces of gold. The most common type of intrusion related gold deposit is hosted in altered igneous rocks ranging in composition from quartz diorite to granite (Lang et al., 2000), associated with ilmenite-series (low magnetic signature) plutons. The style of mineralisation has in the past led to some intrusion related gold deposits being described as "gold porphyry deposits" (Hopwood, 2012).
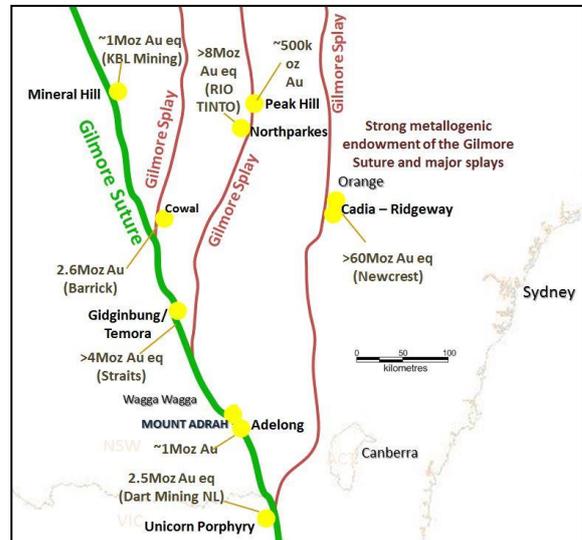
Figure 1. Location of Hobbs deposit on the Gilmore Suture in central western NSW.

The Mt Adrah prospects are approximately 17km northwest of the township and old gold mining centre of Adelong, in central western NSW (Figure 1). The Hobbs deposit at Mt Adrah was discovered by Getty Oil Development Company Pty Ltd geologist Roger Hobbs in 1980, as a result of follow up of arsenic soil anomalies identified in the search for copper-bearing skarns. Percussion and core drilling in the ensuing decade determined that a small outcrop of strongly altered quartz monzonite was the surface exposure of gold mineralisation averaging 1.3g/t gold, open at a depth of 315m and with a horizontal dimension of at least100m by 180m.

The Mt Adrah prospects lie on the Gilmore Suture itself, within a narrow belt of north westerly striking Late Ordovician calcareous sedimentary rocks and mafic volcanics (the Nacka Nacka Metabasic Igneous Complex of Scheibner, 1988). These have been metamorphosed to greenschist facies and intruded by very large granitic masses of Silurian age and younger, possibly Devonian, mafic igneous rocks. The Hobbs deposit lies on one of several jogs clearly defined on the Gilmore Suture by high resolution magnetics (Figure 2).
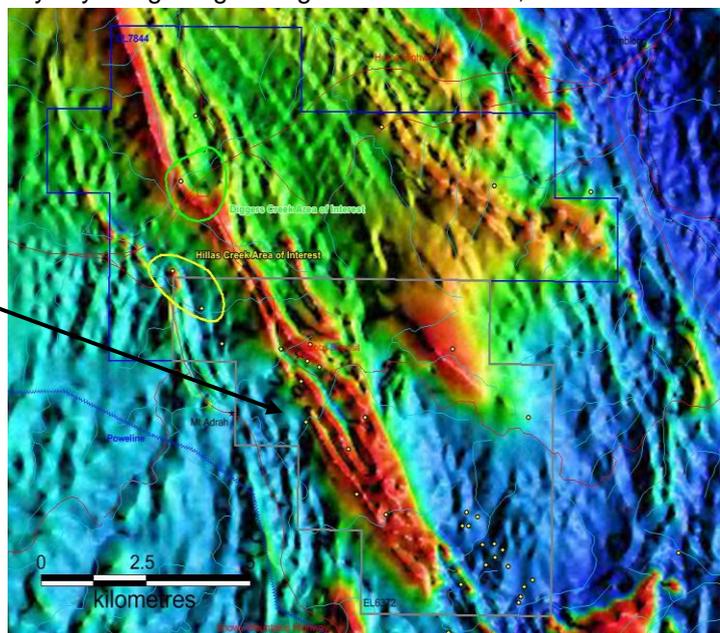
Figure 2. RTP magnetic image of Mt Adrah District.

The partly explored Hobbs deposit is interpreted as an Intrusion Related Gold Deposit (IRGD), comprising a mineralised, phyllic-altered micro-brecciated and micro-veined pipe-shaped zone approximately 200m x 110m within a quartz monzodiorite. The quartz monzodiorite is at the western margin of a large subsurface intrusion characterised by low magnetic intensity, and covered by late Silurian sediments. The only exposure of intrusive in this area is an outcrop of norite several kilometres to the north east of the Hobbs deposit.

The Mt Adrah East monzonite stock lies 800m to the east of Hobbs deposit, and although similar to the Hobbs mineralised monzonite, is untested by deep drilling. Also, Lowenbrae and Bangadang workings lie approximately 4km southeast of the Hobbs deposit, while the Southern Cross and Comedy King groups of workings lie a further 2km south-east. Gold mineralisation at Southern Cross and Comedy King occurs in sulphide-bearing quartz veins hosted by highly deformed fine grained silicified siltstones and metavolcanics. The Hillas Creek and Diggers Creek gold workings are located 2km and 5km north-west of the Hobbs deposit respectively.

The Hobbs pipe (Figure 3) is open at depth below 900m and also to the north-east and south-west. Gold mineralisation occurs as fine-grained inclusions within arsenical pyrite, arsenopyrite and pyrite as well as free gold in quartz veins. The distribution of gold is remarkably homogeneous, and Variography indicates a 20m range of influence in x and y directions and downhole. Assays show that the average grade in drill hole GDH001 for example is 1.2g/t but there are significant intervals of slightly higher grade (400m at 1.4g/t from surface in GDH 001). The contact of the pipe with unmineralised monzodiorite is mostly sharp although minor quartz veins and alteration along fractures occur in the monzodiorite adjacent to the pipe.
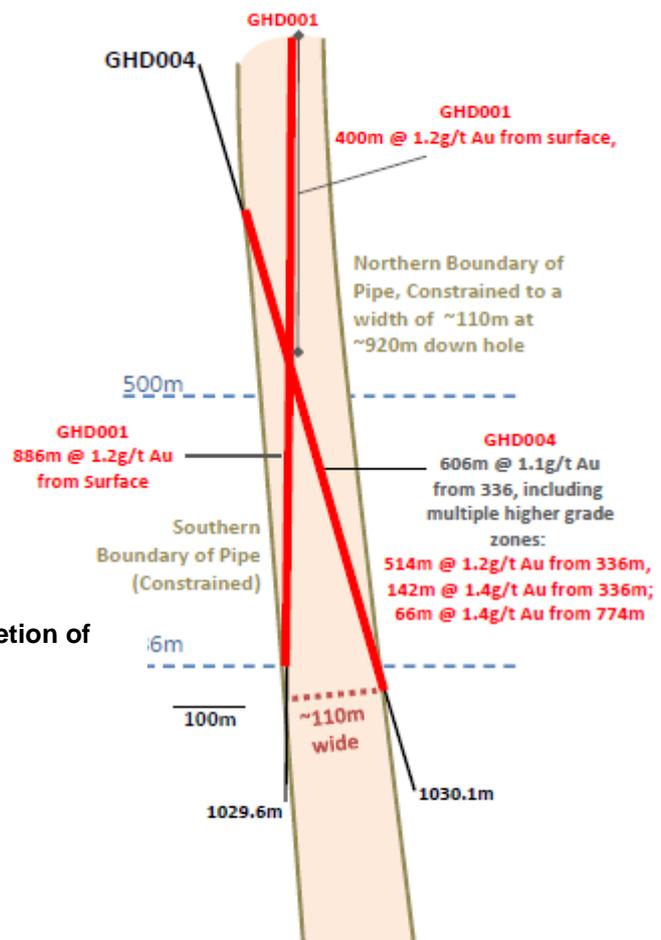
Figure 3. Cross section of Hobbs pipe at completion of drill hole GDH004, looking SW.
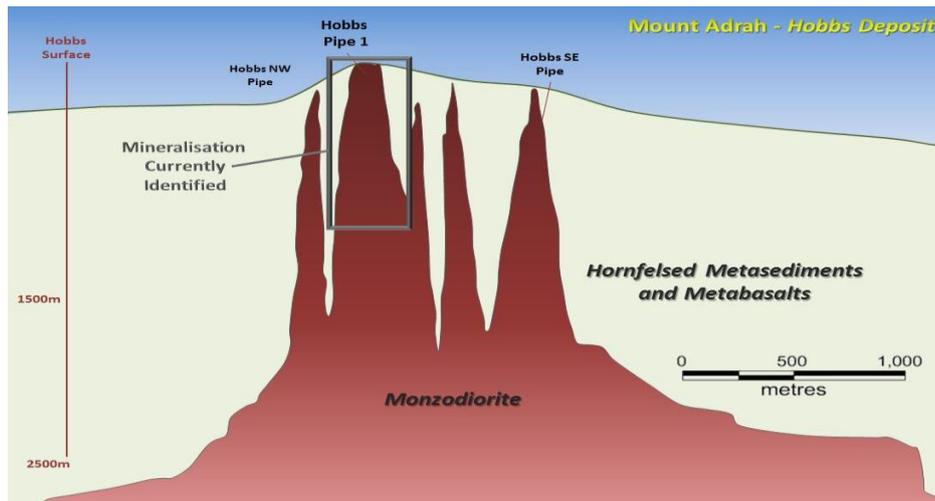
Figure 4. Cartoon summarising multiple mineralised pipe exploration targets in the vicinity of the Hobbs deposit (looking NE).

At the time of writing, a review of assay and drill hole data resulted in the following resource estimate for the deposit:

Cutoff g/t	0.50			0.75		
Category	Tonnes	Grade (g/t)	Ounces	Tonnes	Grade (g/t)	Ounces
Measured	3,171,396	1.10	112,161	2,594,018	1.21	100,915
Indicated	9,279,890	1.13	337,147	7,597,962	1.24	302,912
Inferred	7,731,847	1.12	278,419	6,175,436	1.24	246,199
Total	20,183,133	**1.12**	**727,727**	16,367,416	**1.23**	**650,027**
Initial JORC Inferred estimate was 239,000 oz at 1.13 g/t at 0.5 g/t cutoff (Rankin 2005)						

The ore is mostly refractory with submicroscopic gold inclusions in arsenopyrite and pyrite, although the ~10% gold that is free milling is coarse grained (visible). Metallurgical testing to date indicates that a high grade (>20g/t) sulphide concentrate is readily obtained by grinding and flotation of the refractory gold and BIOX® extraction enables >90% gold recovery. Modelling indicates that provided large scale bulk mining extraction and milling is feasible the deposit has attractive economics.

Soils geochemistry, mapping, magnetic interpretation and IP data from historical exploration indicate prospects for several other pipes in the Mt Adrah area close to Hobbs. Further drilling to define the dimensions of the pipe and a 3D-IP survey to define drill targets on similar pipes are under way.

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