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# 2007

# Mineral Exploration in the Tasmanides

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# Preface

Over what is now (regrettably) decades, I have been impressed by the willingness of many geoscientists to give freely of their time in order to support their profession. This has again been exemplified in this, the second Mines & Wines Conference.

The organising committee, made up of representatives of three groups, NSW DPI Minerals, the Australian Institute of Geoscientists (AIG) and the Sydney Mineral Exploration Discussion Group (SMEDG), is a seasoned and very co-operative team, well assisted for this conference by support staff in DPI Minerals, Orange. It has been a pleasure to work with such a group.

Of particular importance has been the preparedness of the speakers to voluntarily provide significant time and effort to share their specific technical knowledge both with the large number of conference attendees and, subsequently, with a broader range of geoscientists through the publication of AIG Bulletin 46.

Our ability to provide high quality technical conferences at economical rates depends not only on our volunteers (both speakers and organisers), but also on our sponsors and booth holders. The latter groups underpinned the financial viability of this conference and are thanked most sincerely for their support.

Buoyed by the Mines & Wines 2007 Conference, being yet another demonstration of the close fraternity which exists within our profession, and stimulated by the current level of activity within the mineral resources sector, it is easy to forget the longer term picture for our industry. I encourage your support for those of our members who are actively trying to re-dress the effects of the ageing of our geoscientific community and the concomitant loss of impetus in the entry, training and retention of new members of our profession.

Perhaps conferences such as Mines & Wines 2007 provide not only an occasion for intellectual and social stimulus, but also a time to consider how we can support the retention of a strong and very necessary, specialist scientific group into the future.

**Michael Leggo**
*Chairman Mines and Wines 2007 Committee*

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# MINERAL EXPLORATION IN THE TASMANIDES

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# RECOGNITION OF CRYPTIC ALTERATION SURROUNDING CENTRAL VICTORIAN GOLD DEPOSITS

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**Key Words:** wallrock alteration, orogenic gold, lithogeochemistry

## Abstract

Recent studies in central Victoria have demonstrated the presence of widespread subtle, or "cryptic" primary wallrock alteration surrounding gold deposits. In general, alteration is indicated chemically by increases in $CO_2$, Au, S, As and K +/-Sb and Bi. Petrographic studies have indicated the presence of regional ferroan carbonate "spotting" that extends for up to hundreds of metres from major deposits hosted by meta-sedimentary sequences. A slight bleaching of meta-sedimentary host rocks due to sericite alteration is often apparent within 10s of metres of mineralised structures, as is the presence of disseminated arsenical pyrite and arsenopyrite crystals. Techniques that have been used to characterise this alteration include petrography, chemical staining, quantitative XRD, lithogeochemistry, microprobe, laser ablation ICP-MS and visible to short wave infrared analyses.

## Introduction

Although the presence of wallrock alteration around central Victorian gold deposits was long ago recognised (Don, 1898), for many years orogenic gold deposits in central Victoria were considered to have poorly developed primary wallrock alteration haloes. Beginning with the work of Bowen (1972), and subsequently that of Binns and Eames (1989), primary lithogeochemical alteration haloes around central Victorian deposits became the focus of numerous studies (Gao and Kwak, 1997; Bierlein et al., 1998; Li et al., 1998; Mapani and Wilson, 1998; Arne et al., 1998, 1999; Bierlein et al., 2000; Arne et al., 2000; Bierlein et al., 2004; Wilde et al., 2004; Dugdale et al., 2006). In spite of this extensive body of work, the identification of primary wallrock alteration haloes around central Victorian gold deposits remain poorly understood and underutilised as an exploration tool.

A major review of primary and secondary wallrock alteration haloes was initiated in mid-2006 as part of the 3-year, $9 million Gold Undercover initiative by Geoscience Victoria. The focus of this work is to provide a clear indication of the style and extent of wallrock alteration surrounding central Victorian gold deposits for mineral explorers drilling through late Palaeozoic to Cainozoic cover in the Gold Undercover initiative area (Figure 1). The study has been broken into two components: primary haloes and secondary dispersion effects. Initial work involved a summary of wallrock alteration around major central Victorian gold deposits at Ballarat, Bendigo, Castlemaine, Costerfield, Fosterville, Maldon and Stawell. This previous work has been summarised in a series of lithogeochemical "fact sheets" available from the Gold Undercover website (http://www.dpi.vic.gov.au/minpet/goldundercover).

A review of the previous literature was followed by the collection of ~900 fresh diamond drill core samples at varying distances from mineralised structures at the project areas (Ballarat, Bendigo, Castlemaine, Costerfield, Fosterville, Maldon, Wildwood) and their analysis for a suite of 28 major and trace elements. These data will provide a reference lithogeochemical data set collected using a consistent four-acid digestion and analytical approach (in all but one case) that will allow a direct comparison of data between deposits. In addition to lithogeochemical investigations, field staining, petrography and visible to near infrared (VNIR) and short wave infrared (SWIR) methods have been used to further define alteration haloes. The purpose of the investigation is not to present an exhaustive description of wallrock alteration at any particular deposit, but to provide timely information describing alteration types based on characteristic drill core intersections through different styles of gold mineralisation. It is hoped that detailed investigations incorporating 3D modelling and structural interpretations will provide a more refined description of wallrock alteration at individual deposits.

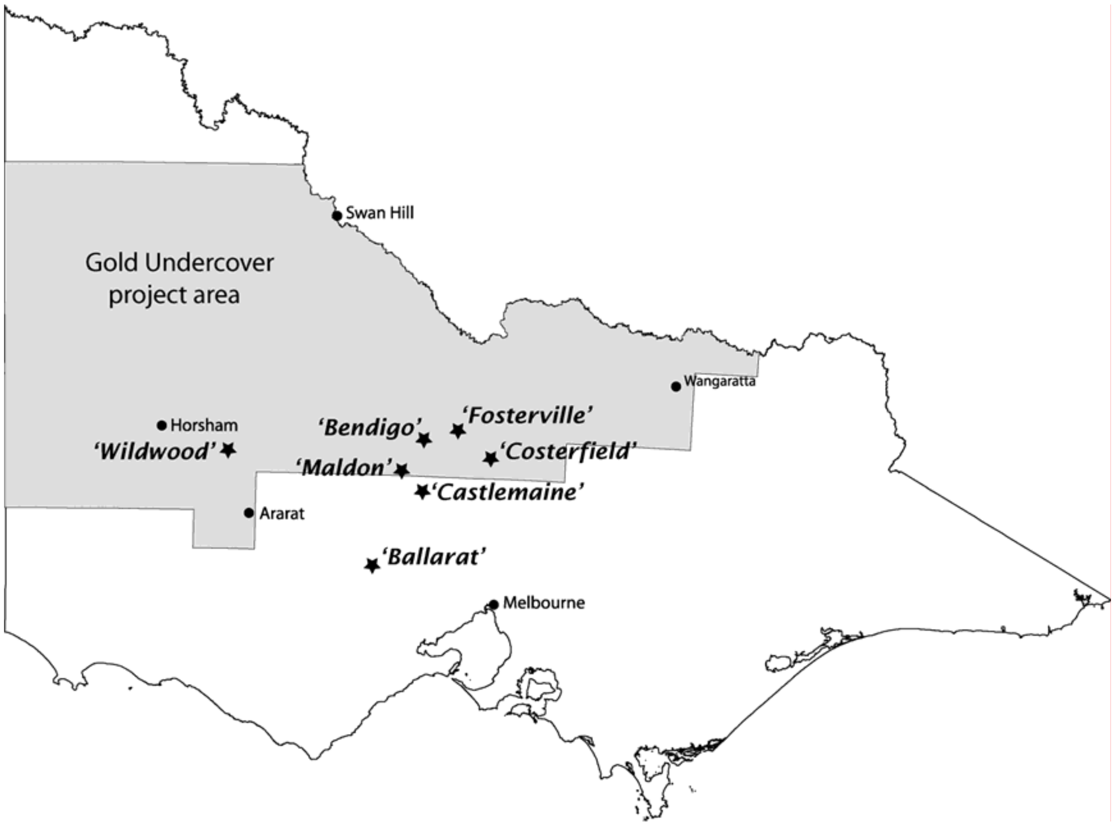


Figure 1: Location of the central Victorian gold deposits under investigation.

**Lithogeochemistry**

Most previous studies have focused solely on the lithogeochemistry of wallrock alteration (e.g. Gao and Kwak, 1997; Bierlein et al., 1998; Li et al., 1998), although others have included stable isotopes (Mapani and Wilson, 1998; Bierlein et al., 2004), detailed petrography (Mapani and Wilson, 1998; Dugdale et al., 2006), quantitative XRD (Bierlein et al., 2000) and preliminary SWIR data (Arne et al. 1999, 2000; Wilde et al., 2004). These studies also highlighted the use of both the carbonate and muscovite saturation indices, as defined by Kishida and Kerrich (1987), to reflect the formation of ferroan carbonate and sericite, respectively, during hydrothermal alteration. Bierlein et al. (2000) also introduced a simple geochemical alteration index involving $CO_2$, K, Na and Al that appears to reflect progressive alteration in many instances (Arne et al., 1999).

Previous lithogeochemical investigations suggested the enrichment of a number of elements, but failed to account adequately for lithological variations that can influence the levels of these elements, as well as the effects of geochemical closure (Rollinson, 1993). For example, Figure 2 demonstrates that the vast majority of zinc data from meta-sedimentary rock samples in the vicinity of a central Victorian gold deposit can be attributed to lithological variations, as defined by the Al content of the samples. By contrast, arsenic data from the same samples show a drift to elevated As contents that can be related to sulphidation of the wallrock (Figure 3). Aside from additions of $CO_2$, Au, S, As and K +/-Sb and Bi, variations in other major and trace elements have yet to be confirmed by the present investigation. An important outcome of the current study will be the provision of geochemical data defining background variations in the rocks hosting most central Victorian gold deposits. Issues related to the effects of lithological variation, closure, error stabilisation and false correlations will be addressed through the use of data transformations and log-ratios (Rollinson, 1993; Stanley, 2006).

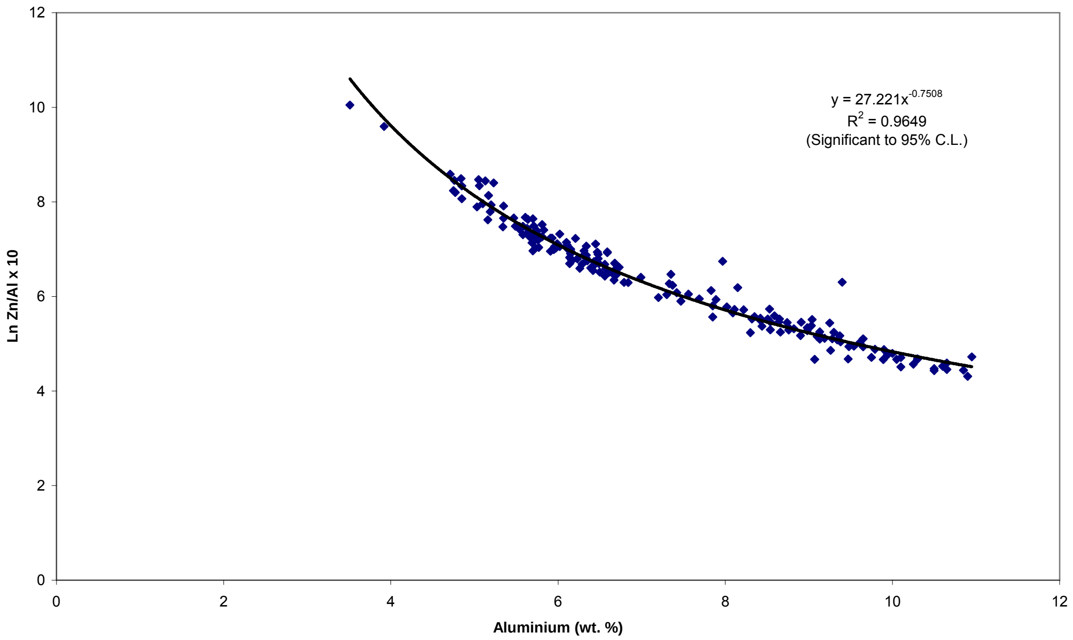


Figure 2: Distribution of zinc in meta-sedimentary rock samples from a central Victorian gold deposit plotted with respect to aluminium content.

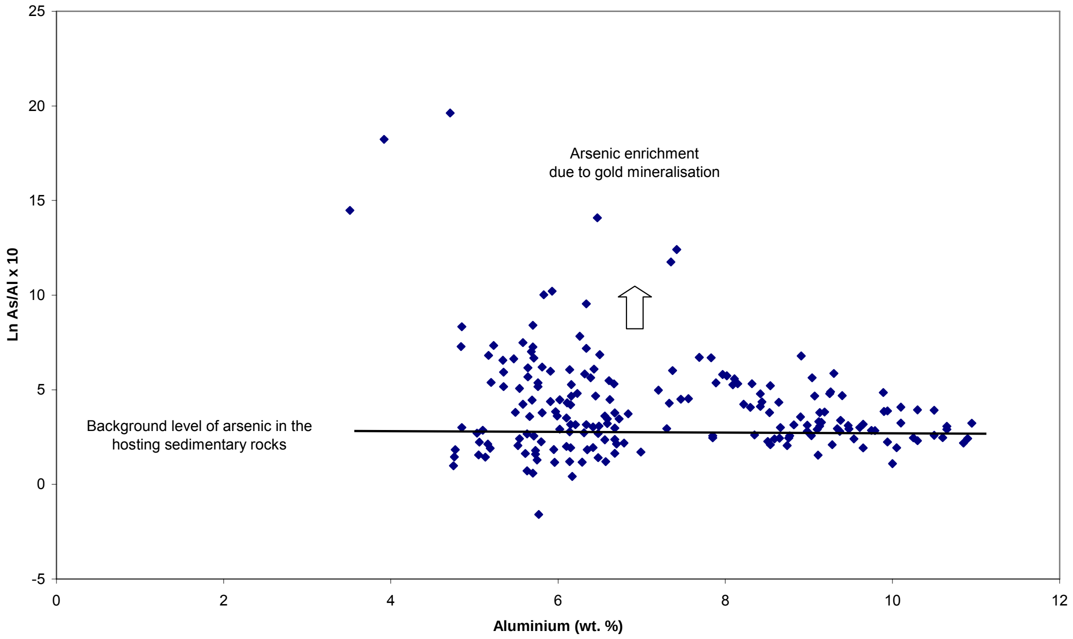


Figure 3: Distribution of arsenic in meta-sedimentary rock samples from a central Victorian gold deposit plotted with respect to aluminium content.

## Mineralogical investigations

Ideally, the recognition of wallrock alteration at the time of drilling or shortly afterwards is desirable. The use of potassium ferricyanide stain in the field can be used to reveal the presence of ferroan dolomite in fresh diamond drill core within minutes (e.g. Eilu et al., 1999). In most instances, visual estimates of ferroan dolomite from meta-psammites correlate well with elemental carbon analyses obtained by gravimetric methods (Figure 4). Siderite/magnesite series carbonate minerals do not react to the stain, and so visual estimates using this method should be considered as minimums. Ferroan carbonate alteration can also be identified petrographically or using XRD analyses. In most instances where quantitative XRD work has been undertaken, ferroan dolomite and chlorite display an antipathetic relationship (Bierlein et al., 2000).

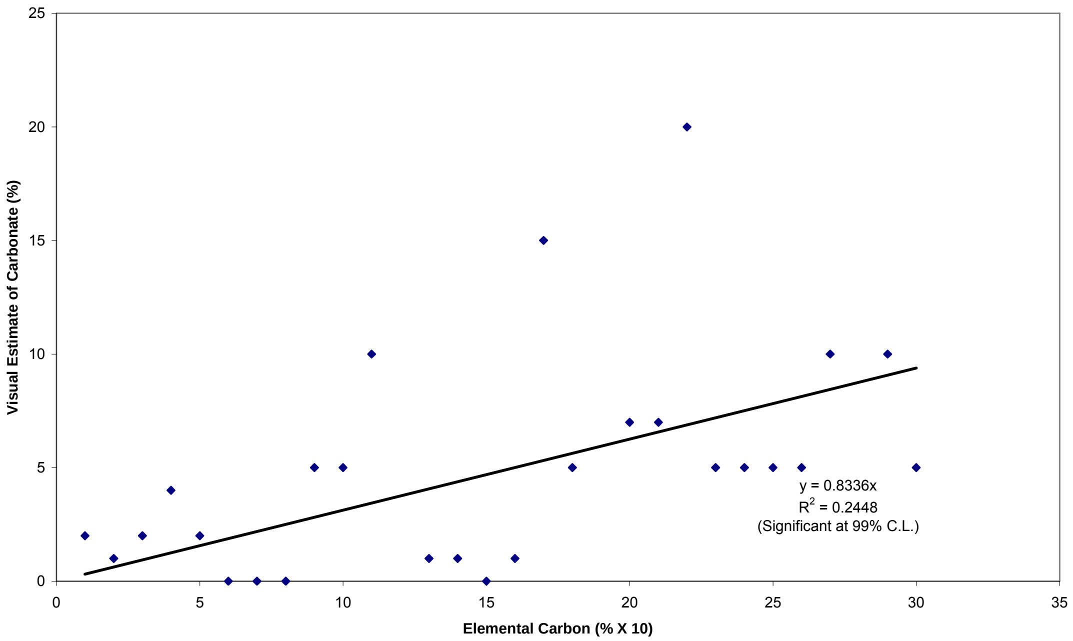


Figure 4: Correlation between visual estimates of ferroan dolomite following staining with potassium ferricyanide plotted against elemental carbon analyses determined gravimetrically.

Another approach that appears to have promise for detecting both sericitic and ferroan carbonate alteration in central Victorian deposits is the use of infra-red mineralogical techniques. Early studies using a portable infrared mineral analyser (PIMA), suggested that sericite alteration was associated with a shift in the position of the main AlOH absorption peak, and that it might also be possible to detect the loss of chlorite as mineralised structures were approached (Arne et al., 1999). All lithogeochemical samples from the current investigation have also been assessed by VNIR and SWIR absorption spectra using HyChips™. A preliminary interpretation of the results indicates that there is a characteristic shift from "phengitic" to more "muscovitic" mica compositions as mineralised structures are approached (Figure 5). This work is currently being extended to include scanning of representative drill cores from each of the gold deposits under investigation in collaboration with the CSIRO Hylogging™ group.

As first described by Don (1898), elevated gold values in wallrock adjacent to many gold deposits correlate strongly with the presence of disseminated sulphide minerals. The same can also be said for arsenic contents (Bowen, 1972). Although arsenopyrite is generally restricted to within a few metres or 10s of metres of mineralised structures, distal pyrite grains often display elevated As contents that reveal their hydrothermal origin. This subtle effect in whole rock lithogeochemical data is enhanced through microprobe or laser ablation ICP-MS analyses of disseminated pyrite crystals (Arne et al., 2000). A similar effect is also noted in the sulphur isotope composition of individual pyrite crystals, with a trend to lower $\delta^{34}S$ noted in several central Victorian gold deposits (Bierlein et al., 2004). These trends not only occur in different samples at varying distances from mineralised structures (Figure 6), they are also present in isotopically and chemically zoned individual pyrite crystals.

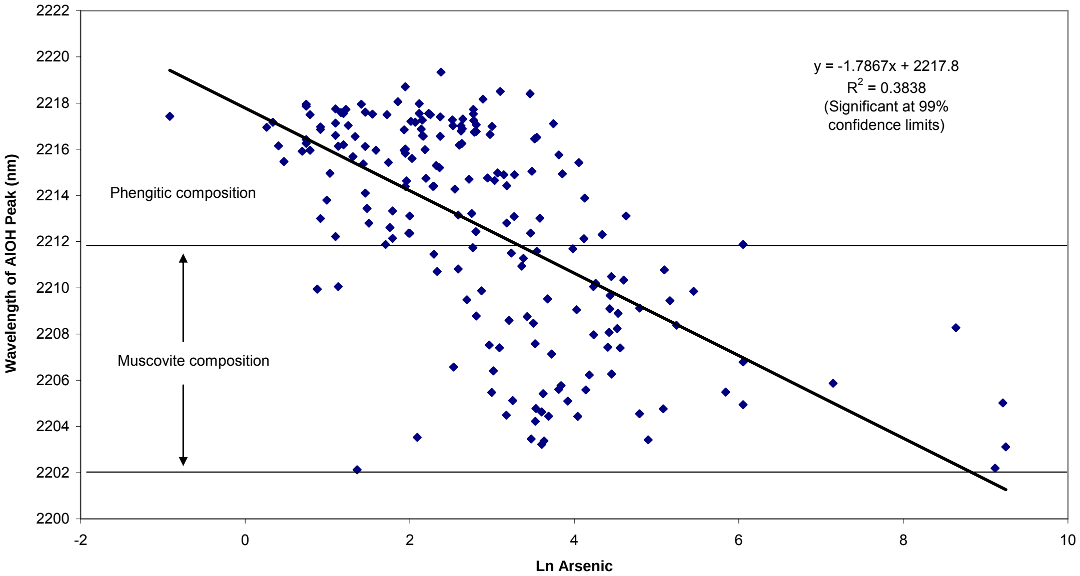


Figure 5: Correlation between AlOH infrared absorption peak position and arsenic content from a central Victorian gold deposit.

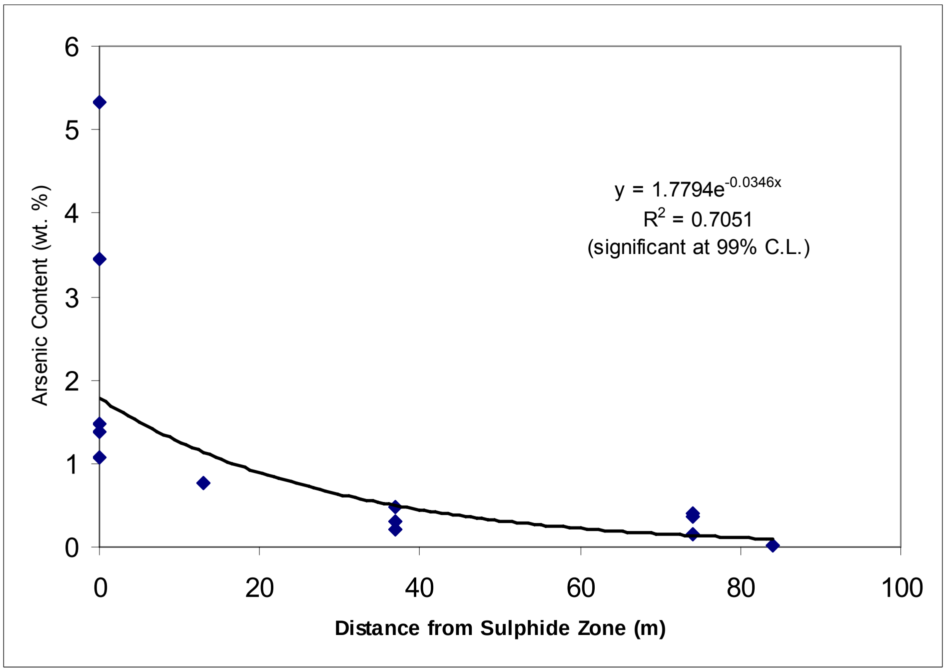


Figure 6: Arsenic content of disseminated pyrite crystals at varying distances from the primary sulphide zone at Fosterville (after Arne et al., 2000).

## Acknowledgements

It would not be possible to carry out a project of this scope without the assistance of the Victorian mineral exploration and mining industry. The following companies have provided access to diamond drill core material: AGD Operations, Alliance Resources, Ballarat Goldfields (now Lihir Gold), Bendigo Mining, Castlemaine Goldfields, Leviathan Resources (now Perseverance Corporation) and Perseverance Corporation.

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# MINERAL SYSTEMS AND THE PMD*CRC COBAR PROJECT

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**Key words:** Cobar, mineral systems, 3D, exploration

## Mineral Systems

The question as to why large ore systems form is a critical one for mineral exploration. Some answers to this question can be gained by using the concept of Mineral Systems - 'all geological factors that control the generation and preservation of mineral deposits… stressing the processes that are involved in mobilising ore components from a source, transporting and accumulating them…' (Wyborn et al., 1994). In the Predictive Mineral Discovery Cooperative Research Centre (***pmd****CRC), we have adapted an approach, initiated in the Australian Geodynamics Cooperative Research Centre (a predecessor of the ***pmd****CRC), called the 'Five Questions' (Walshe et al., 1999). These questions are
1) What are the geodynamic and P-T histories of the mineral system?
2) What is its architecture?
3) What fluid reservoirs were involved?
4) What were the fluid pathways and driving forces?
5) What processes were responsible for metal and sulphur transport and deposition?
This approach ensures that the context of an ore body across a range of scales is considered and by moving away from the misleading concept of traps in mineral systems, application of the five questions makes explicit the range of features than should be considered to understand the development of mineralisation. A further feature of the questions is that they reveal the necessity to think across scales from that of the geodynamic setting to the depositional environment. As much as anything else, this should include considering the chemical architecture, covered in the question concerning fluid reservoirs, at scales ranging from depositional sites upwards. A mineral system is much larger than a depositional system, and a range of depositional system styles may develop in a single mineral system because of local variations in rock type, structural architecture or depth. This paper explores how we can look more deeply at controls on ore formation and link them to the exploration process.
While the Mineral System concept and its application via the Five Questions ensures a systematic consideration of the necessary conditions for ore formation, it is still essentially empirical in nature and it is hard to evaluate why giant systems develop. In general, the rate of precipitation of a mineral is given by the product of the fluid flow velocity and the gradient in concentration of the element of interest (Walsh et al., 1984). A specific expression for this relationship in hydrothermal systems can be created by combining an equation given by Phillips (1991) together with Darcy's Law for fluid flow in a porous medium. This allows the fundamental controls on hydrothermal ore formation to be clearly identified. The basic relationship is:

$$A = \int -\frac{\kappa \rho g}{\mu} \nabla P \bullet \left( \frac{\partial c_e}{\partial T} \nabla T + \frac{\partial c_e}{\partial p} \nabla p + \sum_r \frac{\partial c_e}{\partial c_r} \nabla c_r \right) .dt \qquad (1)$$

where A is the amount of material precipitated at a particular point, $\kappa$ the permeability, $\rho$ the fluid density, g the acceleration due to gravity, $\mu$ fluid viscosity and $\nabla P$ the gradient in non-hydrostatic pressure. $\partial c_e/\partial T$, $\partial c_e/\partial p$ and $\partial c_e/\partial c_r$ are the equilibrium solubility sensitivities to temperature, pressure and concentration of other species respectively, $\nabla T$, $\nabla p$ and $\nabla c_r$ the spatial gradients in T, p and $c_r$, and t is the time the system operates for. The term outside the brackets is equal to the Darcy fluid flux (u), and the sum of terms inside the brackets represents the overall gradient in solubility ($\nabla c_e$) due to variations in T, p and $c_r$. Both of these terms are vector quantities; the dot indicates the scalar product of two vectors, which is maximised when the vectors are large in magnitude and similar in direction. The minus sign appears because the amount of mineral precipitated is the opposite of the change in the amount in solution. There are thus five independent factors (permeability, the gradient in non-hydrostatic fluid pressure, the solubility sensitivities, spatial gradients in T, p and $c_r$, and the duration of flow) controlling the amount of precipitation. Formation of a giant ore body requires A to be maximised; this in turn requires that there is a large decrease in solubility in the direction of flow. Hence it is not only the size and magnitude of the fluid flux and solubility gradient, but also the angular relationship between them, that is important. If fluid flows along isotherms, isobars and isopleths, then there is no change in solubility along the flow path and hence no deposition will occur.

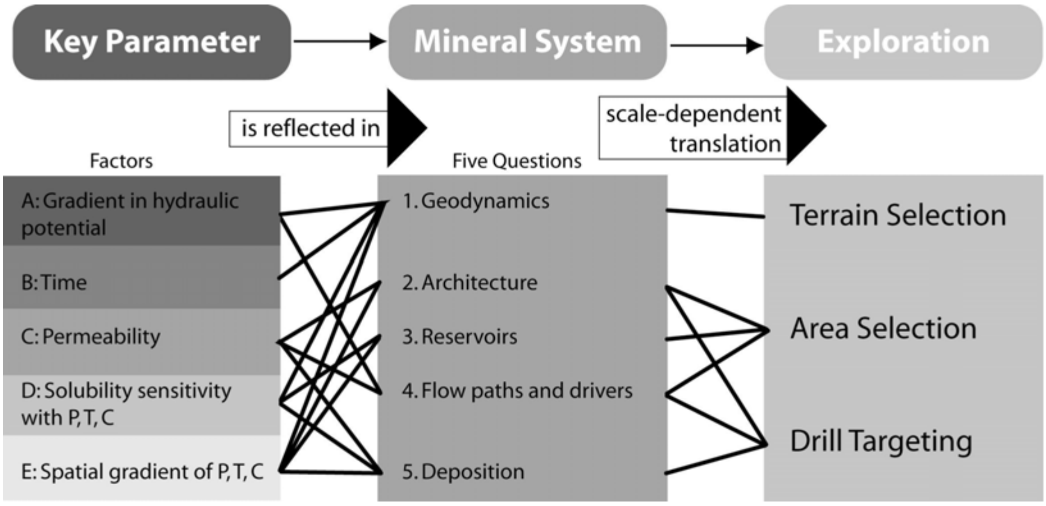


*Figure 1. Linkages within a Mineral Systems framework between the key factors (derived from the basic relationship discussed in the text), the 'Five Questions' and exploration.*

The relationship outlined in Equation (1) above forms the basis for rigorous analysis of mineral systems. In order to utilise the expression and factors described above, it is necessary to translate the terms into more tangible and detectable features. A look at the factors reveals that they can be evaluated if the five questions are answered in an appropriate manner (see the left-hand two columns in Fig. 1). For example, the permeability factor will be explored if the question about architecture is answered with a view to outlining where permeable structures and lithologies are distributed. Gradients in P, T and $c_r$ will be examined in answering the question on metal transport and deposition.

It is thus possible to link the underlying factors responsible for ore formation via the five questions. It is further possible to link the answers to the five questions to the exploration process, with the information drawn from the 'Five Questions' analysis depending on the nature of the exploration issue at hand (Fig. 1). When seeking to make large-scale exploration decisions (terrain/province selection), information concerning the geodynamic setting is most appropriate, whereas when evaluating drill targets, information about controls on ore deposition is relevant. In other words, the information taken from a mineral systems analysis depends on the scale at which exploration decisions are required.

**The *pmd*CRC* Cobar Region 3D Geology Project**

The Cobar Region 3D Geology Project is a collaborative project between mineral exploration companies in an Industry Consortium (Triako Resources; Peak Gold Mines; CBH Resources; Cobar Management PL; Tritton Resources), NSW DPI and ***pmd****CRC. The overall objective of the project is to increase successful mineral exploration investment in Central Western NSW.

The project aims to achieve this by providing the exploration industry with new capabilities to conduct more effective mineral exploration and to identify potential new mineral targets in "difficult-to-explore" areas in the Cobar Region of Central NSW (also referred to as the Central Lachlan Orogen).

Current mineral exploration strategies are highly dependent on 2D data sets, which is an important limitation on exploration effectiveness as ore search moves deeper and under cover. There is now a recognised need to explore using 3D interpretations and employ approaches which involve a clear understanding of how the 3D geological architecture controls the location of ore deposits.

Using state of the art 3D geological map making software, the project aims to help the exploration effort of the consortium companies be developing new targeting strategies and thus sustain a firm commitment to mineral exploration and discovery. An accompanying objective is to stimulate the mineral exploration industry to increase investment in Central Western NSW by building a 3D framework to attract explorers to the region. The project is constructing an integrated 3D model that will build on the 2D data collated by NSW Department of Primary Industries and the consortium companies. The model will provide a rigorous framework that will identify gaps in present geological understanding and therefore offer opportunities for new discoveries by the consortium companies and other parties in the Cobar Region. It is anticipated that the project outcomes will also contribute to a fundamental shift in exploration practice and cost-effectiveness in the region

The ***pmd****CRC was established to:
"*generate a fundamental shift in exploration practice and cost-effectiveness by developing a vastly improved understanding of mineralising processes and a four dimensional understanding of the evolution of the geology of mineralised terrains and converting this into low-cost targeting tools."*
The Cobar Project takes advantage of key ***pmd****CRC capacities developed to fulfil two of the five research objectives of the ***pmd****CRC, namely:
To contribute to resolution of the key areas of uncertainty in current models for the formation of major economic mineral deposits types, within mineralised terrains that have high exploration priority.
To build 3D and 4D images and histories of well known mineralised systems, within their regional exploration context.
The Cobar Region 3D Geology Project has been conceived and designed to achieve these two objectives in the study area. The Cobar Region falls within the wider Tasmanides region of southeastern Australia. The project will benefit from the integration of knowledge of the wider Tasmanides resulting from other ***pmd****CRC Tasmanides projects (T5, T6 and T7) and, after confidentiality expires, will also contribute to this larger scale work being undertaken by the ***pmd****CRC in NSW and Victoria.
**The objectives of the Cobar Project are to:**
Assemble and integrate the available geoscientific data in the region as input data to computer models.
Construct an integrated model that links the geoscientific data to the known mineral occurrences in the region to help predict new target areas.
Identify key parameters, gaps and opportunities for predictive mineral discovery and for future work by NSW DPI.

**The 5 Questions and the Cobar Project**

*Q1 - Geodynamics:* a review of the geodynamic setting of the Lachlan Orogen has been undertaken with construction of five new time-space correlation charts the chief output. The increased understanding of the temporal and spatial variation of geology gained from the new time-space plots has been fed back into the construction of the 3D map.

*Q2 - Architecture:* the Cobar project is principally concerned with defining the architecture of the central Lachlan sub-province through building an integrated 3D map. Fault architecture plays an important role in controlling distribution of lithology, fluid migration and ultimately the location of mineral deposits. More details of the 3D map construction process are provided below.

*Q3 - Fluid Reservoirs:* new sulphur and lead isotopic data from mineralised and unmineralised locations together with the synthesis of existing data and information derived from analysis of the mineral paragenesis have been used to characterise fluid sources.

*Q4 - Fluid flow pathways and driving forces:* the Cobar project has focussed on identifying fluid pathways using two different techniques. The first technique (Chopping, 2006) uses potential field inversions interpreted in terms of mineralogy to map alteration and hence fluid-flow pathways in three dimensions. The second technique uses remotely sensed and laboratory based infrared spectroscopy, principally ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and PIMA (Portable Infrared Mineral Analyser) instruments to identify variations in mineralogy that can be interpreted to yield information on fluid-flow pathways.

*Q5 - Transport and deposition:* the information gathered on fluid sources has been used to facilitate understanding of metal transport mechanisms (in other words the nature of the aqueous complexes responsible for the carrying metal in solution) and this information, in combination with observations on the mineral paragenesis, has allowed the principal causes of metal deposition to be identified

**Building 3D maps**

The ***pmd****CRC Cobar project has developed a workflow around the available datasets to the project and as a result emphasis in this workflow is largely around potential field datasets (Figure 2). The 3D workflow can be broken down into seven stages.

Data compilation - A large volume of public domain geological, geophysical, geochemical and mineral occurrence data exists for the region, and this has been complied into a coherent 2D GIS.

Geophysical value adding – Geophysical processing has involved determining the positions and intensity of potential field gradients ("worms") and also in producing geologically constrained inversions. Historic seismic data has been reprocessed using the current techniques of hard-rock seismic processing.

Compilation of 2D solid geology map - The foundation of all interpretation in the third dimension is the accurate identification of spatially referenced lithological units and faults at surface - the 'solid geology'. Without an accurate 2D dataset the determination of geometries in the third dimension is problematic (Henson, 2006).

Serial cross-section construction - The Cobar project used serial cross-sections (a series of regularly spaced cross-sections) as the basis for constructing the 3D map. These cross sections have been checked by potential field forward modelling. Over the central portion of the study area (the Cobar Basin), cross-sections were spaced at 10 km intervals, and at 20 km separation in the more peripheral parts of the map. Serial cross-section construction approach has been successfully adopted by other ***pmd****CRC 3D map projects such as Tasmania 3D.

Forward modelling - There has been significant conjecture on how best to integrate geophysical forward modelling into 3D geological maps and to date there has been no uniform approach to forward modelling within 3D geology projects. The first phase of forward modelling assumed a homogenous system (i.e. no variation in rock properties between polygons of the same geological unit). If there is no significant divergence between the observed and calculated profiles then results are fed straight into the 3D geology map. Where there is divergence then a second phase of the forward modelling focus on *why*. The results of the second phase of forwarding modelling are fed back into the serial cross-section interpretation.

3D surface construction - The regional 3D geological map consists of approximately 400 hundred surfaces that had to be individually constructed. To streamline surface construction a systematic approach was adapted, with fault surfaces constructed first because they cross-cut and displace lithological boundaries. The resultant fault architecture provides a starting framework for the 3D map. Next, the granites were modelled and finally the boundaries of stratigraphic units. Each surface has been constructed to ensure that it is 'water tight' with its neighbour (in other words that there are. no gaps between surfaces), uniformly named and that it has a good topology (no 'bad 'triangles).

Voxet (block model) construction - The completed surfaces are suitable for visualisation, but they are cannot to be queried spatially and cannot be integrated with other datasets into a whole earth model. Gocad was used to construct voxets, a propriety Gocad object with similarities to block models in other software packages such as Vulcan. Geological Voxets where constructed at 250m, 500m and 1000m cell resolution and integrated with 3D potential field inversion so that the finish model contained a region id, lithological code, density and magnetic susceptibility property.

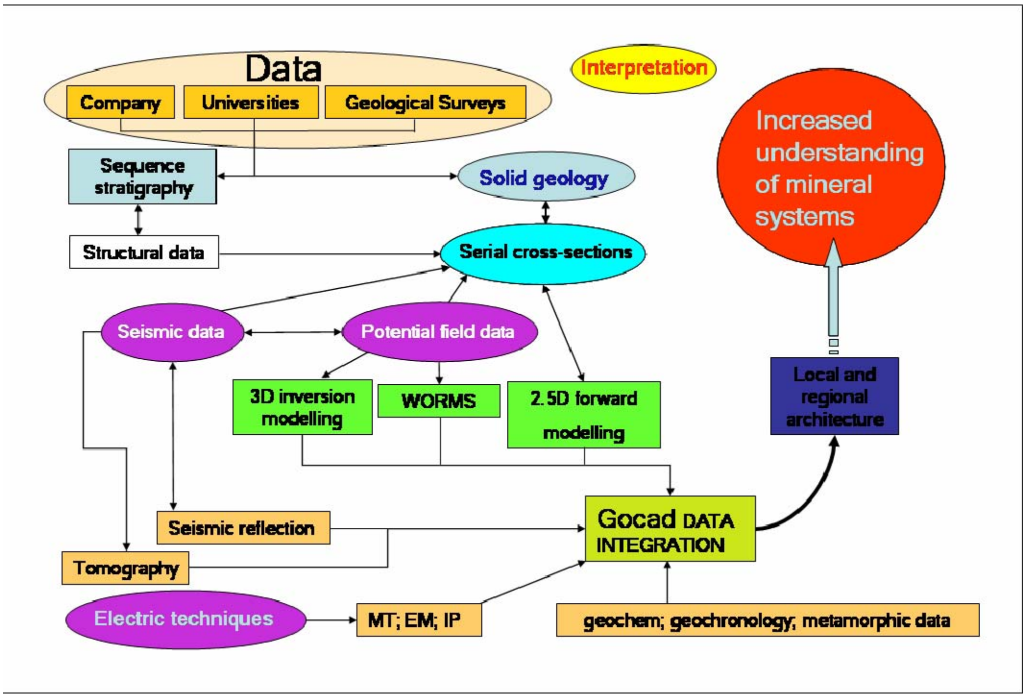


Figure 2: **An idealised 3D map building work flow (Henson, 2006). It is important to note that not all 3D studies have access to every type of data and therefore the workflow changes depending on data availability and the scale at which the project is working.**

**Conclusions**

The application of a Mineral systems approach to understanding ore deposits in the Cobar region has allowed new insights into the known ore bodies and also introduced new concepts into exploration in the region.

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# GRANITE PROSPECTIVITY IN EASTERN AUSTRALIA

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**Key Words**: granite, tin, tungsten, molybdenum, intrusion related gold, exploration, geothermal

## Introduction

Granite magmatism comprises a volumetrically significant proportion of the Palaeozoic fold belts of eastern Australia and is associated with a diverse range of mineralisation, including Sn, W, Mo, Au, Bi, Pb, Zn, Cu and Ag. Several distinct phases of ore-related granitic magmatism are present in eastern Australia with peaks in activity occurring during the Silurian-Devonian, Carboniferous-Permian, Permian-Triassic, and Cretaceous times. The distribution of mineralisation is not evenly coincident, spatially or temporally, with magmatism but reflects the varying roles of "source and process" involved in magma generation, emplacement and crystallisation.

Ore element ratios in intrusive-related mineralisation are a function of the continuum from Cu-Au through to Sn, W and Mo dominated mineralisation related to progressively more fractionated and felsic granites. Granite related mineralisation is the evolved end of a continuum in magmatic compositional space extending back to and including island arc magmatism.

Granitic rocks can be grouped into broad associations throughout eastern Australia. These have similar compositional and isotopic characteristics which are also mirrored in their metallogenic associations. These associations reflect the relative oxidation state, compositional character, and degree of fractionation of the associated granite suite.

## Important mineralised granite provinces in eastern Australia

The major mineralised granites in North Queensland fall into two groups: the Carboniferous I-type granite group (CIG; Sn, W-Mo-Bi and Cu-Pb-Ag-Au), and the Permian I- and S-type granites of the northern Hodgkinson Province. The three mineralised Carboniferous I-type supersuites are potassic, felsic, and show evidence of fractional crystallisation. Permian granites of the northern Hodgkinson Province are associated with Sn and W mineralisation and are isotopically and chemically less mature than those of the CIG. Gold-basemetal mineralisation in the Charters Towers region is associated with Permian magmatism with minor Mo mineralisation associated with Devonian magmatism. Ordovician granite magmatism in the Charter Towers region is felsic and compositionally evolved. The superposition of Palaeozoic granites of distinctly different ages in north Queensland contrasts with spatial and temporal patterns of granite magmatism elsewhere in eastern Australia.

Granites in the New England Orogen (NEO) are isotopically less evolved than those elsewhere in eastern Australia. Significant intrusive magmatism in the Devonian is restricted to the Mount Morgan Tonalite Complex in the northern NEO. Its chemical composition is similar to the M-type granites of New Britain. The central and northern portions of the NEO were the sites of extensive plutonism in the Late Carboniferous to early Permian (e.g. Urannah Batholith) and the early Triassic, extending down along the central NEO into the southern NEO. These granites are typically low- to medium-K diorites, tonalites and granodiorites, with chemical and isotopic signatures indicative of continental margin affinity. Early Cretaceous magmatism also developed along the eastern exposed portion of the northern NEO. While earlier magmatic-plutonic episodes in the central and northern NEO were probably subduction related, early Cretaceous magmatism was related to rifting and opening of the Tasman Sea. All these magmatic stages in the central northern NEO are associated with numerous porphyry style Cu-Mo-Au systems. Permian to Triassic I-type magmatism in the southern NEO is K-rich and related to Sn, W, Mo and Au mineralisation, in contrast to the central and northerly sections of the NEO.

The Silurian-Devonian and Carboniferous granites of the Lachlan Orogen (LO) comprise 20 % (i.e. 61,000 $km^2$) of the total exposed area of the LO, not including remnants of associated volcanic rocks. Significant mineralisation associated with the LO granites occurs in the western portions of the LO in New South Wales (Sn) and in both eastern and western Tasmania (Sn, W). Numerous deposits of Sn, W, Mo, Au, W and Cu have also been mined elsewhere in the LO, and the orogen remains prospective for a range of resources.

The granite metallogenic patterns of east Australian define a series of igneous metallogenic provinces. The boundaries of these provinces (as defined on broadly similar metallogeny and compositional and isotopic character of granites) tend to be rather distinct. This is particularly the case for provinces defined using I-type granites, though provinces so defined may cross tectonostratigraphic boundaries defined by near-surface geology. Provinces based on the distribution of S-type granites have boundaries that coincide more reasonably with tectonostratigraphic boundaries. This may reflect in some instances the relative distributions of sources of I- versus S-types, or in other cases, the relative influence of assimilation of crustal material into magmas.

**Current developments and opportunities:**

- There has been a significant renewed interest in granite related mineral systems in eastern Australia. Exploration success has occurred for Sn, W, Mo, Bi, Zn, Ag and Au.
- There has been little modern exploration in the granitic terranes of eastern Australia. Modern airborne geophysical coverage of many areas postdates ground based mapping and older exploration campaigns and offers the possibility for a new generation of granite and alteration mapping.
- There is a range of metals that could the focus of new exploration initiatives. These metals include intrusion related Au, REE, In, Ta-Nb, F and Re.
- Granites are also prospective sources of geothermal (radiogenic) heat. Geothermal exploration is, in its initial stage, essentially a granite exploration campaign.
- Scientific challenges also remain in understanding the origin of mineralised granites. For example, the Sn mineralised granites of the southern NEO are among the most isotopically juvenile Sn mineralised granites in the world. Such relationships preclude the involvement of ancient and/or evolved continental crust in their generation. New analytical techniques also offer fresh insights into granite formation and mineralisation.

# WHITE ROCK TUNGSTEN DEPOSIT AT RYE PARK, NSW: AN EXPLORATION UPDATE

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**Key Words:** tungsten, magnetite, skarn, molybdenite, cassiterite, granite, greisen, Silurian, exploration

## Introduction

The White Rock tungsten deposit is located 200km west of Sydney, 50km north of Yass near the township of Rye Park, New South Wales (Figure 1). The tungsten deposit has a history of very small scale mining. A shaft was developed on skarn outcrops in the early 1900s, and a small open pit was developed on a shallow ore lens in the 1950s. Several thousand tonnes of ore was stockpiled on site during the early days, and much of this ore remains stockpiled to this day.

Paradigm Metals Ltd (Paradigm) acquired Exploration Licence EL 6274 containing the White Rock deposit in 2007. Paradigm is exploring the White Rock deposit and the surrounding areas targeting a high-grade tungsten deposit, in the size range of 500,000 to 1 million tonnes for future exploitation. It is believed that the shallow depth, the flat lying nature and high-grade of the tungsten skarns may permit the exploitation via open pit mining. The Company is hopeful that the simple mineralogy may also allow the use of gravitational methods for the separation of the heavy tungsten minerals (predominantly scheelite).

## Regional Geology

The White Rock skarn deposit is hosted by acid volcanic rocks and calcareous units of the Douro Group, formed in the Cowra Trough during Silurian extensional tectonics. The host limestone formations are believed to have been laid down near the margin of a sub-basin during Silurian times. The sub-basin is bounded to the east by Ordovician metasediments separated by a NNW trending boundary fault.

Siluro-Devonian granites of the Wyangala Batholith intruded the Ordovician and Silurian stratigraphy. The majority of the granite outcrops are unaltered and unmineralized. A small cupola of highly evolved granite adjacent to the White Rock deposit (the Rye Park Granite) is a light coloured, medium to coarse-grained equigranular muscovite-biotite granite. The Rye Park Granite is greisenised and believed to be responsible for the tungsten mineralization.

## Geology and Mineralization of White Rock

Two small cupolas of the Rye Park Granite outcrop in the immediate vicinity of the White Rock skarn deposit, each outcrop being 150m to 400m in diameter. The southern most granite ('Mica Hill') is strongly greisenised and altered to quartz and muscovite. Minor tourmaline and wolframite occur within the greisen at Mica Hill.

The known tungsten-bearing skarn bodies are developed in flat lying limestone and volcaniclastic units on the eastern contact of the northern granite cupola (Figure 2 and 3). The granite contact appears to be flat dipping at the prospect scale, but where it has a moderate dip it cuts across the limestone where the best skarn mineralization has developed. The change of dip may also reflect a fault, which would explain the quartz veining on the granite margin. The skarn / limestone lenses dip gently to the west towards the granite. The best mineralization occurs at depths shallower than about 40m from surface. In general mineralization is shallower at the southern end of the skarn, deepening to the north.

There is a zonation in skarn types away from granite contact. The following zonation has been recognized from the granite margin outwards, presumably reflecting (in part) decreasing temperature from the source granite:

(1) Proximal magnetite-epidote-garnet-scheelite skarn with minor quartz-clinopyroxene-amphibole.
(2) Garnet skarn with minor actinolite-epidote-scheelite-cassiterite.
(3) Unmineralized epidote-quartz-amphibole-chlorite skarn.

The width of the skarn mineralization away from the granite is approximately 30-40m. The strike length of known skarn mineralization is at least 200m, while skarn mineralization occurs in lenses up to 12m in thickness.

The highest grade tungsten mineralization is associated with the magnetite-rich type 1 skarn. Magnetite comprises around 40% of the skarn by volume. A sulphide rich skarn consisting of (4) pyrrhotite-pyrite-biotite appears to truncate the earlier skarn types, but is weakly mineralized with tungsten-tin. The tungsten-tin-molybdenum mineralization in the skarn bodies occurs as scheelite (dominant), wolframite, and molybdenite. Other sulphides/oxides include pyrrhotite, pyrite, chalcopyrite, sphalerite, and cassiterite. Native bismuth has also been described.

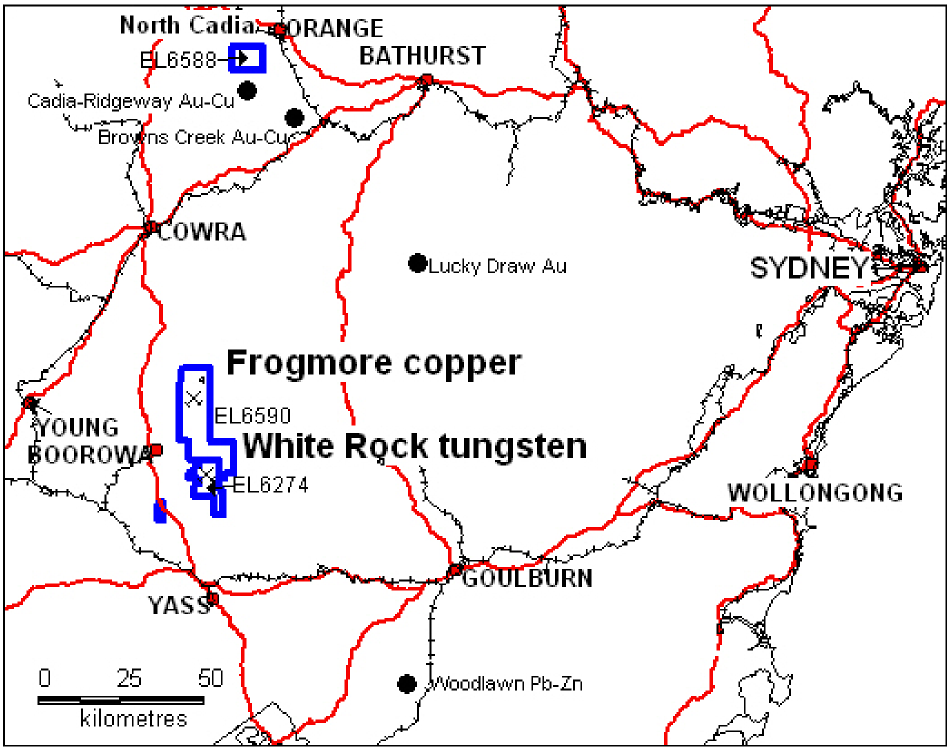


**Figure 1: Location map of the White Rock tungsten deposit and Paradigm exploration interests in central eastern New South Wales**

**Mineral Resource**

Paradigm has calculated a Mineral Resource estimate (indicated and inferred) at the White Rock deposit of 150,000 tonnes at 0.9% tungsten trioxide, on the basis of results from Tungsten Consolidated Ltd diamond drill holes (Sullivan and Dallwitz, 1952), and additional check drill holes carried out in 2006. An update to this mineral resource is likely this calendar year.

**Current Exploration and Mineralogical studies**

Given the close association between magnetite and scheelite, recent exploration has focused on identifying shallow magnetic anomalies for drill testing using detailed ground magnetic surveys. Previous exploration noted that the ground magnetic anomalies closely mapped out the tungsten-bearing skarns (Horvath and Davidson, 1958). Upcoming drill programs will also concentrate on the testing of targets along the altered granite contact. Metallurgical test work is currently taking place on the magnetite-rich ores. The Company is hopeful that a simple flow sheet involving magnetic and gravity separation techniques may be sufficient for the economic exploitation of the tungsten, tin and magnetite ores. Preliminary testwork already completed on the magnetite indicates it could be suitable for use in coal washing plants.

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**Figure 2. Map of Paradigm drill holes and grade-intercepts at White Rock**

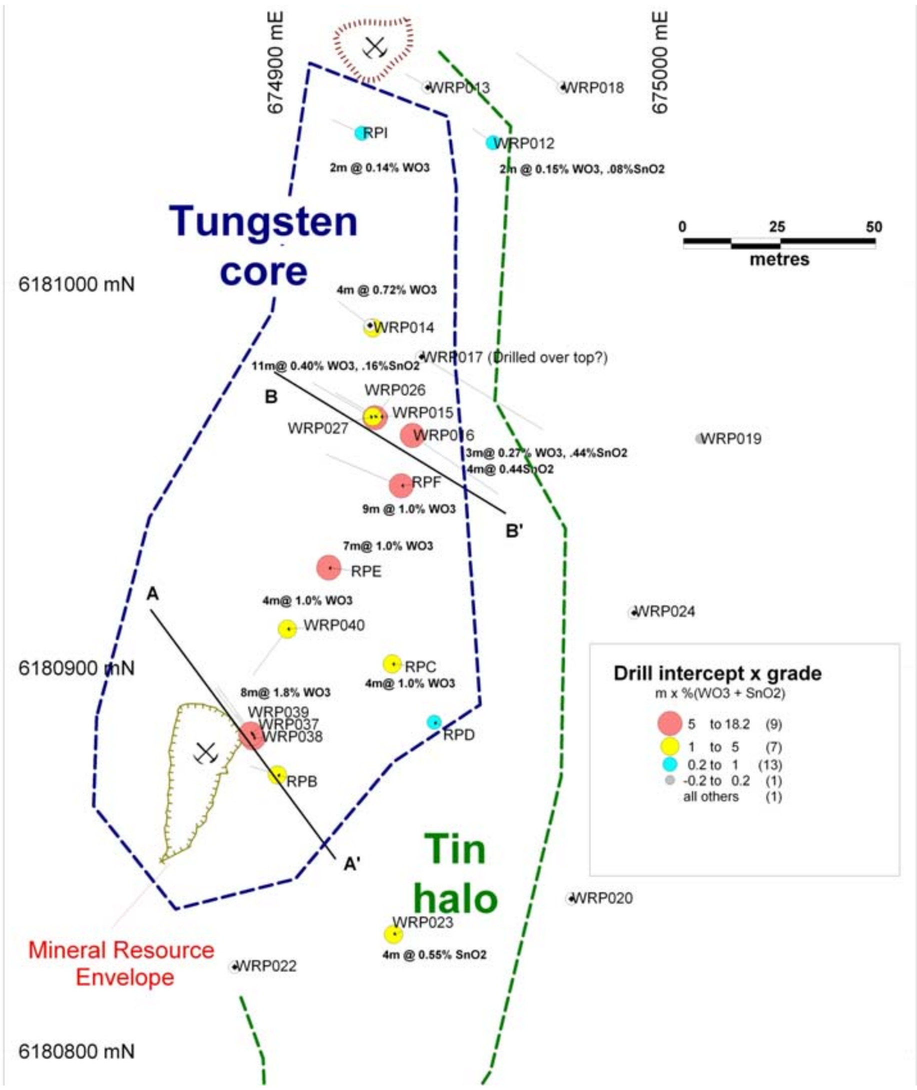
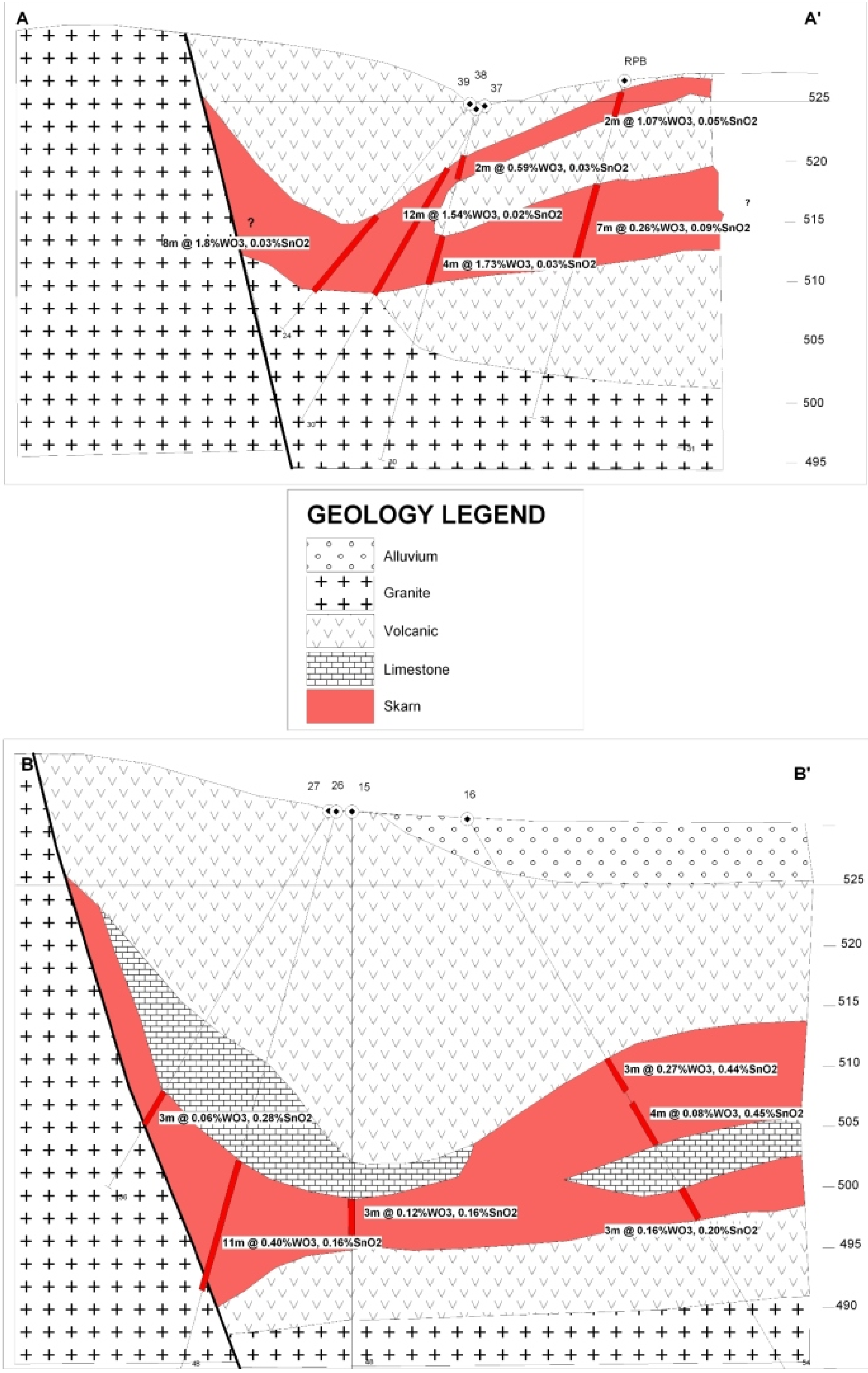


**Figure 3. Cross sections of the White Rock tungsten deposit**



# OROGENIC GOLD IN THE EAST LACHLAN

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**Keywords:** East Lachlan Orogen, orogenic gold, Wyoming, McPhillamys

## Extended Abstract

### Introduction

The East Lachlan Orogen is known for its world class porphyry gold-copper systems associated with late Ordovician magmatism. Historically many small, mainly quartz vein deposits and their associated alluvial systems, produced substantial amounts of gold. The larger of these were discovered and mined in the 1850's through to the early 1900's. Cumulative historic production with some more modern resources give total contained gold such as Hill End +700,000oz; Gulgong 540,000oz; Adelong 800,000oz; Lucknow 500,000oz; West Wyalong 450,000oz; Parkes 600,000oz; Forbes 450,000oz; Young 500,000oz; Bodangora 200,000oz; Stuart Town 170,000oz and Araluen-Majors Creek 1,400,000oz (Suppel et al 1990). Most of these deposits display the characteristics of orogenic gold deposits, although Majors Creek (Dargues Reef) is currently interpreted to be an Intrusion Related Gold deposit (Fisher et al 2006).

Modern exploration for orogenic gold deposits in the region has been limited until recent years, encouraged by Alkane Resources Ltd discovery (2001) of significant deposits at Wyoming (Chalmers et al 2004, 2006), near Tomingley at the northern end of the Forbes-Parkes belt. In 2006, Alkane in partnership with Newmont Australia Limited, made another significant discovery at McPhillamys, to the east of Blayney (Alkane web site). This deposit is also considered to be of orogenic origin.

Groves et al (2004) summarised orogenic gold deposits as those that formed in metamorphic or orogenic belts with a broad suite of similar characteristics. In the same paper Groves et al (2004) described metamorphic belts as complex regions where accretion or collision has added to, or thickened, continental crust. Gold-rich deposits can be formed at all stages of orogen evolution, so that evolving metamorphic belts contain diverse gold deposit types that may be juxtaposed or overprint each other. This partly explains the high level of controversy on the origin of some deposit types, particularly those formed or overprinted/remobilized during the major compressional orogeny that shaped the final geometry of the hosting metamorphic belts.

Orogenic gold deposits range in age from Middle Archean to Tertiary, and include several giant (>250 t Au) and numerous world-class (>100 t Au) examples. Their defining characteristics and spatial and temporal distributions are now relatively well documented. They form as an integral part of the evolution of subduction-related accretionary or collisional terranes in which the host-rock sequences were formed in arcs, back arcs, or accretionary prisms.

General characteristics of orogenic gold deposits are:

(1) deposits cover a wide spectrum of depositional environments;

(2) have previously been called mesothermal, lode or structural, and emplacement depth can be from the near surface to more than 20 kilometres;

(3) have a proximal association to crustal scale structures with significant fluid flow capacity;

(4) fluid focus through intersecting secondary structures, fault flexures and competency contrasts;

(5) fluids are generally near neutral with low to moderate salinity, and can have a metamorphic, magmatic and possibly meteoric origin;

(6) alteration typically sericite, carbonate, quartz, chlorite and sulphides; and

(7) mineralisation dominant pyrite, pyrrhotite, arsenopyrite with minor chalcopyrite, galena and sphalerite. Gold is almost always late.

### The Lachlan Orogen

The Lachlan Orogen is composed of a complex association of early Cambrian to Devonian sedimentary, volcanic and intrusive rocks. These sequences developed in a setting which has been interpreted to have similarities to modern southwest Pacific oceanic island arc and back-arc basin environments (Glen et al. 1998; Gray et al. 2002; Bierlein et al 2002; Gray and Foster 2004). Based on structural and lithostratigraphic criteria, the Lachlan Orogen has been divided into three provinces, namely the Western, Central and the Eastern belts (Bierlein et al 2002; Gray and Foster 2004).

The Western Belt is largely a turbiditic sequence which hosts the major “slate belt”-type orogenic gold mineralisation, including the 17 million ounce Bendigo goldfield. The Central Belt is also dominated by turbidites but also hosts granite-associated tin-tungsten-molybdenum deposits in its southern portion, while orogenic gold and base metal deposits in extensional basins around Cobar predominate in the northern part of the Central Belt, including the 2 million ounce Peak gold mine (Stegman 2001). Both the Western and Central belts may have developed in back arc environments, with the Eastern Belt representing the magmatic and fore arc environments (Gray and Foster 2004). This setting has been named the Macquarie Arc (Glen et al. 1998; Glen et al. 2004) and hosts porphyry-epithermal bodies, including the world-class 30 million ounce deposits at Cadia and Ridgeway.

Within the Macquarie Arc, several individual belts of mafic to intermediate volcanic, intrusive, volcaniclastic and turbiditic rocks have been identified. These sequences are segmented by a number of generally north–south to north-northwest trending arc-parallel structures, many of which are thought to be thrust faults with either west or east vergence, or major strike-slip faults (Glen et al. 1998). Glen et al. (1998) have suggested that the Macquarie Arc initially formed as one composite oceanic island arc or volcano-sedimentary prism which was subsequently dislocated by major thrusting and extensional rifting to form the three discrete volcanic belts (i.e. Junee-Narromine, Molong, Rockley-Gulgong volcanic belts; figure 1 insert) that are observed today (Glen et al. 1998). The inter-belt zones are largely represented by Devonian aged thick turbiditic trough in-fills and later discrete clastic sedimentary basins.

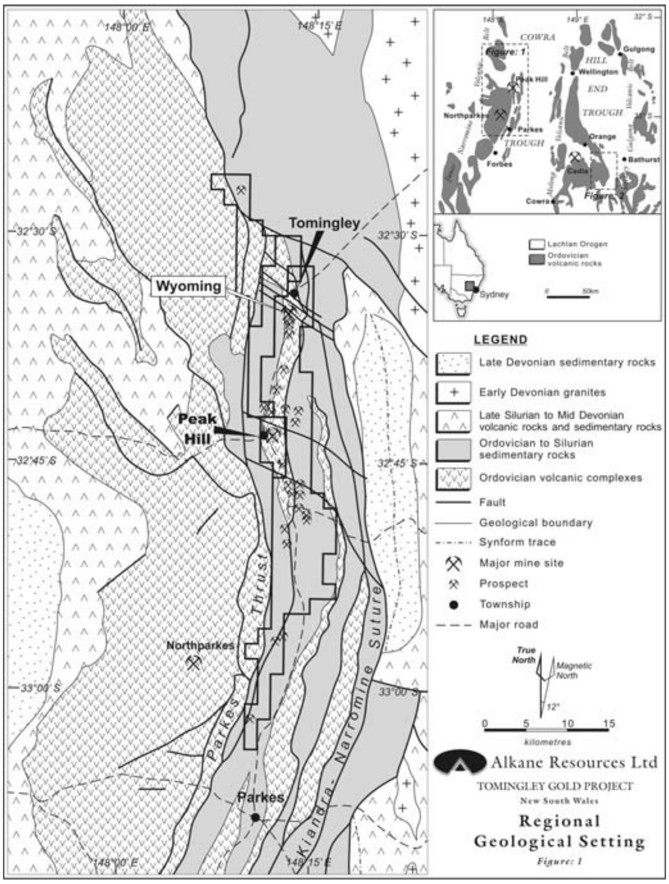
The volcanic belts comprise Ordovician to Silurian rocks with predominantly mafic to andesitic composition, with limited more felsic rocks, and display a spectrum of rock types including lavas, breccias, volcaniclastic sandstone and siltstone, and monzonitic to dacitic intrusions associated with the porphyry copper-gold systems. The three principal volcanic belts are characterised by near-vertical, upright intrusive complexes situated within relatively undisturbed, flat-lying stratigraphy with broad open folds. By contrast, the marginal and inter-belt areas are more structurally disturbed with tight to isoclinal folding in apparent thrust segmented slices.

Granitic bodies of variable size and composition, and of Silurian to Carboniferous age, intrude into all arc sequences.

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, crustal-scale breaks that were irregularly reactivated throughout the geological development of the Eastern Belt. The structures also show a relationship to intrusive centres and mineralisation, intersecting and occasionally offsetting arc-parallel structures (Squire and Miller 2003).

### The Wyoming Deposits

The Wyoming gold deposits are located about 40 kilometres north of Parkes within Alkane’s Tomingley Gold Project (TGP) near the eastern margin of the Junee-Narromine volcanic belt, to the east of the interpreted Parkes Thrust. This structure separates the flat lying Goonumbla volcanic complex from a thin slice of north-south trending andesitic volcanics identified by regional aeromagnetic data and interpreted to be equivalents of the Goonumbla volcanics (previously named Mingelo volcanics). The TGP covers much of this interpreted north-south belt extending almost the entire length of the tenement and being about 2 kilometres in width north of Trewilga reducing to approximately 500 metres width in the south (Figure 1).




Drilling by Alkane through the widespread transported cover sequence in 2001 to follow up the trend of historically reported mineralisation, discovered extensive alteration and gold mineralisation within an andesitic feldspar porphyry intrusion and adjacent volcaniclastic sandstones and siltstones. Subsequent detailed resource definition drilling has identified a substantial mineralised body at Wyoming One comprising a number of distinct zones, associated with sericite–carbonate (ankerite)–albite–quartz-(±chlorite ± pyrite ± arsenopyrite) alteration. A smaller but similar body was identified at Wyoming Three about 500 metres to the north. As at 31 December 2006, total identified resources stood at 606,000 ounces (Alkane web site).

In 2006-07, following several years of drilling and compilation of the geological data, Alkane tested a new target called Caloma located about 500 metres to the east of the Wyoming deposits. While the exploration is at a very early stage, Caloma appears to be a faulted offset of the Wyoming area but it shows similar characteristics to the Wyoming deposits and could have the same resource potential as the Wyoming One deposit (500,000 ounces). This would bring the total resource inventory at the project site to plus 1 million ounces of gold.

The Wyoming deposits appear to have formed as the result of a rheological contrast between the feldspar porphyry host and the surrounding volcaniclastic rocks, with the porphyry showing brittle fracture and the metasedimentary rocks ductile deformation. Current interpretation also suggests that the Wyoming One feldspar porphyry is located near the axis of a tight, easterly vergent, antiform.

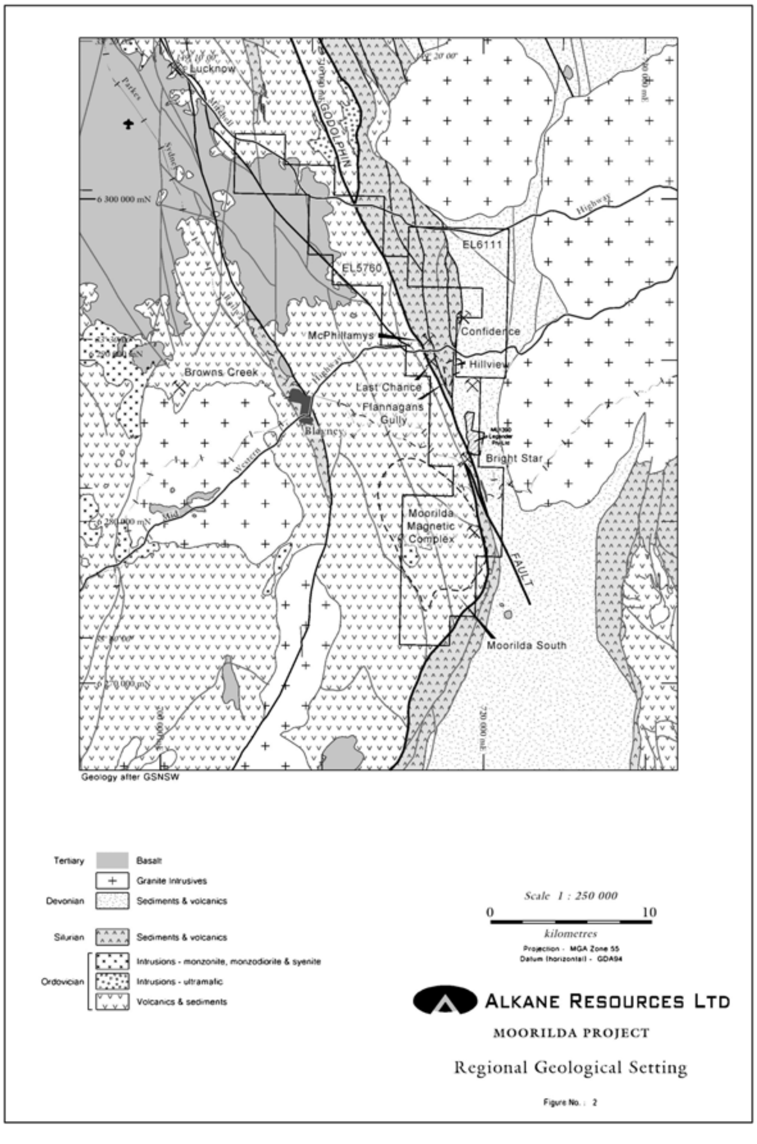
Recent structural analysis and modelling indicates a complex history involving a sinistral transpressional event with a rotation of the stress field to develop the mineralised vein array. The deposits have a close relationship to northwest-southeast structures which appear to be linking structures between the major north-south trending Kiandra-Narromine fault system in the east and the Parkes Thrust in the west. The northwest-southeast structures align with one of the interpreted northwest corridors referred to above.

**McPhillamys Deposit**

The McPhillamys prospect in located within Alkane's Moorilda Project, which is centred 35 kilometres south east of Orange. The Project forms part of the Orange District Exploration Joint Venture (ODEJV) with Newmont Australia Limited.

Moorilda straddles the structural contact, marked by the Godolphin fault zone, between the Ordovician aged Molong Volcanic Belt in the west and the Siluro-Devonian sediments and volcanics of the Hill End Trough to the east. Numerous historical gold workings are scattered along the structure. The giant Cadia-Ridgeway gold-copper monzonite associated orebodies of Newcrest Mining are located 30 kilometres to the west while the major historic producer at Lucknow (~500,000 ounces of gold) is 5 kilometres to the northwest (figure 2).

Modern exploration of the area had been sporadic with limited, shallow drill testing of some historic prospects during the 1980's and regional surface sampling in the 1990's. Alkane's interpretation of the data and structural setting indicated a number of potential targets along a 15 kilometre corridor paralleling the Godolphin fault zone. These included the Bright Star, Last Chance and Confidence Mines and the McPhillamys Prospect which had previously been highlighted by a reconnaissance regoleach soil survey.




At McPhillamys, soil auger sampling delineated a robust +100ppb gold response within a 650 x 200m area with coincident anomalous indicator trace elements. The anomaly includes a maximum 2g/t gold, and is centred about the historic McPhillamys Hill Gold Mine (1880's). Reconnaissance mapping of the area noted intensely altered felsic volcanic rocks, thought to be part of the Silurian Anson Formation, hosting up to 50% iron-oxide after sulphide, and sheeted 1-

30cm quartz veins within the target zone. In addition, the area was close to the terrane bounding Godolphin Fault and a suite of north-south trending fault splays.

Initial reconnaissance aircore drilling, and follow up RC drilling and one core hole confirmed the existence of extensive gold and base metal mineralisation over a 300 metre strike length and up to 200 metres width, associated with highly altered volcanics with variable sulphide and quartz veining throughout. Selected intersections are:

| | |
|---|---|
| **KP 047** | **54 metres grading 1.69g/t gold from 123 metres**<br>**Including 20 metres grading 3.10g/t gold from 146 metres** |
| **KP 048** | **123 metres grading 1.96g/t gold from the surface**<br>**including 28 metres grading 3.83g/t gold from 19 metres**<br>**and 12 metres grading 3.48g/t gold from 101 metres** |
| **KPD 001** | **77 metres grading 1.65g/t gold from 140 metres**<br>**including 13 metres grading 2.78g/t gold from 165 metres**<br>**Also 7 metres grading 5.56g/t gold from 191 metres** |
| **KPD 001** | **31 metres grading 1.64% zinc, 12g/t silver, 0.18g/t gold from 64 metres including 7 metres grading 2.49% zinc, 17g/t silver, 0.22g/t gold from 65 metres** |

Exploration of the McPhillamys prospect is at a very early stage but it is possible to conclude that the host rocks were comprised of a suite of felsic volcanic and associated sedimentary rocks, extensively altered to sericite rich argillites with variable quartz veining and pyrite, sphalerite, chalcopyrite, galena and gold. No attempt has been undertaken to quantify the resources within the prospect at this stage, but a potential of 1 million ounces of gold is possible.

While the volcanic sequence is known to host volcanogenic massive sulphide deposits elsewhere in the region, the authors believe that the structural setting, alteration style and distribution of mineralisation at McPhillamys is more typical of orogenic type gold deposits.

## Conclusions

The East Lachlan Orogen is famous for its world class porphyry-epithermal gold copper deposits but the discovery of the Wyoming and McPhillamys deposits, demonstrates that potential does exist in the region for major orogenic gold deposits.

The basic targeting parameters for orogenic gold deposits are generally well understood, and can be used to focus exploration effort and lead to additional discoveries.

## Acknowledgements

Many geologists have contributed to the development of the understanding of the deposits and models described but the input of Rimas Kairaitis and Justin Tolman (Newmont), and Peter Schaubs (pmd*CRC) on the structural controls at Wyoming, is particularly acknowledged.

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# UPDATE ON THE COPPER HILL CU-AU PORPHYRY PROJECT

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The Copper Hill Cu-Au porphyry project is located about 45 km north along the Macquarie Arc from the Cadia Valley copper-gold deposits and five kilometres north of the town of Molong. Copper Hill was mined intermittently for copper and gold in the mid 1800's to early 1900's. In modern times, the Copper Hill area has been explored from the 1960's into the new millennium by a variety of companies including Amax, Homestake, Cyprus, MIM and Newcrest in various joint ventures. The project is currently 100% owned by Golden Cross and contains an in situ inferred, indicated and measured resource of 133 million tonnes at an average grade of 0.31% copper and 0.28 grams per tonne gold at a 0.2% copper cut-off grade. The deposit contains over 420,000 tonnes of copper and over 1.2 million ounces of gold.
Over the past twelve months, 15,000 metres of drilling, geophysical surveys, along with ongoing geological interpretation and re-logging, combined with an Honours project (Hoye, 2007) and reviews by consultants (in particular Corbett, 2006) has better defined the spatial relationships between intrusions and hydrothermal vein types, advanced the understanding of the volcanology and tectonic history and led to the construction of a coherent resource geological model.

## Spatial Relationships between Intrusions & Vein Types

Copper Hill is hosted by an igneous complex of diorite through quartz diorite (in the eastern part) to sub-volcanic tonalite/dacite intrusions. Many dacite phases have been identified at Copper Hill by various workers. However, these have often proven difficult to trace between drill sections.
Following recommendations by Corbett (2006), a logging system has been adopted whereby dacites are classified according to the presence or absence of different hydrothermal vein types as well as texture, grainsize and alteration assemblage. This has enabled several groups of dacite to be classified, including pre-mineral host, syn-mineral "mineralizor", intra-mineral, and post-mineral dacite dykes.
Classic porphyry vein types at Copper Hill include:
rare, ptygmatic quartz +/- sulphide "A" veins in pre-mineral host intrusions;
sheeted or stockwork +/- laminated quartz+magnetite+sulphide"M" veins, most common in the carapace zones of early syn-mineral intrusions;
stockwork quartz+medial sulphide "B" veins, common on the margins of carapace zones and extending into pre-mineral host intrusions;
stringer to semi-massive chalcopyrite "C" veins, commonly cross-cutting "M" and "B" veins and occupying "copper haloes" around and above syn-mineral intrusions;
sericite selvedged stringer pyrite +/- quartz+calcite+pyrite+/-molybdenite "D" veins.
Applying these vein types to the various dacite generations has enabled "mineralizor" and carapace zones to be interpreted and digitised into wireframes. Future work will hopefully allow additional dacite boundaries to be delineated across drill sections.

## Volcanology & Tectonic History

The Copper Hill complex has intruded the Middle to Upper Ordovician Fairbridge Volcanics, of basaltic andesitic through to dacitic composition. Units of the upper, dacitic portion of the Fairbridge Volcanics and the lower Cheeseman's Creek Formation (also of dacitic composition), within which the Reedy Creek Limestone was deposited, probably represent the extrusive equivalents of the Copper Hill igneous complex. In this interpretation, the dacitic portion of the Fairbridge Volcanics, the Reedy Creek Limestone and the lower, dacitic Cheeseman's Creek Formation are time-equivalent units. The presence of accretionary lapilli in dacitic volcanics to the west of the Wattle Hill prospect, in Newcrest hole NCH001, provides evidence for sub-aerial volcanism.
The Copper Hill complex is bounded to the southwest by the Western Fault, a steeply north-easterly dipping fault zone that may have up to 700m of sinistral strike-slip displacement, based

on apparent off-sets of ground magnetic features. Or may represent a structure marking the south-western boundary of a dilational jog created by sinistral movement on a major NNW-trending structure. The jog was intruded by the Copper Hill Intrusive Complex.
Subsequent, post-Devonian tilting of strata has resulted in the Reedy Creek Limestone and the north-western portion of the Copper Hill complex having a moderate tilt towards the southwest. The tilt becomes greater along the axis of the complex to the southeast, with the result that Wattle Hill prospect is oriented almost on its side, while the Reedy Creek limestone has a steep south-westerly dip.

**Resource Domains**

The most important dacites for resource modelling are the "mineralizors" (MIN) and the post-mineral dykes (DYK), since MIN broadly define the 0.2% copper envelope and DYK dilute some ore zones. For resource modelling purposes, MIN domains include syn- and intra-mineral dacites. Near the apices of the MIN domains are several higher grade (~1% copper) carapace zones (CAR). Much of the pre-mineral dacite and surrounding volcanics falls into the >0.1%, "low grade copper" (LGC) domain.
Other domains include the argillic alteration zone (ARG), a possible lithocap in the central-western portion of Copper Hill.

**Resource**

The recent resource estimate gives an in situ inferred, indicated and measured resource of 133 million tonnes at an average grade of 0.31% copper and 0.28 grams per tonne gold at a 0.2% copper cut-off grade. The breakdown is given in the table below for the fully diluted block model.

| Class | Tonnes (Mt) | Copper (%) | Gold (g/t) | Contained Copper (Kt) | Contained Gold (M oz) | % of Tonnes |
|---|---|---|---|---|---|---|
| Measured | 16.9 | 0.390 | 0.429 | 66 | 0.23 | 13% |
| Indicated | 66.9 | 0.325 | 0.288 | 217 | 0.62 | 50% |
| Inferred | 48.7 | 0.284 | 0.225 | 138 | 0.35 | 37% |
| Total | 133 | 0.318 | 0.283 | 421 | 1.20 | 100% |

| Copper Cutoff (%) | Tonnes (Mt) | Copper (%) | Gold (g/t) | Contained Copper (Kt) | Contained Gold (M oz) |
|---|---|---|---|---|---|
| 0.10 | 328 | 0.214 | 0.200 | 702 | 2.11 |
| 0.15 | 211 | 0.264 | 0.240 | 557 | 1.62 |
| 0.20 | 133 | 0.318 | 0.283 | 421 | 1.20 |
| 0.25 | 83 | 0.375 | 0.332 | 310 | 0.88 |
| 0.30 | 51 | 0.438 | 0.389 | 224 | 0.64 |

The new geological interpretation was used in the resource modelling process. Two block models were created, one unconstrained by the geological wireframes and the other constrained. The results were very similar with the constrained model returning 8MT less than the unconstrained. Looking at the block allocation in the constrained model versus the unconstrained model it was felt that the unconstrained model better represented the observed distribution of grade between the domains. The modelled area was further divided into three domains reflecting the observed change in dip of the mineralizors. The domains were modelled separately using unique search parameters. The kriging parameters were derived from the domain with the greatest number of data points and used across all three domains.
GCR provided the drill hole database, which Hellman & Schofield (H&S) accepted in good faith as being reliable, accurate and complete. GCR also supplied a detailed geological interpretation of the Copper Hill deposit, which formed the framework for the resource estimates. H&S has not validated the GCR database or geological interpretation in any detail, so responsibility for these aspects of the resource estimates, including quality of the data, resides with GCR.

**Economics**

Australian Mine Design and Development Pty Ltd (AMDAD), using mining costs generated internally and process costs provided by Cullen Mining Services (CMS), has completed conceptual pit optimisation studies using the April 2007 resource estimates. AMDAD's review of the August estimate is ongoing however given the estimate is similar the pit optimisations are expected to also be similar.

| | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| US$/oz Au | 500.00 | 600.00 | 700.00 |
| US$/lb Cu | 1.80 | 2.65 | 3.50 |
| Operating NPV | | | |
| @ 8 Million tonnes/annum | A$250 million | A$600 million | A$900 million |
| | | | |
| Mill Feed million tonnes @ 8Mtpa | 44 | 94 | 118 |
| CMS Capital Cost Estimate for 8Mtpa operation. | | A$333 million | |

Using a range of price and throughput assumptions, as set out in the table above, several operating net present values (NPV's) were estimated, exclusive of capital costs for mill, plant and infrastructure. Mining equipment leasing costs are included.

At an 8Mtpa operation at Case 2 metal prices, sufficient material could be treated to produce, in aggregate, about 240,000 tonnes of copper in concentrate with 400,000 to 500,000 ounces of recovered gold over a twelve year mine life.

CMS's capital cost estimate of $333 million indicates an NPV of about $270 million is possible using Case 2 metal prices and treating 8 million tonnes of ore per annum.

**Airborne Magnetics**

A high resolution airborne magnetic survey was completed over most of the tenement area. An area over the township of Molong was not covered for obvious reasons. The survey was conducted using a fixed wing aircraft flying at a nominal height of 60 metres. The survey confirmed the area of low response associated with the Copper Hill mineralisation. The relationship between the magnetic response and the known mineralisation is not as straight forward as first thought. It has now been recognised that for the most part the mineralisation appears to be located on the shoulders of the magnetic highs. This observation is repeated in the third dimension.

This has obvious implications for developing exploration programs within the immediate prospect areas particularly with respect to siting drill holes. On a tenement scale it also has implications as to possible target areas whereas previously highs and lows may have been preferentially excluded or targeted.

**Offset Pole Dipole IP Survey**

Earlier this year a detailed offset pole-dipole survey was undertaken over the Copper Hill and Larras Lee prospects. The results for Larras Lee were not encouraging and the observed anomalies in that area have now been drill tested. The prospectivity of the Larras Lee area has now been downgraded. The Copper Hill area is well defined by the chargeability, with the mineralisation more often than not occurring on the shoulders of the chargeability highs. Again this is borne out in the third dimension.

This is what was observed with the magnetics and this too has implications for future exploration programs. One such anomaly, the Power anomaly in andesite, about 1.5 kilometres east of Copper Hill was tested with a 424 metre drill hole. The drill hole was designed to pierce the centre of the anomaly and anomalous copper and gold were intersected. Only trace chalcopyrite was observed but gold grades of 1.5 grams per tonne were returned over two 5-metre intervals. Surface rock chip sampling yielded one result of 7 grams per tonne gold supported by elevated copper values in soils south of the IP anomaly.

**Future Work**

GCR has focused its attention on the Copper Hill deposit over the past year and has attempted to increase both tonnes and grade by additional drilling. We were not successful in this quest and additional zones of high grade have not been intersected. However we believe the Copper Hill deposit can be economically exploited in the right metal market scenario and, at copper and gold prices mid-way between long term averages and current spot, positive NPV's can be determined using industry average assumptions. The estimated capital cost of about $330 million means that GCR will require a joint venturer to share the costs to take the project to development.

In addition, a number of IP and magnetic anomalies have been identified from the two surveys within the vicinity of Copper Hill. Delineation of mineralisation in these areas would add to the economics of that found to date and provide a significant upside to the project.

Looking further a field, five to 10 kilometres further south, analysis of the high-resolution airborne data has identified magnetic highs which have been interpreted to represent magnetite skarns, formed at the base of the overlying limestone by ascending hydrothermal fluids. This untested area holds potential for new intrusive complexes or discrete porphyries beneath the limestone cover. Mineralisation proven in this area would be within economic trucking distance to a plant site at Copper Hill and would add to the value of a mine located there.

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# THE CADIA EAST DEPOSIT – ENSURING AT LEAST 30 MORE YEARS OF MINING AT CADIA VALLEY. – NEWCREST MINING.

**Dean L Collett**, Principal Geologist

Cadia East comprises a 1100 million tonne resource containing an estimated mineral endowment of approximately 22 million ounces of gold and 3.6 million tonnes of copper. The deposit occurs immediately east of the Cadia Hill mine and extends in an arcuate strike for about 2000m. Beneath a cover sequence of up to 200 metres of post mineralisation shales and sandstones the ore deposit extends to at least 1500 metres below surface. Exploration drilling continues to define the limits to the system.

The deposit is classified as a low grade alkalic porphyry gold-copper style. Two overlapping main mineralisation events consist of an upper disseminated chalcopyrite (copper rich) open pit part and a deeper gold-rich, quartz-vein hosted underground section. The main sulphide mineral species are chalcopyrite, pyrite, bornite and molybdenite.

The mine sequence host rocks are the Ordovician age Forest Reef Volcanics (90%) which are the wall rocks to central monzonite intrusives (10%) at depth. The volcanics comprise a layered gently dipping sequence of volcaniclastics and mafic lavas along with co-genetic sills and dykes of porphyry intrusives. The monzonites are part of an intrusive complex that underlies Cadia Valley and is both spatially and temporally related to the gold-copper deposits including Ridgeway, Big Cadia, Cadia Central, Cadia Hill and Cadia East.

The mineralisation at Cadia East is accompanied by an alteration system forming a roughly concentric zonation of porphyry style events (potassic, propylitic, magnetite, silica, sodic feldspar and pyrite shell) about the core of the deposit.

Various generations of faults are present throughout the deposit, the most prevalent being numerous steep pyrite – sericite faults and several moderate to steeply dipping late carbonate thrusts. One major thrust (the Gibb fault) separates the Cadia Hill deposit from Cadia East.

Feasibility studies currently underway envisage an open pit to about 500 metres depth adjoining Cadia Hill pit and a large panel cave mine for the deeper gold rich portion of the deposit. The established processing infrastructure at Cadia Valley is currently treating 22 million tonnes per annum producing a gold-copper concentrate and gold dore (gravity). The feasibility studies are examining an upgrade to the processing infrastructure to optimally treat the higher copper grades, harder ore and production of a molybdenum concentrate.

Based on current Ore Reserves development of the Cadia East deposit will see mining continue at Cadia Valley for about 30 years.

# ASPECTS OF LACHLAN OROGEN MAGMATIC ARC Au-Ag-Cu

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**Key words**: magmatic arc, porphyry Cu-Au, epithermal Au-Ag, gold, copper, silver

## Abstract

Exploration decisions involving the prioritisation of finite human and financial resources amongst portfolios of exploration projects are aided by an understanding of the styles and characteristics of magmatic arc porphyry Cu-Au and epithermal Au-Ag mineralisation, and the controls to metal grade, deposits size, distribution, metallurgy etc. There is an improved definition of the anatomy of intrusion-related Cu-Au deposits. Analysis of temporal and spatial patterns of mineralisation and alteration zonation within porphyry and epithermal deposits, as well as linkages between deposit types, may aid it vectoring towards economic mineralisation. Although bonanza Au-Ag grades tend to occur in the uppermost portions of low sulphidation epithermal Au-Ag deposits, the more eroded Lachlan Orogen hosts bulk low grade porphyry and wall rock porphyry Au-Cu deposits

## Introduction

Porphyry Cu-Au-Mo and epithermal Au-Ag mineralisation developed within magmatic arcs account for a significant portion of the world's metal endowment. Much of the Cu and most Mo occur within porphyry deposits, while porphyry and epithermal deposits are significant sources of Au, and the latter noted as Ag resources. Here I will briefly consider selected styles of magmatic arc mineralisation, drawing upon other Pacific rim ore systems, in order to provide an introduction to the deposit case histories presented in this session of the 2007 Mines and Wines conference. Because to the limited time available, many of the concepts and terminology used are expanded upon in earlier papers by this author - www.corbettgeology.com

Magmatic arc ore systems are interpreted to host metals derived from differentiated intrusion source rocks at depth and gangue minerals deposited from hydrothermal fluids dominated by mixes of variably evolved magmatic and meteoric hydrothermal fluids. Porphyry Cu-Mo-Au deposits extend from considerable depths (as much as 6km) to within 1-2 km of the surface, the latter commonly as apophyses to more major buried magmatic source bodies. Better ore systems develop where ore fluids are concentrated in the cooler intrusion apophyses. Epithermal Au-Ag deposits formed within 1 km of the surface are distinguished as low and high sulphidation, on the basis of the ore mineralogy (Corbett and Leach, 1998 and references therein), deposited respectively from near neutral or hot acidic hydrothermal fluids. The low sulphidation deposits are further divided into varying styles as a continuum (figure 1) from porphyry Cu-Au (Ridgeway & Goonumbla, Australia), through wall rock porphyry (Cadia Hill, Australia), quartz-sulphide Au ± Cu (Lihir, Papua New Guinea; Nolan's, Australia), carbonate-base metal Au (Cowal, Australia; Porgera, Papua New Guinea; Kelian, Indonesia) and polymetallic Ag-Au (Fresnillo & Palmarejo, Mexico; Arcata, Caylloma, Corani, Peru) as the generally deeper level deposits with strongest associations with intrusions. Bonanza Au grades are more commonly associated with the two highest crustal level epithermal end members comprising: the high Au fineness epithermal quartz Au-Ag (Porgera Zone VII) style, with a stronger intrusion association, and the low Au fineness, banded chalcedony-ginguro Au-Ag veins (Vera Nancy, Australia; Waihi, New Zealand; Hishikari, Japan), which display more distal relationships to intrusion metal source rocks, and were formerly termed adularia-sericite Au deposits (figure 1). These highest crustal level epithermal deposits are not well developed in the older deeply eroded eastern Australia and so are not discussed herein.

### Controls to mineralisation

Controls to quality (higher metal grades and more substantial size) magmatic arc ore systems include:
Host rocks as competent rock facilitate formation of throughgoing fractures as low sulphidation vein hosts. Permeable host rocks favour fluid flow in high sulphidation deposits (Pierina, Peru; La Coipa, Chile), and some low sulphidation epithermal deposits (Round Mountain, Nevada).
Structures act as plumbing systems for ore fluids to rise from magmatic source rocks at depth to cooler settings of metal deposition and may focus ore fluids to provide higher metal grades commonly within ore shoots controlled by varying styles of deformation. Ore shoots develop within fault flexures and jogs, and vary from steep plunges in settings dominated by strike-slip fault movement (Vera Nancy, Waihi), and are vertically zoned within negative flower structures from near surficial pull-apart basin fracture arrays, which control the distribution of deeper level fissure veins (Cowal, Waihi), and then splays at deeper porphyry levels (Chuquicamata, Chile; Far South East, Philippines). Flat plunging ore shoots develop in flat dipping portions of reverse faults (Jaing Cha Ling, China), and steep dipping portions of normal faults (polymetallic veins of Mexico and Peru), including at the intersections of normal faults and hanging wall splays (Porgera Zone VII).
Style of mineralisation accounts for differences in metal ratios and ore grades varying from lower grade porphyry Cu-Mo to bonanza Au grade low sulphidation epithermal styles (discussed herein and Corbett and Leach, 1998). Metallurgical characteristics, which should be given consideration during exploration, also differ significantly. Both the hypogene enargite ores of high sulphidation systems (Peak Hill, Australia; El Indio, Chile), and Au encapsulated in fine grained quenched low sulphidation quartz-sulphide Au ores (Lihir), display costly difficult metallurgy.
Mechanism of Au deposition provides the greatest influence on precious metal grades varying from low Au grades where pregnant ore fluids have cooled slowly, and rising progressively in settings where ore fluids have mixed with ground waters varying from: deep circulating meteoric waters (evidenced by opal in the ore assemblage), to shallow oxygenated meteoric waters (evidenced by haematite in the ore assemblage), to bicarbonate waters (evidenced by mixed FeMnMgCa carbonates in the ore assemblage), and low pH acid sulphate waters (evidenced by kaolin in the ore assemblage).

### Deposit types

Porphyry Cu-Au deposits, have previously been considered as large lower metal grade open pit operations (Panguna, Ok Tedi in Papua New Guinea), but newer discoveries also include higher metal grade ores associated with repeated intrusion emplacement and mineralisation in settings where major structures focus ore fluids into apophysis capping speculated buried magma sources (Ridgeway, Oyu Tolgoi, Grasberg, Goonumbla), or with complex mineralised breccias (El Teniente, Chile). Although of low metal grades, the considerable size makes porphyry deposits attractive targets. Targeting tools vary from, the identification of the major structures, which localise intrusion apophyses to deeper level magmatic source rocks (Corbett, 1994; Corbett and Leach, 1998), and influence the trend of mineralised veins, to the analysis of zoned and overprinting alteration patterns. The increased understanding of the anatomy of porphyry Cu-Au deposits is an important exploration tool.

Wall rock porphyry Au deposits comprise porphyry-style mineralisation as sheeted veins deposited outside the ‘productive’ intrusion within competent wall rocks, commonly intimately associated with lower metal grade porphyry intrusions and breccias (Cadia Hill; Gaby, Ecuador, Maricunga Belt, Chile). Dilational structural environments are an important component to allow concentration of metals during evolution from deep crustal level low metal grade intrusion source rocks, to higher level cooler settings of mineral deposition. Although of low metal grades, the large size, high Au:Cu ratios and generally favourable metallurgy render these deposits attractive exploration targets.

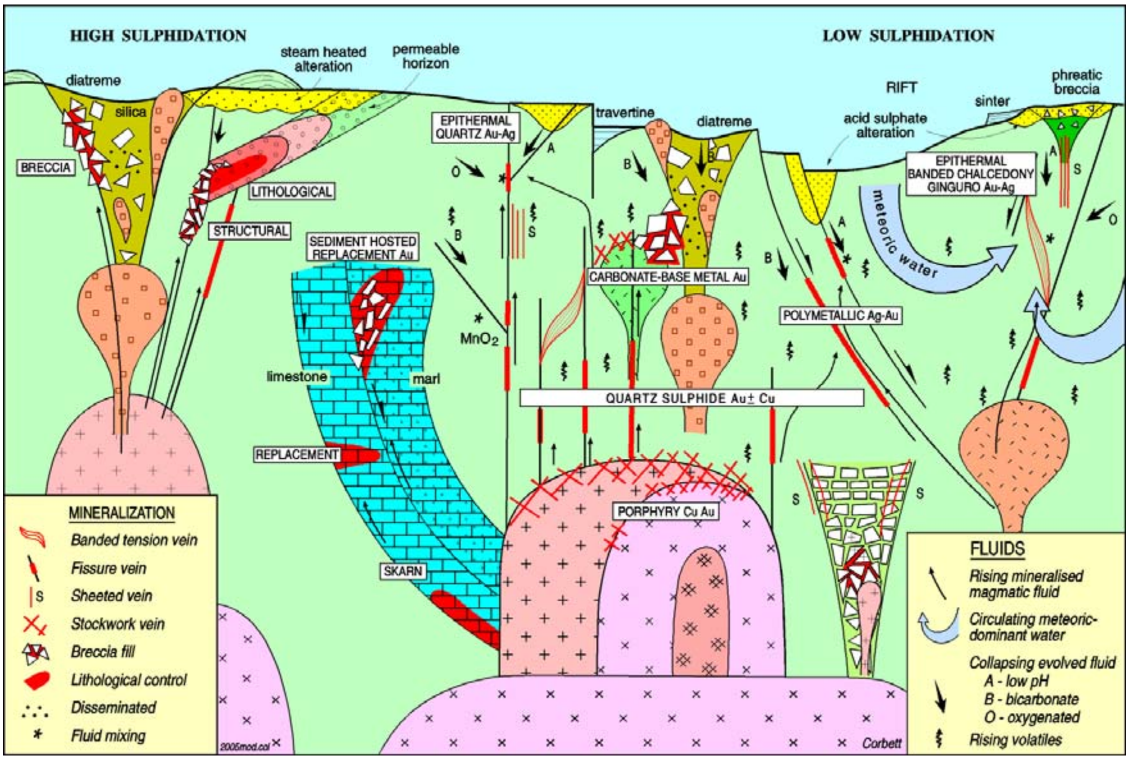

Figure 1. Model for zonation in styles of magmatic arc Au-Ag-Cu-Mo mineralisation.

Quartz-sulphide Au + Cu mineralisation occurs in transitional crustal settings between wall rock porphyry and low sulphidation epithermal deposits as deep crustal level low sulphidation ‘epithermal’ locally including D veins described in the porphyry Cu literature (Gustafson and Hunt, 1975). Quartz-sulphide ores occur as an early stage in many carbonate-base metal deposits described below (Porgera, Kelian), and vary from high grade underground lodes (Adelong & Mineral Hill, Australia) to bulk low grade disseminated and stockwork vein deposits (Nolan’s, Australia; Round Mountain, Nevada; San Cristobal, Chile). Coarser grained ores commonly display favourable metallurgy and so very low Au grades are treated in heap leach operations (0.9 g/t Au at Round Mountain). However, rapidly quenched ore fluids result in difficult metallurgy, fine grained ores where Au may be encapsulated within in pyrite, and more commonly arsenean pyrite. Caution is urged as quartz-sulphide Au mineralisation is susceptible to near surficial supergene Au enrichment and so sub economic veins often distract explorationists but fail to develop into meaningful targets.

Carbonate-base metal Au deposits occur in higher crustal level more distal settings to intrusion source rocks than porphyry Cu-Au deposits, where magmatic ore fluids have mixed with bicarbonate ground waters as a most efficient mechanism of Au deposition (Leach and Corbett, 1994; Corbett and Leach, 1998). Consequently these deposits have been some of the most prolific Au producers in the SW Pacific rim (Porgera, Kelian; Antamok & Acupan, Philippines). Dilational structures such as pull-apart basin fracture arrays are important to facilitate the evolution of ore fluids into elevated crustal settings (Cowal) of mineral deposition. In eastern Australia, where generally older ore systems are deeply eroded, the telescoping of carbonate-base metal Au mineralisation upon quartz-sulphide Au $\pm$ Cu deposits provides elevated Au grades (Kidston). In younger tertiary rocks many carbonate-base metal Au ores are associated with phreatomagmatic breccias within diatreme flow dome complexes.

Polymetallic Ag deposits of Central and South America provided significant wealth to the Spanish empire and Catholic church for several hundreds of years, but were passed over by major mining companies during the later 20th century. These deposits have more recently represented exciting exploration targets for junior companies (Palmarejo & Fresnillo in Mexico; Arcata, Caylloma, Corani in Peru; San Cristobal in Bolivia; El Penon in Chile; San Jose [Hevos Verde], Martha in Argentine Patagonia), and as such commonly represent ‘company makers’. While mined primarily for Ag, many include Au credits, as well as significant Pb-Zn and locally Cu, particularly at deeper levels. Recent discoveries in Australia including Twin Hills by Macmin and Mungana by Kagara are typical of this deposit type. Two end metallurgical end members represent Ag within tennantite-tetrahedrite (commonly freibergite), or the metallurgically more favourable argentite-acanthite ores. Polymetallic deposits, similar to the related carbonate-base metal Au style (Corbett and Leach, 1998), are strongly temporally and spatially zoned with a bonanza Ag grade portion locally developed where the uppermost portion is preserved, such as within blind deposits below clay caps. In strongly dilational structural settings with appropriate hydrothermal fluid input, these deposits may evolve at higher crustal levels into the chalcedony-ginguro Au-Ag low sulphidation epithermal deposits.

High sulphidation epithermal Au deposits represent only a very small part of the metal budget in Australia (Peak Hill, Gidginbung), but are major Au-Ag resources in South America (Yanacocha & Pierina, Peru; El Indio, La Coipa & Pascua, Chile; Lama & Veladero, Argentina). These deposits vary from precious metal rich at elevated crustal settings to Cu-rich at depth, while SW Pacific rim high sulphidation deposits are Ag-poor while those in South America are Ag-rich. A two stage magmatic-derived hydrothermal fluid comprises an early hot acid volatile-dominant portion which promotes the development of characteristic zoned wall rock alteration, while the later liquid-dominant portion deposits overprinting sulphides such as auriferous pyrite-enargite, varying to low temperature luzonite, and covellite at deeper levels, with quartz-alunite-barite-sulphide gangue (Corbett and Leach, 1998). Permeability controls to mineralisation include variable combinations of structure (dilational feeder structures), lithology (permeable tuffs) and breccias (often phreatomagmatic breccias in flow dome complexes). Although these deposits display generally low metal grades with poor recoveries, and significant environmental liabilities (Hg, As and acid mine drainage), localised temporal and spatial evolution to lower sulphidation mineralisation contributes towards the development of higher Au grades and better metallurgy either overprinting or marginal to high sulphidation systems (El Indio, Wafi, Papua New Guinea; Goldfield, Nevada). At Mt Carlton, (Australia) the presence of low sulphidation minerals (polybasite) and local elevated Ag are consistent with such an evolution.

## Conclusion

Mineral exploration management often includes allocation of finite resources (human and financial) to portfolios of exploration projects which must be prioritised according to apparent merit of each project on the data to hand. The use of empirical geological models developed by the comparison of many exploration properties facilitates exploration management decisions as to which projects may be more prospective. Studies of other Pacific rim magmatic arc deposits, which might be well exposed in deeply dissected terrains (Peru) or by extensive drill testing, have aided in an understanding of the anatomy, including patterns of temporal and spatial alteration and mineralisation zonation, in porphyry Cu-Au-Mo and intrusion-related epithermal Au-Ag deposits, as well as linkages between deposit styles. This understanding of the three dimensional geometry of magmatic arc deposits allows better targeting of mineralised portions of particular prospects, including ore shoots, especially in blind high crustal level deposits noted for bonanza ore shoots (polymetallic Ag veins), and facilitates the evaluation of poorly mineralised projects. In particular the analysis of the controls to low and high sulphidation deposits aids in an understanding of whether anomalies, or poorly mineralised prospects, are likely vector towards economic mineralisation, as well as provision of some exploration science to facilitate exploration decisions.

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# THE TRITTON COPPER PROJECT: THREE NEW OREBODIES

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**Key Words:** copper, gold, silver, Girilambone, Murrawombie, Larsens, North East, feasibility study, development.

## Abstract

Exploration drilling, targeting sulphide deposits beneath the copper oxide pits at Girilambone and Girilambone North in central New South Wales, has successfully delineated three new orebodies (Larsens, North East and Murrawombie). The ore is amenable to treatment at the Straits Resources Limited ("SRL") owned Tritton Copper Mine and process plant located 26 kilometres south west of Girilambone.

The Tritton Copper Mine, which was commissioned in late 2004, currently produces approximately 90,000 tonnes of copper concentrate per year containing 22,000 tonnes of copper, 3,000 ounces of gold and 36,000 ounces of silver. The three new orebodies underpin a plan to expand the Tritton plant over the next 2 – 3 years to produce approximately 45,000 tonnes of copper per year.

The decision to commence a decline at Girilambone North was announced in the June quarter and development is expected to start in the September quarter with production scheduled mid 2008. The decline will access the Larsens and North East deposits.

Resource definition drilling is continuing on the Murrawombie deposit at Girilambone. Historical drilling was limited to the first 100 metres beneath the pit in what is now known as "The Neck", a zone of low grade, thin, short strike length sulphide mineralisation that discouraged previous explorers. The application of the Tritton model, more particularly the geometric shape of a steeply south east plunging sulphide shoot, facilitated the discovery of a large tonnage copper sulphide deposit containing in excess of 100,000 tonnes of copper. A feasibility study is underway to determine the optimal development scenario for Murrawombie which is likely to include a cut back of the existing pit and contemporaneous decline to access deeper ore.

The Larsens, North East and Murrawombie sulphide deposits have many features in common with the Tritton orebody. Most importantly the mineralisation is readily amenable to treatment through the Tritton flotation plant. All the deposits are structurally controlled and form tabular and steeply south east plunging ore shoots. The mineralisation is both massive or banded pyrite and chalcopyrite. A feature of the deposits, including Tritton, is their depth extent which exceeds 1000 metres at Tritton, although all the orebodies are open at depth.

## Introduction

The Tritton orebody was discovered in 1995 by the Straits Resources and Nord Resources Joint Venture ("GEJV") following up a high order, late time SIROTEM anomaly. By the end of 1997 in excess of 70,000 metres of drilling in 140 holes had been completed. A feasibility study concluded the deposit was uneconomic at the prevailing metal prices and the project was mothballed.

In 2003 Tritton Resources Limited ("TRL") purchased the deposit and surrounding tenements from SRL (Figure 1). During a feasibility study undertaken in 2003 a resource (at a 1%Cu cutoff) of 14.0 million tonnes at 2.70%Cu, 0.30g/tAu and 12g/tAg and a reserve of 8.9 million tonnes at 2.86%Cu, 0.24g/tAu and 11g/tAg was determined.

A decision to proceed with development was made in 2004, the decline was commenced in April, and the plant commissioned in December of that year. The Tritton orebody is currently being mined at a rate of about 750,000 tonnes per year producing approximately 90,000 tonnes of concentrate containing approximately 22,000 tonnes of copper, 3,000 ounces of gold and 36,000 ounces silver. The concentrate is railed to Newcastle and shipped to smelters in South East Asia.

SRL completed a takeover of TRL late in 2006 and now owns 100% of the Tritton operation. SRL has continued an aggressive exploration programme commenced by TRL targeting additional sulphide resources to supplement the Tritton operation. Drilling has focused on delineating sulphide deposits beneath the oxide copper pits at Girilambone (Murrawombie pit) and Girilambone North (Larsens, Hartmans and North East pits).

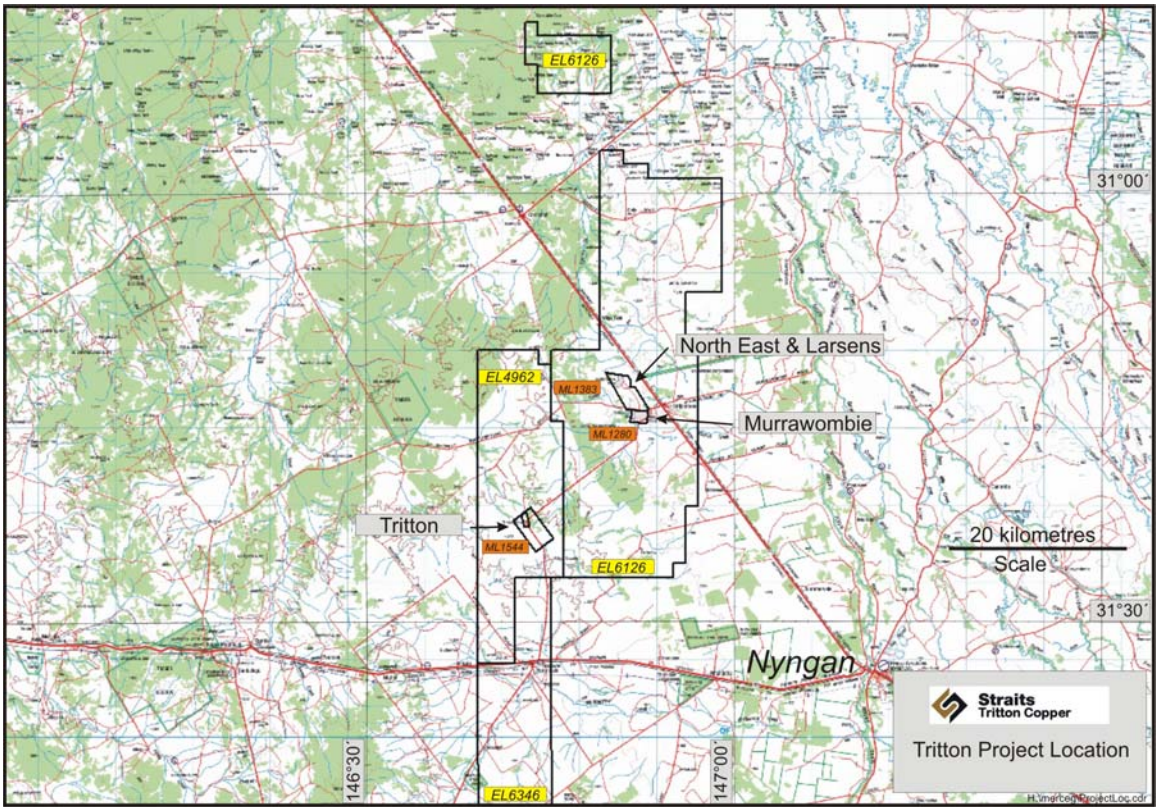

Figure 1: Project Location

**Girilambone (Murrawombie deposit)**

The Girilambone copper deposit, later to become the Murrawombie pit, was discovered by Thomas Hartman and Charles Campbell (co-founders of Cobar), George Gibbs and George Hunter in 1879 and was originally mined from 1881 to 1907 to yield 58,408 tonnes of ore at 1.96%Cu. The GEJV mined and treated 6 million tonnes at an average grade of 1.69%Cu of oxide/secondary copper from Murrawombie in the period 1993 to 1997 producing 96,200 tonnes of copper metal (Fogarty, 1998).

The rocks exposed in the Murrawombie pit are quartz-chlorite schists, metasandstones and minor altered mafic volcanics all showing signs of multiple deformation. The dominant schistosity is north-south with a sub-vertical dip. The dominant feature in the open pit is the northwest trending Eastern Shear. Alteration (dominantly silicification) and mineralization (both massive and stringer pyrite and chalcopyrite) occurs immediately below the Eastern Shear. Similar rocks are intersected in drilling of the sulphide deposit that plunges to the south east from the base of the pit.

The stringer or laminated ore consists of a multitude of parallel quartz-sulphide (pyrite, chalcopyrite) stringers. The laminated ore is folded, but the folding is quite distinct in style from the folding observed in the host quartz-mica schists; it is one single generation of folds, which are commonly angular or kink-like. Host rock layers between the quartz sulphide veins contain the fine pervasive $S_1$, and the differentiated crenulation cleavage $S_2$ is roughly parallel to the stringers (Mawer 1998).

The massive ore consists of coarse grained sulphide (pyrite, chalcopyrite) and does not show obvious folding. It is however generally strongly fractured and brecciated although individual fragments have not been displaced far from their original sites. Petrology of a massive sulphide sample indicates that the chalcopyrite occupies the interstitial space between pyrite grains (i.e. later than pyrite formation), the pyrite occurs as individual euhedral crystals and larger polycrystalline pyrite aggregates (Mawer 1998).

From the many field and experimental studies performed on the deformation of sulphide minerals, under the types of metamorphic conditions shown by deformation in the host schists (temperatures of perhaps 300-350°C, pressures of a few kilobars, ample and ubiquitous hydrous fluids) the sulphide minerals would deform and recrystallise readily to a fine, equant grainsize. Chalcopyrite would be the most ductile, deforming by dislocation processes, and pyrite would deform by pressure solution and grain boundary sliding. A thinly laminated, micaceous, sulphide rock would show the same sorts of multiple refolding and shearing textures preserved in the host rocks. That this has not happened is abundantly clear from petrology, as indeed in outcrop. Original crystallization textures are commonly preserved, and the intensity of deformation in both types of sulphide ore is very much weaker than the host rocks. From all the lines of evidence it is concluded that sulphide mineralization is quite late in the deformation history of the quartz-mica schist sequence (Mawer 1998).

Mawer (1998) interprets that alteration and mineralisation occurred during a period of compression or crustal shortening correlated to the basin inversion phase in the Cobar area dated at ?mid-late Devonian. Rising fluids were trapped by the Eastern Shear and other faults. The laminated ore formed in the footwall to the Eastern Shear. Later massive ore was introduced into larger dilatant sites associated with fault intersections.

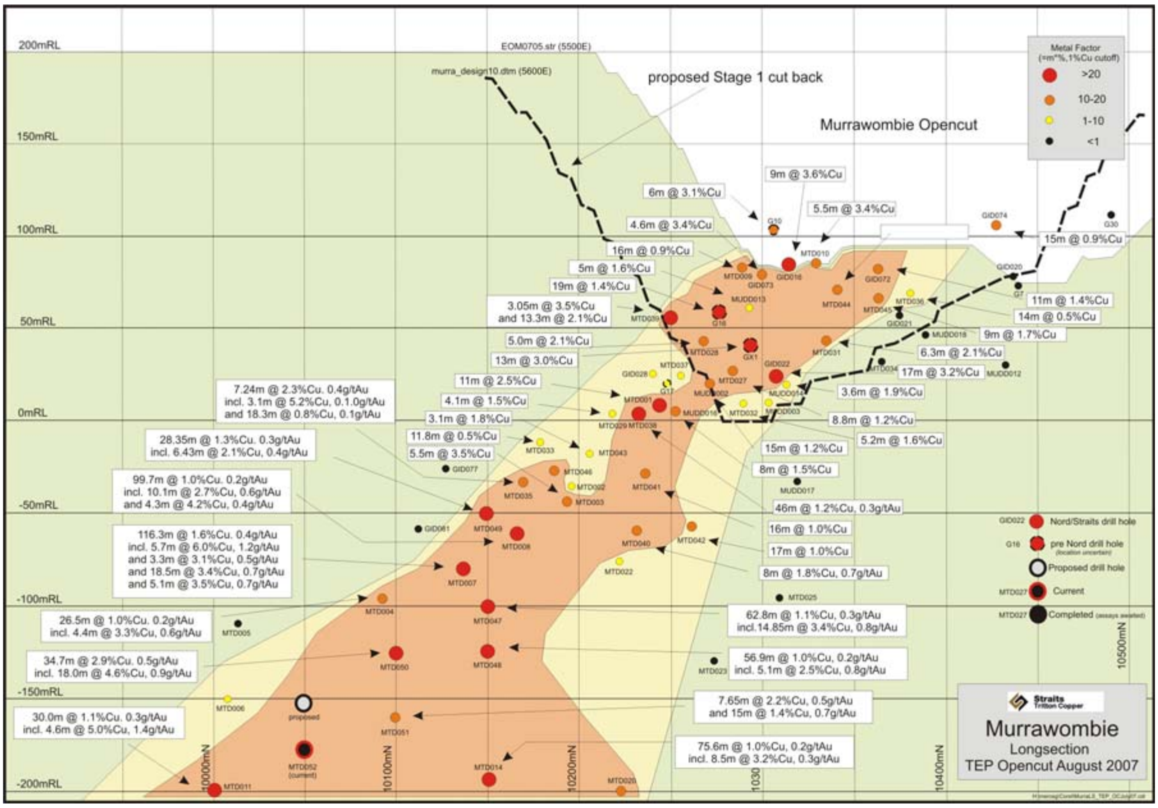


Figure 2: Longsection of the Murrawombie Deposit

**Girilambone North (North East and Larsens deposits)**

Prospectors were drawn to the Girilambone North area in the late 1800s by outcrops of siliceous and ferruginous rocks. Three shafts, Larsens, Hartmans and Hunters were sunk with some development on copper carbonate ore (Chrismas, 1979). Australian Section Pty Ltd collected samples of gossaneous material from a backfilled trench, 250m east of Hartmans, which assayed up to 4150ppm copper. This prospect was subsequently named the N.E. prospect (Uren, 1976) (for North East). An indicated resource of 1.09 million tonnes at 2.52%Cu, at a 1%Cu cutoff, was calculated at North East (Uren and Sands 1977).

Exploration by GEJV in the 90s defined a total oxide reserve at Girilambone North, including Larsens, Hartmans and North East deposits, of 5.3 million tonnes at 0.78%Cu and in April 1996 mining commenced (Fogarty 1997). Ore was trucked to the heap leach/SXEW plant at Murrawombie for treatment.

The lithologies present within the Girilambone North pits (Larsens, Hartmans and North East) comprise multiply deformed quartz chlorite schist, sericite schist, mafic schist and greywackes (Berthelsen, 1999). There is no "quartzite" within the northern pits which makes these deposits different from the Tritton and Murrawombie deposits.

## North East

TRL drilled 20 holes between 2005 and 2007 and announced a resource of 1.6 million tonnes at 1.6%Cu (SRL Annual Report 2006) as sulphide mineralisation beneath the North East pit. The mineralisation occurs as banded pyrite and chalcopyrite in weakly altered schist. The shoot, which has been drilled to 300m below the pit floor, has a strike length between 100 and 200 metres, a thickness up to 10 metres and plunges to the south east (Figure 3). The shoot is open at depth.

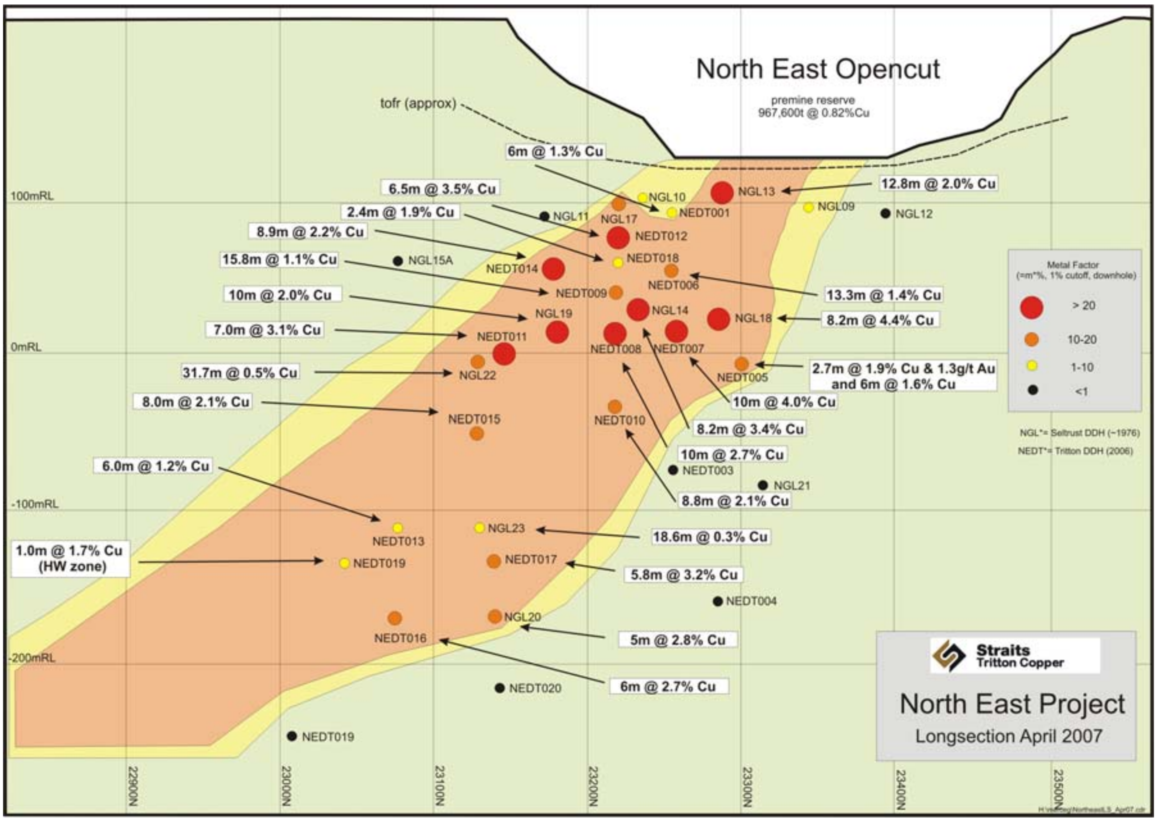

Figure 3: Longsection of the North East Deposit

**Larsens**

In 1993, the GEJV implemented orientation SIROTEM surveys over the North East area and discovered the Larsens orebody. Subsequent drilling outlined a resource of 1.9 million tonnes at 1.04%Cu of predominantly oxide copper ore which was subsequently mined and treated at the Girilambone heap leach/SXEW plant. A remnant 250,000 tonnes of sulphide ore at 1.79%Cu remained in the bottom of the pit. Although high grade copper intercepts (>4%Cu) were returned for some of the drill holes immediately beneath the final pit floor from mixed chalcopyrite/chalcocite lenses, subsequent wide spaced (>100m) drilling below this did not intersect comparable mineralisation.

The remnant sulphides attracted the attention of Tritton Copper Mine's mining engineers in 2006 as a potential source of short term, high grade ore to supplement the Tritton operation as it mined through the gap between the upper ore zone and the lower ore zone (Slade et al 2006). To reduce the resource risk of the planned small underground operation several drill holes were designed to test down plunge of the high grade intercepts in both the southern and central shoots. Five drill holes (LRDT15, 19 and 21 to 23) intersected high grade massive sulphide (Figure 4).

A decision to proceed with the development of the Larsens orebody was announced in June 2007 and mining is scheduled to commence in September 2007 and ore production early in 2008. Final resource/reserve figures are expected to be announced in the September quarter.

The Larsens orebody comprises at least two shoots separated by a major steep SW-NE fault (Berthelsen, 1999).The host rocks are multiply deformed quartz chlorite schists, and metasandstone. Dark green mafic schist is exposed in shear zones in the southeastern pit wall. These rocks do not appear to be closely related to sulphide mineralisation as observed in core.

The ore shoots comprised both massive and banded chalcopyrite and pyrite. The southern shoot is associated with a significant fault zone whereas the central shoot does not appear to be. The central shoot is the largest and comprises two sub parallel lenses each several metres thick, 10 or so metres apart and with a strike length of approximately 40 metres.

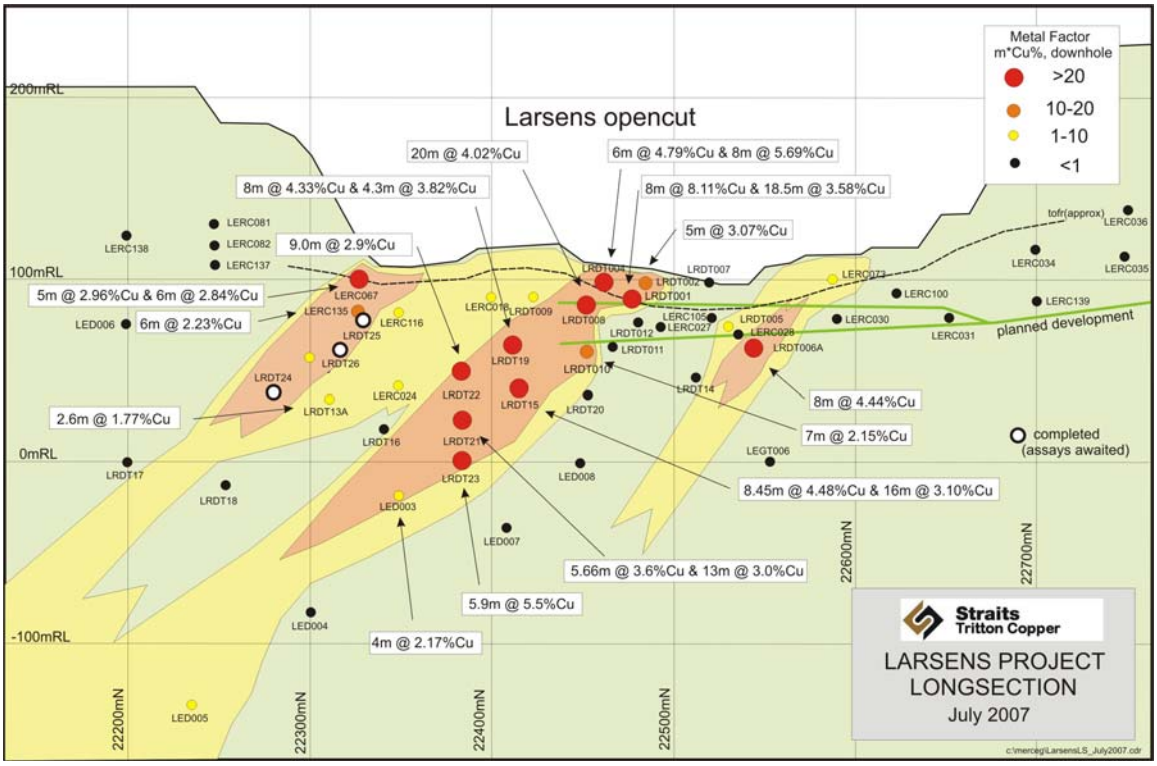

Figure 4: Longsection of the Larsens Deposit

## Conclusions

Exploration success since 2004 has established three new orebodies beneath the oxide pits at Girilambone and Girilambone North. All three are scheduled for development in 2007/2008 underpinning a plant expansion at the Tritton mine.

The North East orebody was discovered and drilled in the late 70s by Australian Section Pty Ltd and the oxide mined by SRL in the 90s, but the sulphide potential was overlooked until recently. The sulphide deposits beneath Murrawombie and Larsens oxide pits were previously missed due to limited drilling below the oxide boundary and oversight of the plunge component to the overall geometry of the orebodies.

Armed with this new knowledge, the potential of the whole of the Girilambone Mineral belt is being reassessed. At least three other known massive sulphide deposits (Budgery, Budgerygar and Bonnie View) and numerous copper shows occur within SRL's licence areas. A continued strong commitment to exploration should ensure a sustainable mining future for the area.

## Acknowledgements

Straits Resources Limited, in particular Ivan Jerkovic (Chief Geologist) and Ian Kennedy (Tritton Resident Manager) is acknowledged for permission to present this paper. Special mention is made of the former Tritton Resources Ltd director and geologist Mick McMullen, and geologists Ben Thompson and Brad Underwood who have been directly involved with the identification and delineation of the deposits since 2004.

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# EUROW CU AU AG ZN MASSIVE SULPHIDE DEPOSIT

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The historical Eurow-Vychan copper mine is located 30 km south-southwest of Parkes, NSW. The sulphide deposit is stratabound and hosted within Silurian volcanic-sedimentary rocks and lies in close proximity to Devonian granite. On a regional scale Eurow is proximal to the intersection of the Narromine-Coolac Fault and the Lachlan Transverse Zone.

Drilling by Southern Gold in conjunction with previous drilling has outlined a two to three meter thick zone of >2% Cu over a strike length of 280 m to a vertical depth of 240 m with a width of approximately 50 m. Sulphide mineralisation peters out laterally to form low grade margins. The dominant sulphides are pyrite and pyrrhotite with up to several percent chalcopyrite. Mineralisation also includes gold, silver, sphalerite and minor galena, with variably elevated As, Bi, Co, Cd and Mo.

# THE MUNGANA PORPHYRY-RELATED POLYMETALLIC DEPOSIT

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## ABSTRACT

Mungana is a Mid-Carboniferous porphyry-related polymetallic deposit located near the township of Chillagoe in North Queensland. It was extensively explored and drilled by Amoco, Elders and Niugini Mining through the 1980's and 90's in conjunction with mining and exploration at the nearby Red Dome gold operation, which ceased in 1998. After purchasing the Red Dome and Mungana leases in 2002, Kagara Zinc carried out substantial deep drilling programmes and has committed to development of the deposit for its high grade base metals. Published Indicated + Inferred Resource figures are *1.96Mt @ 14.3% Zn, 2.8% Cu, 2.2% Pb, 188 g/t Ag, and 1.15 g/t Au*. Outside of the base metal resource, a further Inferred Resource of *53.7 Mt @ 1.1 g/t Au, 0.2% Zn, 0.1 % Cu, 0.1% Pb, 8 g/t Ag* has been announced.

## GEOLOGICAL SETTING

Mungana is near the western margin of the Siluro-Devonian Hodgkinson Province. It is within the highly prospective Chillagoe Formation, which abuts Proterozoic high-grade metamorphic basement to the west along the northwesterly trending Palmerville Fault. Historical development of the fault is complex and includes major thrusting events during the Late Devonian to Early Carboniferous.

A feature of the widespread mineralization in the Chillagoe district is the diversity in commodities, mineralization styles and highly telescoped systems that all appear to have genetic links with regionally extensive Permo-Carboniferous magmatism. Many of the deposits show multi-episode activation and reactivation, as at Red Dome and Mungana.

Red Dome and Mungana occur within a 4 km corridor ("Mine Corridor") of intensely faulted, brecciated and altered, steeply-dipping Chillagoe Formation rocks. The corridor is overall strike-parallel with the Palmerville Fault and is defined by strong base metal anomalism. It has a complex configuration in detail. Generally it is defined by a central limestone wedged between siliciclastic units that dip steeply inwards towards the axis of the corridor. Well-developed breccia columns in several places along the corridor have an inverted funnel shape in cross section.

High-grade Cu-Pb-Zn-Ag base metal mineralisation is well known at several historic mining centres along the corridor (Griffiths' Hill, Lady Jane, Girofla, Hookworm), and also at Mungana. Gold is conspicuously absent except at Red Dome and Mungana where it is intimately associated with Mid-Carboniferous dyke-like porphyry bodies that commonly display unidirectional solidification textures. The gold occurs mostly in quartz stockwork veinlets or skarns within and around the porphyries.

## AGE DATING

Three recent SHRIMP age dates of zircons from the porphyries yielded an average of 317.3 ± 2.3 Ma corresponding to the O'Briens Supersuite, the earliest of three Permo-Carboniferous metallogenic epochs recognised in the district. The Mungana massive sulphide lenses are cross-cut by the porphyry bodies and are, therefore, earlier. This is supported by petrographic studies that show sphalerite intergrown with and in comfortable co-existence in semi-equilibrium with high temperature skarn phases, especially wollastonite but also garnet and pyroxene.

A previously unknown coarse-grained biotite granite pluton, the "Mungana Granite", was intersected in 2005 in some of the deepest drill holes 1 km below surface. Minor sericite and K-feldspar alteration zones and isolated quartz veinlets are present in the granite but overall these are quite minor and restricted. No geochemical anomalism was detected in or around the granite.

A single SHRIMP date of zircons from the fresh granite yielded 307.1 ± 2.5 Ma, corresponding to the Almaden/Ootann Supersuites.

## GEOCHEMISTRY

Anomalous elements in the Mungana system are Au, Ag, Cu, Pb, Zn, As, Mo, Bi, Sn, W, and Sb. While the geochemical picture is somewhat clouded by telescoping, there are two reasonably clear associations ie, Zn-Pb-Ag-Cu-As-Sn and Au-Bi±Cu±As. The role of Mo, Sb, and W is not known at this stage.

## PARAGENESIS

The polymetallic mineralization at Mungana can be rationalized within a framework of fluid derivation by fractionation off an O'Briens Creek magma chamber at depth during a protracted hydrothermal event. The earliest fluids travelled along favorable structures ahead of the magmas, depositing high-grade base metal lenses and skarn with traces of tin. As the system evolved, the main bodies of porphyry were emplaced along with the Au-Bi mineralization.

The Mungana Granite does not appear to have any significance to the bulk of the mineralization, although a single recent Re-Os isotopic age on molybdenum of 307.11 ± 1.28 Ma, which is identical to the SHRIMP date on the granite, is puzzling and requires further investigation. Fluid inclusion studies are envisaged as a fruitful avenue of future pursuit. Preliminary examinations have shown high temperature vapour-rich inclusions that coexisted with sulphide-rich inclusions suggesting they were an important component of the ore fluid.

# METALLOGENESIS OF THE KOONENBERRY BELT

**Phil Gilmore [1], John Greenfield [1], William Reid [1] and Kingsley Mills [2]**

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**Key Words:** Koonenberry, metallogenesis, orogenic Au, VMS, Besshi Cu, epithermal, orthomagmatic Ni

**Abstract**

The Koonenberry Belt in northwestern New South Wales is an underexplored terrane that has been a focus of the Geological Survey of NSW through the Discovery 2000, Exploration NSW and the current New Frontiers initiatives. New geological mapping, analysis of geochemistry and geophysics, and 3D modelling, have resulted in revised interpretations of the tectonic evolution of the Belt, with direct implications for the Belt's metallogenesis and exploration potential.

The Belt is prospective for orthomagmatic Ni-Cu-PGE, VMS Cu-Zn-Ag-Au, turbidite hosted orogenic Au, and epithermal Ag-Pb-Cu. In addition to primary mineralisation, the Belt has undergone multiple deformation events, providing structural complexity and the potential for upgrading mineralisation. A complex landscape evolution has resulted in alluvial related Au deposits in Cretaceous and Quaternary units.

## Introduction

The Koonenberry Belt wraps around and defines the eastern margin of the exposed Curnamona Craton in northwestern New South Wales (Figure 1a and 1b). A complex tectonic history has resulted in a diverse range of sedimentation and volcanism with multiple phases of deformation (Figure 2). The Koonenberry Fault is a long-lived deep crustal structure that has provided a conduit for fluid flow in association with other structures.

The Geological Survey of NSW commenced a program of 1:100 000 mapping of the Belt in 1995 that continued through the Discovery 2000, Exploration NSW and the current New Frontiers initiatives. This new generation of geological mapping followed regional mapping at 1:250 000 scale in the 1960's. The analysis of new geological mapping, geochemistry, geophysics and 3D modelling have resulted in revised interpretations of the tectonic evolution of the Belt under the New Frontiers initiative.

The aim of this paper is to explain the metallogenesis and potential for mineralisation styles in the Koonenberry Belt with respect to tectonic setting and landform evolution through time.

## Mining and Exploration History

In terms of modern exploration, the Koonenberry Belt remains an underexplored region despite significant occurrences of Au, Cu and Ag. The remoteness and aridity of the area, lack of outcrop, metal price slumps, and the richness of commodities in adjacent areas (e.g. Broken Hill) have hindered past exploration.

Four main periods of exploration and mining activity have been recorded in the Koonenberry Belt.

- **Au, 1880 to 1933.** Gold was first reported in the Koonenberry Belt in 1880 near Mount Poole Station with the peak of the gold rush between 1881 and 1886 (Kenny, 1934). The commencement of mining at Broken Hill, coupled with the arid and remote conditions led to gradual winding down of production.

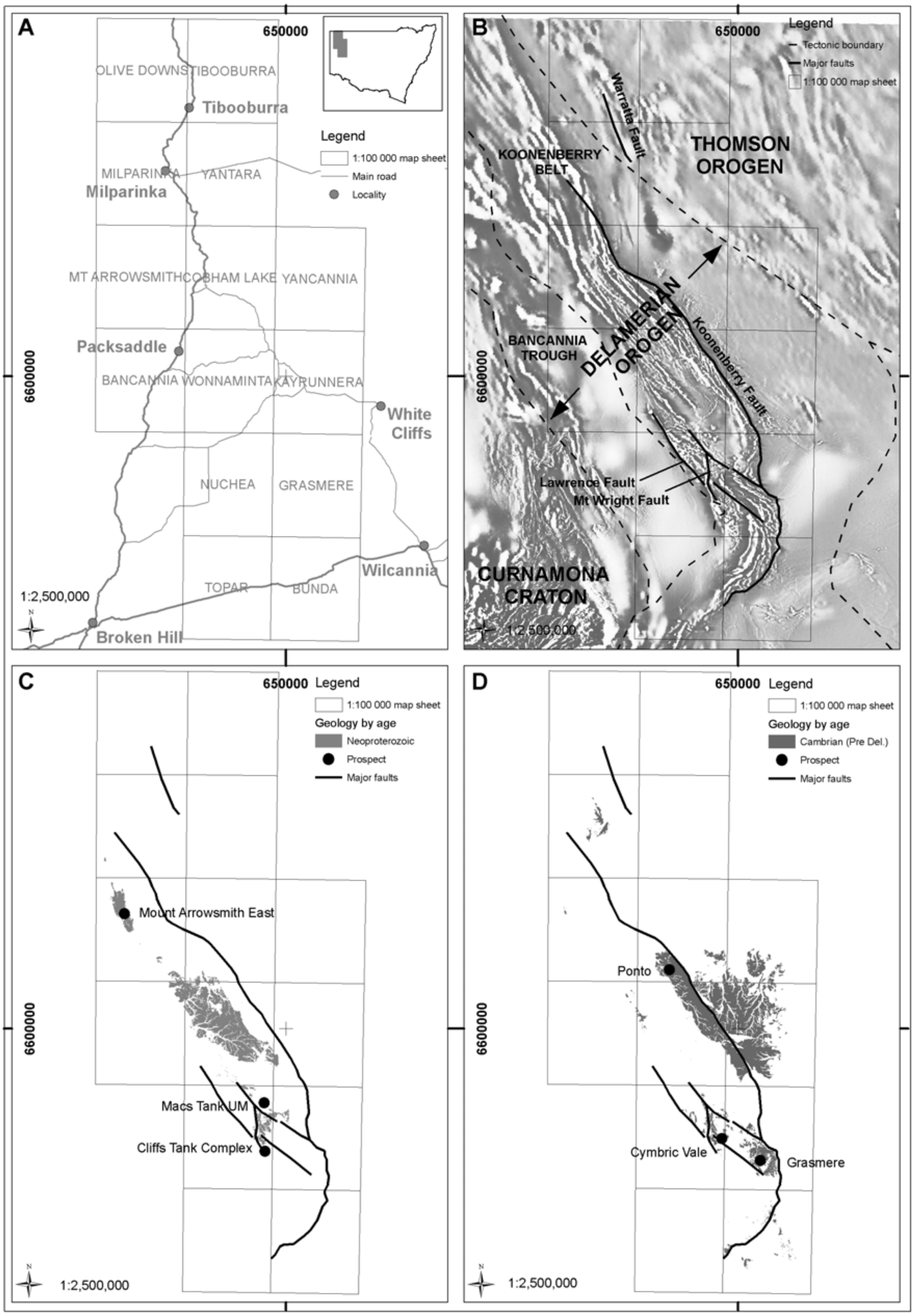


Figure 1:

a. Location plan of the Koonenberry Belt.
b. Tectonic framework, outcrop geology and major faults with 1vd of Total Magnetic Intensity image.
c. Neoproterozoic outcrop and prospects.
d. Cambrian (pre-Delamerian) outcrop and prospects.

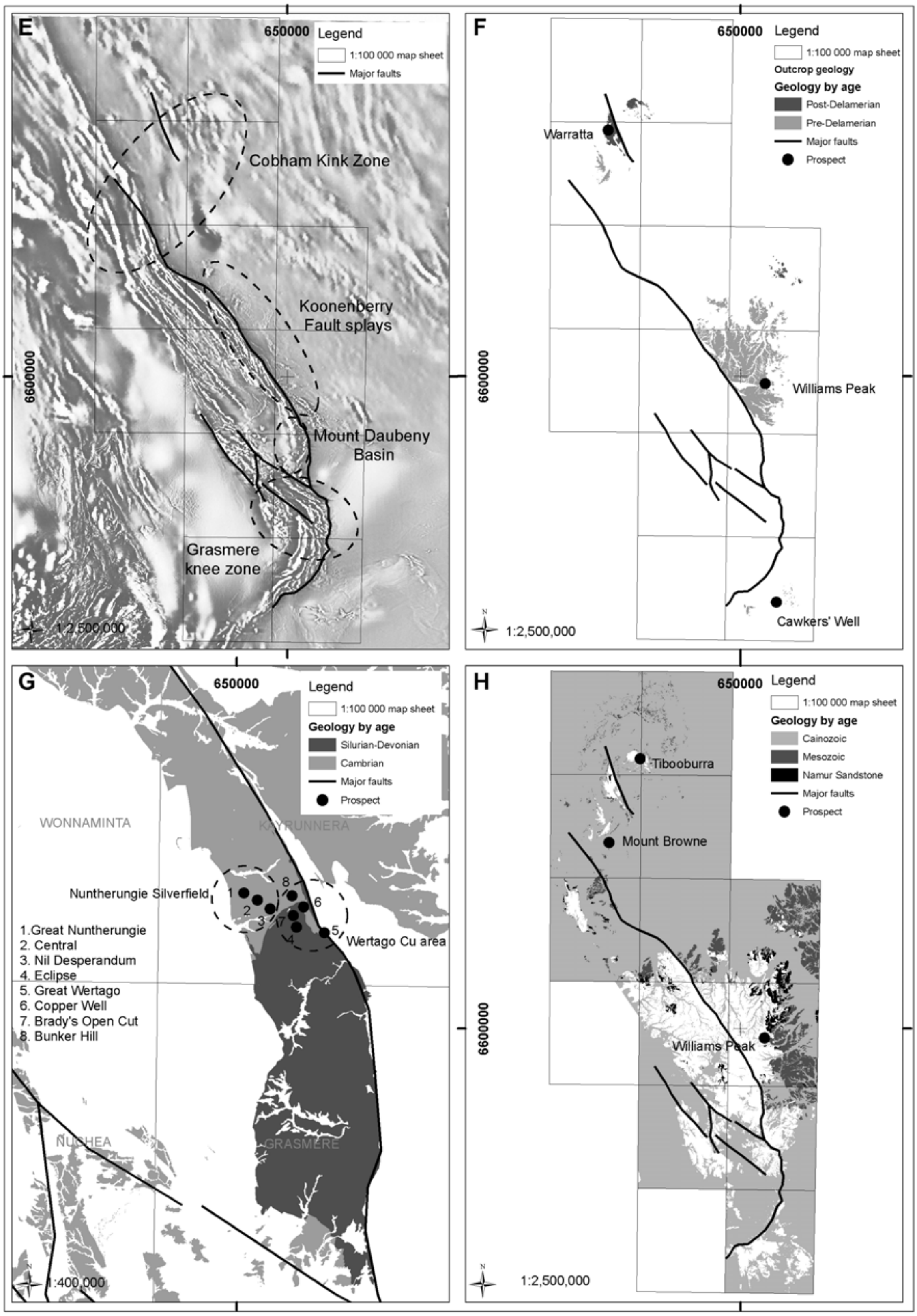


Figure 1 (cont):

e. Potential zones of upgrade due to deformation in the Delamerian and Kanimblan-Alice Springs orogenic events with 1vd of Total Magnetic Intensity image.
f. Benambran Orogeny related orogenic Au prospects to the east of the Koonenberry Fault.
g. Epithermal prospects associated with the Mount Daubeny Basin.
h. Distribution of Mesozoic and Quaternary units with reworked Au prospects.

- **Cu, Ag, Pb, 1870 to 1908.** Mining of Cu near Wertago commenced in 1870, with the nearby township of Nuntherungie established in 1890 to mine Ag-Pb from the Nuntherungie Silverfield. Cu was first mined from the Grasmere mine in 1898. Development of the fields was impeded by the geographic isolation, high costs of transport, and the lack regular water supplies (Kenny, 1934).
- **Au, Cu, 1960's to 1990's.** Sporadic exploration focussed on gold, copper and base metals predominantly in the Grasmere and Wertago areas. Despite encouraging drill intersections, tenements were relinquished due to economic conditions at the time.
- **Au, Cu, Ni, 2000 to present.** Modern exploration has been invigorated by the commencement of the Geological Survey of NSW's initiative programs in the region from 1995 to the present and buoyant metal prices.

**Tectonic evolution and metallogenesis**

Neoproterozoic intracontinental rifting (~585 Ma)

The Neoproterozoic Grey Range Group comprises the 585.5 ± 3.2 Ma (Black 2007) Mount Arrowsmith Volcanics (MAV) and shelf to deeper marine sediments of the Kara Formation. The MAV consists of alkali basalt, trachybasalt, trachyte, submarine and subaerial lava flows, pyroclastics, sills, and related intrusives. The Kara Formation is dominated by slates, but also contains quartzites, dolomitic limestone, black shale, pyritic siltstone and exhalative units. In outcrop the Kara Formation lithologies have a weathered pale to buff appearance, and black shale and siltstone units are hard to identify.

The Grey Range Group is interpreted to represent continental shelf deposits that accumulated during intracontinental rifting associated with the break-up of the Rodinia supercontinent, with equivalents on the western side of the Bancannia Trough defined as the Adelaidean Farnell Group.

*Orthomagmatic Ni sulphides*

The MAV sequence is prospective for orthomagmatic nickel sulphide deposits (Figure 1c). Ultramafic sequences at Macs Tank and the Cliffs Tank Complex (formerly Barrongie Tank) are anomalous for Ni, and despite their association with the MAV their age and relationship to the MAV is unknown. Further ultramafic bodies identified from high resolution aeromagnetic surveys have been targeted with drilling confirming the presence of disseminated primary sulphides (pyrite, chalcopyrite and pyrrhotite) in ultramafic intrusives at the **Mount Arrowsmith East** prospect (Sharp 2006). Primary mineralisation occurs within a peridotite intrusive with gabbroic margins, with drilling intercepting up to 0.5% Ni and 0.45% Cu (Sharp 2006). In addition structural dislocation of the ultramafic units may have resulted in hydrothermal remobilisation of the metals.

Further work is required to determine the nature of Ni and other mineralisation with respect to geochemistry such as sulphur saturation, stratigraphic setting, flow / intrusion dynamics and the location of the feeder conduit to determine deposit style.

*Mississippi Valley Type (MVT) Pb-Zn*

The Kara Formation may be prospective for MVT Pb-Zn mineralisation. MVT deposits are generally associated with marginal-slope carbonate rocks near growth faults, basin margins and interbasin highs in rift related intracontinental basins (Dörling *et al.* 1998). The carbonate units of the Kara Formation tend to be thin rather than thick accumulations, but little exploration has been undertaken for MVT mineralisation in the Koonenberry Belt.

However, recent drilling in the Adelaidean sequence to the west of the Mundi Mundi Fault within the Curnamona Craton intersected MVT style mineralisation (Richardson 2007). This sequence is an equivalent to the Kara Formation in age, lithology and tectonic setting.

Cambrian Extension (~542 to ~505 Ma)

Further extension in a passive continental margin setting gave rise to the shallow marine shelf sediments of the Gnalta Group, detrital mica-rich siltstone and sandstone proximal turbiditic continental slope sequences of the Teltawongee Group and the Copper Mine Range Formation. The Ponto Group is a sequence of distal continental slope sediments with dominantly tholeiitic submarine extrusive volcanics and related intrusions. Interbedded tuffaceous units (512.0 ± 3.1 Ma and 508.6 ± 3.2 Ma, Black 2005) in the Ponto Group represent distal airfall ash deposits that may have been sourced from the calc-alkaline Mount Wright Volcanics (MWV) of the same age.

Extension led to attenuation of the continental crust, and the setting may be interpreted as the back-arc extensional regime to a subduction zone well to the east. Alternatively, a forearc basin to a west-dipping subduction zone may be interpreted. In this model the MWV represent a volcanic arc. This period of sedimentation represents a time equivalent of the deposition of sediments in the Kanmantoo Trough in South Australia.

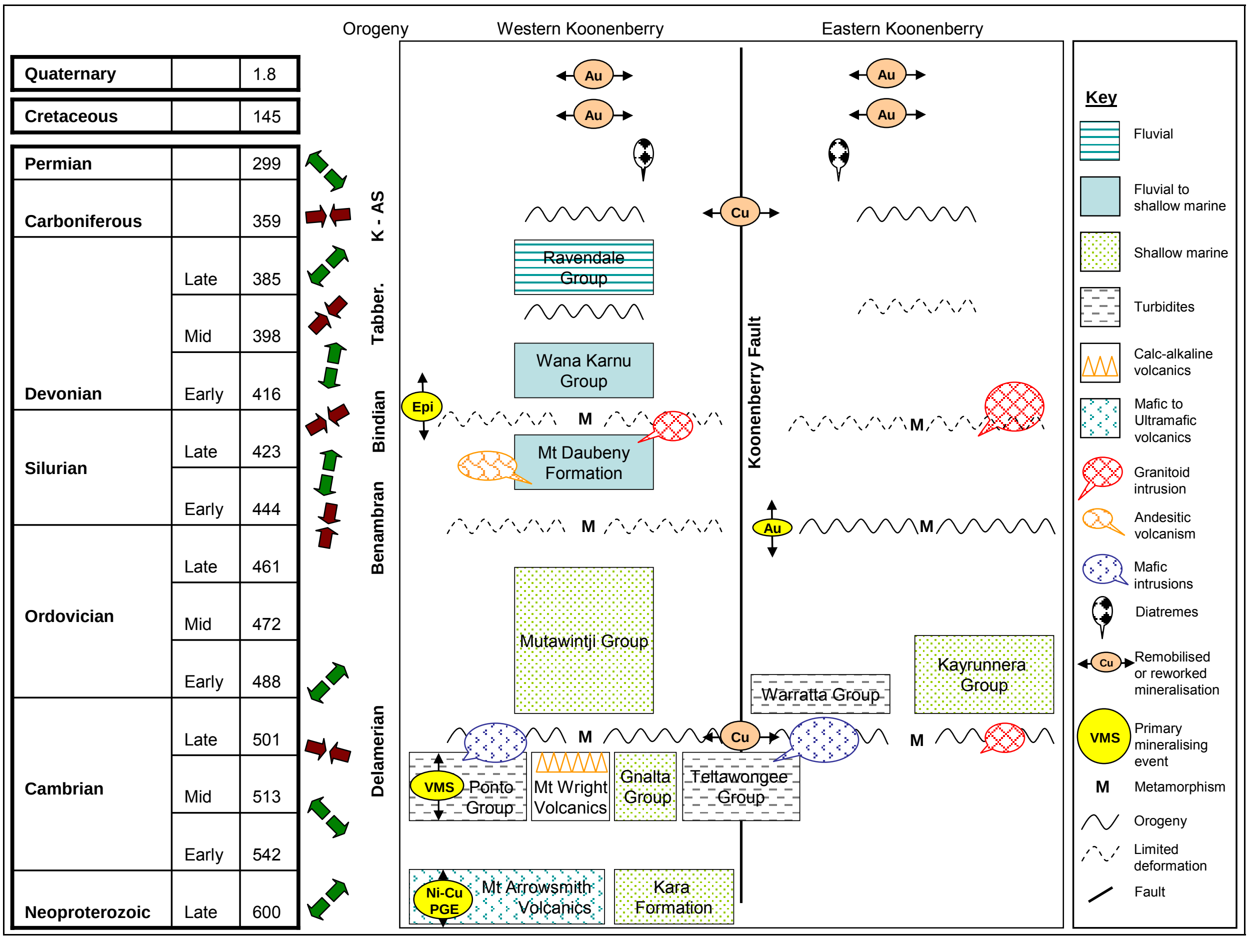


Figure 2: Time-space plot for the Koonenberry Belt also displaying geodynamics (arrows represent compression and extension) and mineralisation. Note: Tabber. = Tabberabberan, K–AS = Kanimblan – Alice Springs, VMS = volcanic massive sulphide style, epi =epithermal style. Not to scale. After Greenfield and Reid (2006) and FrOG Tech (2006).

### *Volcanic Massive Sulphide (VMS) base metals*

The Ponto Group are a prospective host for VMS base metal deposits. Known base metal occurrences, particularly Cu, occur throughout the Ponto Group and despite historic mining operations at Grasmere, Ponto and Cymbric Vale, the Ponto Group remains under explored (Figure 1d).

The **Grasmere** deposit is a polymetallic VMS deposit with an inferred JORC resource estimate of 584 000 tonnes @ 2.47% Cu, 0.94% Zn and 5.24 g/t Ag with elevated Pb, Co and Au (Vallerine 2006). Mining at the Grasmere prospect was first recorded in 1898 (Mills and Buckley 2000) with the majority of ore mined to date being oxidised ore mined in shallow open cuts with average grades of up to 18% Cu recovered by selective mining along a prominent line of gossanous outcrop (Kenny 1934).

The sequence at Grasmere comprises a hangingwall sequence of barren laminated slates grading to mylonite adjacent to the ore zone of massive sulphides. The footwall sequence includes mylonite adjacent to a calc-silicate schist zone with strong chlorite-epidote-pyrite alteration. Further work is required to ascertain whether this alteration is metamorphic or propylitic alteration. The calc-silicate schist may represent a mafic tuffaceous unit. Massive basalt units are also observed. Strong deformation is present with later quartz-carbonate veining. Deformation is visibly more intense near the north-south Bedford Fault (a Delamerian feature?) with abundant quartz-carbonate veins supporting a remobilisation of primary mineralisation.

Two episodes of mineralisation have been identified at Grasmere. Pontifex (in Lewis 1977) recognised stratiform pyrite with minor bornite-sphalerite-chalcopyrite and remobilised vein like quartz-carbonate and chalcopyrite. Mineralisation is associated with banded coarse and fine-grained pyrite reflecting the replacement of original grain size. Blebby sphalerite and zones of brecciated quartz-pyrite-chalcopyrite are common.

Pb isotope analyses support the model of two mineralising episodes, with remobilisation possibly related to the Delamerian Orogeny (Zhou *et al.* 1992) (Figure 3). Recent analyses found two distinct Pb isotope populations, one plotting in the Besshi / VMS range of Carr *et al.* (1995), and the other suggesting a mantle-signature Zhou *et al.* (1992).

The location of the massive sulphide zones between the non-magnetic barren laminated shales and magnetic calc-silicate schists suggests that this contact and hence the margins of magnetic highs may be the target for future exploration in the Ponto Group.

The **Ponto Mine** was opened in 1907 with fifty tons of ore grading 18.5% Cu mined from a 102 feet deep shaft and drive (Kenny 1934). Historic drilling confirmed the presence of a Cu lode along strike and at depth, through further step out drilling has never been undertaken. The Ponto mine has many similarities to the Grasmere deposit including the presence of mafic units, tuffaceous horizons within a sedimentary sequence and exhalative and Fe-rich units nearby. Pb isotope analyses suggest a deep mantle reservoir as a source of lead (Figure 3).

Historic workings in the **Cymbric Vale** area mined Cu ore with similar characteristics to Ponto and Grasmere, though hosted in higher metamorphic grade schists. Pb isotopes analyses indicate Besshi-style mineralisation (Figure 3). Recent exploration drilling has confirmed Cu mineralisation at depth (Buckley *pers. com.* 2007).

<u>Late Cambrian Delamerian Orogeny (~505 to ~498 Ma)</u>

In the Koonenberry Belt, the Delamerian Orogeny resulted in west-vergent tight folding and thrusting, with a sinistral strike-slip component, sub-vertical cleavage formation and low-grade regional metamorphism. The maximum age for the onset of the Delamerian Orogeny is dated by intrusion of the pre-syn kinematic Williams Peak Granite at 515.5 ± 2.7 Ma (Black 2007) and the end of deformation is indicated by dating of an intrusive felsic volcanic cross-cutting Delamerian foliation at 497.2 ± 2.6 Ma (Black 2005).

Calc-alkaline volcanism associated with the Delamerian Orogeny is represented by the Mount Wright Volcanics (MWV) of the Early to Middle Cambrian Gnalta Group, a belt of andesite, basalt, rhyolite and dacite. An ignimbrite from the upper part of the Gnalta Group has been dated at 510.5 ± 2.9 Ma (Black 2007) and was possibly one source of the airfall tuffs in the Ponto Group.

The cause of the Delamerian Orogeny has been suggested to be:

- The result of subduction and collision of convergent plate margins with the MWV representing the volcanic arc (e.g. Scheibner and Basden 1998, Mills and David 2004).
- The consequence of ridge-push stresses to the previously attenuated continental margin at the beginning of a subduction zone well to the east with the MWV the result of contaminated melting of continental lithosphere (Foden *et al.* 2006).

The latter model is preferred for the Koonenberry Belt because it can explain the absence of obduction of oceanic crust in the Belt and also the apparent lack of orogenesis to expose Delamerian mountain roots.

The orogeny was responsible for remobilisation of fluids and upgrading of mineral deposits (Figure 1e). For example, as discussed above, the Grasmere deposit was strongly deformed by the Delamerian Orogeny (and subsequent orogenies). Pb isotope analyses indicate primary mineralisation in the Early to Middle Cambrian was remobilised in the Delamerian (Zhou *et al.* 1992) resulting in quartz-carbonate-pyrite-chalcopyrite assemblages (Figure 3).

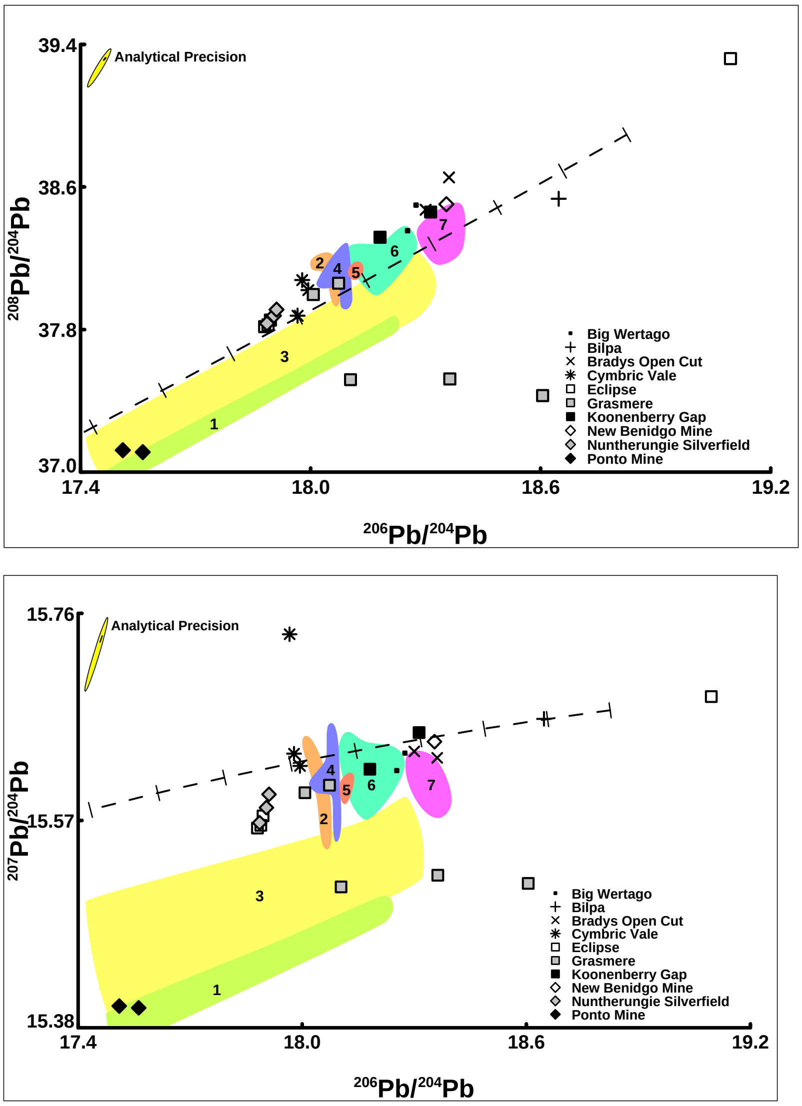


Figure 3: Pb isotope analyses by prospect relative to the signature of Ordovician to Carboniferous metallogenic events in the Lachlan Orogen (after Carr *et al.* 1995) and with the Lachlan Orogen crustal growth curve (Carr *et al.* 1995). (1 = Ordovician Cu-Au, 2 = Ordovician Besshi Cu, 3 = Siluro-Devonian Cu-Au, 4 = Silurian VMS, 5 = Devonian VMS, 6 = Devonian granite, 7 = Carboniferous granite).

Late Cambrian–Early Ordovician Extension

Exhumation and subsequent erosion in the Late Cambrian–Early Ordovician was the result of relaxation of faults that had been active during the Delamerian Orogeny. In the southern Koonenberry Belt, shelf deposits of the Kayrunnera Group, and the deltaic deposits of the Mutawintji Group were deposited reflecting shallow marine to fluvial systems. In the north of the Belt, extensional basins were partly filled with turbidite sequences of the Warratta Group, reflecting localised deeper water depositional environments

Late Ordovician–Early Silurian Benambran Orogeny

The Benambran Orogeny represented another period of shortening. Deformation was greatest east of the Koonenberry Fault producing tight east-vergent folds and reverse faults, and a penetrative steep west-dipping cleavage. Major faults are generally parallel to cleavage and are observed to cut across fold noses, producing hangingwall anticlines and footwall synclines (Greenfield and Reid 2006). West of the Koonenberry Fault, deformation was west-vergent, with east-dipping faults and cleavage development including pencil cleavage where Delamerian structures were refolded (Mills and David 2004).

*Turbidite hosted orogenic Au*

Potential for orogenic Au exists in turbidite sequences to the east of the Koonenberry Fault in units that were strongly deformed by the Delamerian and the Benambran Orogeny (Figure 1f). Historically quartz-reef Au was mined in the Warratta Inlier (Albert Goldfield) and in the Cawker's Well (Bonley Creek) area. Recent drilling has intersected Au mineralisation in the Cambrian Teltawongee Group near Williams Peak.

The Albert Goldfield consisted of reef mines in the **Warratta Inlier**, and reworked alluvial and Cretaceous deposits around the Tibooburra, Warratta and Mount Browne Inliers. In the Warratta Inlier, the Pioneer, Warratta, Phoenix, Rosemount and Elizabeth quartz reefs were worked, with the Pioneer mine yielding 66 oz Au from 77 tons of ore in 1884 and 30 oz Au from 40 tons of ore in 1886 (Kenny 1934). Reefs were also mined at New Bendigo where several shafts were sunk to ~100 feet (Kenny 1934).The quartz reefs are hosted by the Jeffreys Flat Formation of the Warratta Group, a 2km thick turbidite sequence with pyritic siltstone and minor conglomerate and limestone (Greenfield and Reid 2006).

Greenfield and Reid (2006) concluded that Au mineralization in the Warratta Inlier is associated with syn-deformation quartz veins, which were injected parallel to Benambran formed cleavage and formed long narrow stringer zones. Thalhammer (1992) related Au mineralisation to the second (of three) generation of veins predominantly comprised of quartz, albite and carbonate, with variable pyrite, arsenopyrite, chalcopyrite, galena, pyrrhotite and native Au. Thalhammer (1991) concluded gold mineralisation occurred under P-T conditions of 300-350ºC and 200-400 Mpa based on illite crystallinity. Auriferous fluids were probably oxidized, low-sulphide, $CO_2$-bearing fluids produced during peak metamorphism (Thalhammer 1992).

Au mineralisation is associated with two alteration zones, i.e. narrow phengite–chlorite–pyrite–carbonate halos around quartz veins, and carbonate–sericite 'bleached' zones extending kilometres along strike (Greenfield and Reid 2006). A 15-20km long and 500-1000m wide magnetic low, caused by magnetite destruction, correlates with the bleached zone (Greenfield and Reid 2006). Two whole-rock K–Ar dates from quartz-vein alteration halos in phyllites gave dates of 441 ± 5 Ma, and 438 ± 3 Ma (Thalhammer 1992).

A later deformation event in the Warratta Inlier, perhaps the Bindian Orogeny as discussed below, folded quartz vein networks and produced chevron folds (Greenfield and Reid 2006). A dextral strike-slip component is indicated by abundant en-echelon fold patterns and rotation of fold axes (Thalhammer 1992).

The source of Au in the Warratta inlier remains problematic. Pb isotope analyses suggest a mixed composition of Pb, composed of a dominant crustal and a minor mantle component

(Thalhammer 1991). Sulphur isotope analyses suggest a magmatic source of the sulphur in vein sulphides (Thalhammer 1991). Large *et al.* (2007) suggests that in sediment hosted orogenic Au systems, Au is already present within the basin and is mobilised relatively late during tectonism. Further work is required to investigate the sulphide evolution and determine the exact nature and generation of Au.

Greenfield and Reid (2006) compared the alteration and structural controls of Au mineralisation in the Warratta Inlier favourably to turbidite hosted orogenic Au deposits as defined by Bierlein *et al.* (1998), and to the world class deposits of the Bendigo Zone of the Victorian Goldfields.

Despite average grades of up to 25 g/t Au (Kenny 1934), the Pioneer-Phoenix area was not drilled until 2006 when exploration drilling confirmed the down dip continuation of mineralisation including 4m @ 4.39 g/t Au from 88m in hole TP003 (Mortimer 2007). Further structural mapping and interpretation is required to locate structural traps for mineralisation (such as saddle reefs).

Gold was discovered near **Cawker's Well** in 1889 with assays up to 19 g/t (Kenny 1934). Recent exploration drilling intersected anomalous Au associated with quartz veining in several holes (Edgecombe *pers. com.* 2007).

In a recent greenfield exploration program, Au-As soil geochemical anomalies corresponding to structural trends in the Cambrian Teltawongee Group near **Williams Peak** were drill tested. Anomalous Au intercepts represent the first Au intercepts in basement in the area (Edgecombe *pers. com.* 2007). The area has also yielded reworked Au nuggets associated with the basal Cretaceous unit.

<u>Late Silurian – Early Devonian 'Bindian' Orogeny</u>

The main effects of the Bindian Orogeny included:

- Dextral strike-slip movement creating northeast-southwest oriented spaces for fluids to exploit, such as later (D3) veins seen in the Warratta Inlier and felsic porphyry intrusions in the Mount Daubeny Basin.
- Monzodioritic intrusions into Jeffreys Flat Formation (dated at 423.3 ± 2.1 Ma and 421.3 ± 2.0 Ma (Black 2006)).
- I-type granite intrusions to the east of the Koonenberry Fault at Tibooburra with the main granodiorite body dated at 420.6 ± 3.3 Ma and 420.2 ± 3.3 Ma (Black 2007) and plutons at Cresswells Tank dated at 427.7 ± 2.3 Ma and Dynamite Tank dated at 425.7 ± 2.2 Ma (Black 2007).
- A granite intrusion near the Allambie Woolshed on Bunda 1:100 000 map sheet was dated at 423.1 ± 2.4 Ma (Black 2006).

In addition, the Mount Daubeny Basin (MDB) may have been opened by dextral strike-slip movement along the Koonenberry Fault. Buckley (2003) suggested the MDB was a pull-apart basin opened by dextral strike-slip movement in the Benambran Orogeny. Alternatively, Scheibner and Basden (1998) proposed that the basin opened as a sinistral transtensional pull-apart basin, created along the Koonenberry Fault. Further work is required to determine the kinematics of basin opening, including the role of northwest oriented structures.

The presence of andesitic volcanism (including lava flows, pyroclastics, tuffs and volcaniclastics) interspersed with basal conglomerates in the Mount Daubeny Formation suggest that volcanism occurred soon after basin opening. Black (2007) dated an andesitic lava flow within the conglomerate unit at 425.0 ± 7.0 Ma. Volcanism is concentrated in the northeast corner of the MDB. Dacite and andesitic plugs intruding the pile show chilled and hornfelsed contacts and positive magnetic anomalies (Buckley 2003). The 6 km thick sequence in the MDB also includes feldspathic, non-marine sediments (Neef *et al.* 1989). Neef *et al*. (1989) proposed a short period of deposition of ~0.5 to ~5 my on the basis of the lack of unconformities in the basin and sedimentary features indicating very rapid deposition.

Felsic intrusions (commonly porphyritic rhyolite) of the Wertago Suite intruded both the sediments of the MDB (where they cut bedding) and the adjacent Cambrian units (Ponto and Teltawongee Groups). They have been dated at 414.2 ± 2.7 (Black 2005) and 417.7 ± 1.9 Ma (Black 2006). In the north of the Basin, these intrusions have a dominant northeast-southwest trend, exploiting preferred extensional orientations.

*Epithermal polymetallic mineralisation*

The northern margins of the MDB and the adjacent Cambrian Ponto and Teltawongee Groups includes the historic copper mines of the **Wertago** area and the **Nuntherungie Silverfield** (Figure 1g).

From 1870 mining in the Wertago area focussed on open cut, high grade copper oxide and carbonate rich zones (<39% Cu) including Brady's Open Cut, Big Wertago, Copper Well and Bunker Hill (Kenny 1934). The Eclipse mine, which produced the only sulphide mineralisation in the field, yielded 200 tons of sulphide ore grading 25 to 30% Cu from the 108 feet level between 1905 to 1907 (Kenny 1934) illustrating the richness of the mineralisation. Primary mineralisation was confirmed by historic drilling under Eclipse intersecting pyrite and chalcopyrite associated with propylitic and phyllic altered porphyritic andesite and quartz-carbonate veining. Cu mines in the Wertago area are hosted by both Cambrian and Silurian-Devonian units.

On the Nuntherungie Silverfield mining began in 1890 and included the Great Nuntherungie, Central and Nil Desperandum mines (Kenny 1934). Primary ore of argentiferous galena associated with chalcopyrite, siderite and calcite, and oxidised ore of cerargyrite, embolite, cerussite in a gangue of siderite was mined (Kenny 1934). Barnes (1974) noted two probable generations of siderite alteration.

The similarity of ore at Nuntherungie to Thackaringa-style mineralisation in the Broken Hill Block was first described by Kenny (1934). Thackaringa-style veins are defined as silver-lead bearing siderite-quartz veins and copper-bearing siderite-quartz veins (Barnes 1988). Thackaringa-style veins at the type locality near Silverton are interpreted to have formed during the Delamerian Orogeny (Barnes 1988).

Ore zones in both areas are brecciated with botryoidal quartz and malachite, comb textures and quartz cavity fill textures with native sulphur and zones of argillic, phyllic, silicic and propylitic alteration. These characteristics are indicative of an epithermal event, similar to those described by Corbett (2007) in pull-apart basins elsewhere.

Pb isotope analysis of samples from the Eclipse and Nil Desperandum mines produced similar results suggesting a mixed mantle and crustal source with a Cambrian Pb age (Figure 3). This suggests that the source of Pb may be a either a Cambrian unit or a Thackaringa-style mineralising event that was overprinted by an epithermal event. Argillic alteration may represent further fluid flow.

We suggest that mineralisation on the Nuntherungie Silverfield and in the Wertago area represent different crustal levels of a low sulphidation epithermal event related to the opening of the MDB and associated volcanism. Pb-Ag mineralisation formed at a lower temperature in a higher crustal level, with Cu mineralisation forming at a lower crustal level close to the heat source (Ashley 2006). The different alteration assemblages throughout the area also reflect closeness to source and controlling structures. Competency contrasts between lithologies may have been important in mineral deposition.

Although epithermal textures have not previously been documented, Buckley (2001) suggested the area may be prospective for epithermal mineralisation. Analogies have been drawn between the MDB and the Cobar Basin in terms of tectonic setting and mineralisation potential (e.g. Buckley 2003). In addition, the Drummond Basin in Queensland may provide a further analogy where low sulphidation epithermal mineralisation is related to basin opening and volcanism.

Limited historic drilling in the area has not targeted epithermal style mineralisation. Further work is required to map the structures, facies variation and alteration assemblages to further define the mineralised zones. Sulphur isotope studies are recommended to test the source of mineralising fluids.

### Devonian Extension and the Tabberabberan Orogeny

Quartzose sediments were deposited on continental shelves and in basins across the area during the early Devonian. The Wana Karnu Group were deposited in a fluvial to deltaic environment, and folded by the Tabberabberan Orogeny under east-northeast / west-southwest compression (Mills and David 2004). Erosion of areas uplifted by the Tabberabberan Orogeny led to the deposition of the quartzose sediments of the Ravendale Formation in fluvial environments (Mills and David 2004). There is little evidence of mineralisation or remobilisation associated with these features.

### Carboniferous Kanimblan-Alice Springs Orogeny

A major episode of faulting and deformation during the Carboniferous Kanimblan-Alice Springs orogenic cycle produced shear zones and tectonic breccias. Remobilisation of fluids through these new and reactivated structures provided potential for deposit upgrade (Figure1e).

For example, at Brady's Open Cut, copper carbonate mineralisation is related to conjugate faults near primary epithermal deposits (e.g. Eclipse). Pb isotope analyses indicate a Pb source at 350 to 325 Ma, suggesting fluid movement and remobilisation along structures as a result of the Kanimblan-Alice Springs Orogeny. This model is supported by similar Pb isotope analyses from the Great Wertago mine where Cu mineralisation is associated with fault breccia on the Koonenberry Fault (Figure 3). Minor historical Au workings adjacent to the Koonenberry Fault throughout the Belt indicate Au was remobilised in addition to Cu.

### Cretaceous

Further erosion and deposition in fluvial to marine environments occurred through the Cretaceous, forming thick accumulations of sediment in the Eromanga Basin. Sea level fluctuations are represented by marine and terrestrial fossil assemblages throughout the Cretaceous sequence.

*Alluvial Au*

The sandstones and conglomerates of the Namur Sandstone represent the basal unit of the Cretaceous sequence (Figure 1h). This unit is a prospective horizon for palaeo-placer Au, as well as being a known fluid and hydrocarbon aquifer. Sediments were sourced by erosion from emergent basement and distributed by high-energy fluvial to tidal marine processes, including possible reworking in a beach environment (Chamberlain 2001). Cretaceous units have a shallow dip away from the inliers (Brown *et al.* 2006).

In the southern Koonenberry Belt, the basal units of the Cretaceous have yielded Au nuggets in the **Williams Peak** area.

In the northern Koonenberry Belt, the majority of Cretaceous alluvial Au workings are located along the margins of the **Tibooburra Inlier** (e.g. Tunnel Hill, Nuggetty Hill, Six Mile, Easter Monday) and the eastern margin of the **Mount Browne Inlier** (e.g. Billygoat Hill, the One Mile, The Four Mile, Stringers Gully). Between 1887 and 1933 approximately 16 082 oz Au was reported from the Mount Browne Field and 18 890 oz Au from the Tibooburra field, with over 25 000 oz Au jointly reported from the Mount Browne and Tibooburra goldfields from 1881 to 1886 (Kenny 1934).

An estimated resource of 40 000t @ <0.5g/t Au in the Easter Monday area and a preliminary resource of 10 000t @ <1.0 g/t Au in the Nugget Creek area (downstream of Tunnel Hill) have been calculated (Marston 1984).

There has been much speculation on the source of the Au in the Tibooburra and Mount Browne Inliers given the lack of known basement mineralisation in those inliers. Gibbons (2005) found Au nugget morphology ranged from flaky nuggets (interpreted to be proximal to source) to round and spherical nuggets (reflecting a high degree of transportation). The Warratta Inlier, the closest known occurrence of primary gold, is not favoured as a source due to the partial crystallinity of Au grains and the uniform distribution of Au around the Tibooburra Inlier (Brown et al 2006).

Hill (2007) proposed a Au source to the NW based on palaeocurrent directions in the Namur Sandstone, and that the Tibooburra and Mount Browne Inliers were emergent during the Cretaceous causing interruptions to flow and sediment deposition. In contrast, the Warratta, Mount Poole and the Gorge Inliers were probably submerged during this time, thus explaining the lack of Cretaceous deposition and associated Au around these inliers.

### Quaternary

The Koonenberry Belt was subjected to an arid environment in the Quaternary resulting in the formation of aeolian dunes, salt lakes, gibber plains and the establishment of modern drainage systems. Neotectonism is apparent in the Koonenberry Belt and is represented by young fault scarps and recorded earthquakes (Davey 2005).

*Alluvial Au*

Reworking of the Cretaceous sequence resulted in the redistribution of Au nuggets into present day drainage systems. Workings exploiting Quaternary alluvial leads are present in all inliers in the northern Koonenberry Belt. Examples include; Mt Browne (eastern margin from The Four Mile to Billygoat Hill), Tibooburra (Stuart Mine, The Granites) and Warratta (Good Friday, Evans Gully, Warratta Creek, Moffitt's Gully).

In the Tibooburra Inlier, Au nuggets have been found with a clayey loam developed in areas occupied by the Tibooburra Granodiorite at The Granites. Brown *et al.* (2006) suggested that the Cretaceous sediments have been eroded away, leaving gold-rich alluvial deposits on top of the exposed Tibooburra Granodiorite.

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# TASMANIDES – THE BIG PICTURE

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## Introduction

The Tasmanides occupy the eastern one third of Australia and record the interaction between the Australian part of Gondwana and the proto-Pacific plate. This interaction spanned ~600 million years, from ~830 Ma in the Neoproterozoic until ~230 Ma in the Triassic.
The Tasmanides host several world class ore systems, including the gold-bearing veins in deformed Ordovician turbidites in central Victoria, gold-copper deposits mainly associated with intrusive rocks in the Macquarie Arc in central NSW; intrusive-related deposits of North Queensland and coal in Permian strata in the Sydney, Gunnedah and Bowen basins. Other sizeable ore systems include those in the Mt Read Volcanics in western Tasmania and the base metal and gold deposits in rift basins in the Lachlan Orogen.
In this presentation, I deconstruct the Tasmanides, using subduction-related volcanic arcs as key markers. By tracking the location of such arc fragments in time and space, it is possible to infer the presence of subduction zones and plate(let) boundaries. If we can also identify either coeval backarc basins and/or forearc and accretionary complexes, we have established triplets that shed light on subduction zone geometry.
Why do this? Because arcs and back arc basins have elevated heats flows. As such, they are favourable settings for enhanced fluid flow and for focusing deformation as hot rocks are relatively weak. It is no surprise that they contain major mantle and deep crustal-derived ore bodies.
The 'vertical' time scale used is the concept of tectonic cycles Glen (2005) and in Mines & Wines 2006 (Glen 2006) named after terminating orogenies although I have included post-collisional events in each cycle. These comprise:

- Delamerian Supercycle (~830–500 Ma) and consisting of two major cycles, either side of ~526 Ma.
- Lachlan Supercycle consisting of Benambran Cycle (490-438 Ma), Tabberabberan Cycle (437-380 Ma) and Kanimblan Cycle (~380-344) Ma, with post tectonic granites to ~320 Ma.
- Hunter-Bowen Supercycle (~360 Ma to 230 Ma), overlapping somewhat with the Kanimblan Cycle.

## Delamerian Supercycle

### Passive margin to rift tectonics

The early history of the Delamerian Supercycle reflects passive margin development on the trailing eastern edge of Gondwana. In the Tasmanides, this is reflected by the formation of the largely amagmatic Adelaide Rift Complex from ~830 Ma to ~600 Ma, at which time major magmatic rifts appeared in a zone running from the Koonenberry Belt in far northwest NSW through ?western Victoria and King Island to western Tasmania. Rifts also occurred in the eastern part of the Thomson Orogen (Anakie Inlier) and in the North Queensland Orogen. Rifting led to sea floor spreading, with the oldest ocean crust dated at 652 Ma (Bruce *et al*. 2000) in the northern New England Orogen. Continent-continent collision and closure of the Mozambique Ocean in pan African times (~660-520 Ma) led to the proto-Pacific margin of Gondwana becoming an active plate margin.

## Convergent margin tectonics

### Delamerian Orogen-West Tasmania

In the Crawford and Berry (1992) model, Middle Early Cambrian (~520-513 Ma) mafic-ultramafic complexes represent forearc igneous crust that formed on the proto-Pacific plate above an east-dipping subduction zone. Because this crust is allochthonous, the subduction vector is based on the model of boninite formation occurring in front of island arcs. There is no identified arc, back arc or forearc basin or accretionary complex.

### Delamerian Orogen-West Victoria

The Delamerian margin in western Victoria is largely obscured, strongly deformed, and thus controversial. Arc rocks have been inferred from the 350 km long Dimboola Igneous Complex east of the Moyston Fault (VandenBerg *et al.* 2000). This inference, coupled with the back arc nature of 515 Ma Stawell basalts immediately to the east (Squire *et a.* 2006), has been used to infer west-dipping subduction, In this west dipping model, I suggest that the Kanmantoo Trough is a back arc basin and boninitic rocks in the hangingwall of the Heathcote Fault Zone represent forearc crust rifted off after the Delamerian Orogeny (Glen and Crawford 2005). However, the east-dipping Tasmania model has also been applied to west Victoria (Crawford et al. 2006, 2003). In this model, boninitic serpentinites in the Mt Stavely belt west of the Dimboola Igneous Complex represent forearc crust and there is no arc. Maybe there were flips in the subduction direction.

### Delamerian Orogen- Koonenberry belt

Mapping and geophysical modelling by the Geological Survey of NSW over the years (see also Gilmore et al. this volume) suggest that Mt Wright Volcanics and overlying Cymbric Vale Formation represent an arc (Sharp and Buckley 2003) rather than a rift as previously thought (Crawford *et al.* 1997). The latter unit is now dated at ~510 Ma (Gilmore et al. this volume) rather than 526 Ma as previously inferred. In a W-dipping subduction zone model, which I prefer, the western part of the Warburton Basin, west of the Mooracoochie Volcanics (Gravestock and Gatehouse 1995) that link into the Mt Wright Arc, may function partly as a back arc basin. Sedimentary rocks east of the arc may represent forearc basin deposits (the Teltawangee beds) and accretionary complex rocks (Ponto beds with ~510 Ma ash beds derived from the arc and with tholeiitic basalts to be slices of ocean crust on the down going plate, Gilmore et al. this volume). It is still debated whether the Mt Wright Arc is a continental margin arc or is an intraoceanic arc developed on the Gondwana plate and accreted in the Delamerian Orogeny.

### Lachlan Orogen

In central Victoria, Delamerian Supercycle Cambrian boninite and tholeiites occur in the hangingwalls of the Heathcote Fault Zone and Governor Fault Zone whereas calc alkaline rocks volcanics occur in the hangingwall of the Mt Mount Wellington Fault Zone (VandenBerg *et al* 2000). Rather than these representing separate arc or forearc systems as suggested by some authors, they were interpreted by Glen and Crawford (2005) as fragments of the deformed Delamerian margin that were rifted off during plate roll back after the Delamerian Orogeny.

### Thomson Orogen;

Because this orogen is almost totally concealed beneath the Eromanga Basin, hard geological data is restricted to very sparse drill holes. A gabbro with possible Neoproterozoic to Cambrian ages occurs near Louth (see Glen et al. this volume)

### New England Orogen

Along the Peel-Manning Fault System, disrupted boninitic suprasubduction zone ophiolites dated at 530 Ma (Aitchison *et al.*1992*)* represent another, more outboard zone of forearc crust possibly incorporated into New England Orogen from underlying Lachlan crust.

**North Queensland Orogen**

## Delamerian Orogeny

The Delamerian Supercycle was terminated at 510 Ma in west Tasmania and at ~514 Ma in South Australia and ~ 500 Ma in Koonenberry Belt (Gilmore et al. this issue). In the west Tasmania model, the orogeny was caused by thicker and thicker passive margin continental crust entering, and then jamming, the subduction zone, with resultant south and westwards obduction of forearc crust and exhumation of metamorphosed old crust. In the W-dipping subduction model, a collider needs to be invoked to terminate subduction. In either case, rollback of the proto-Pacific plate resulted in formation of extensional Dundas Trough and the post-collisional Mt Read Volcanics in west Tasmania, the Mt Stavely Volcanics and Late Cambrian turbidites in western Victoria, and the rifting of fragments of the accreted margin, as above. A second phase of deformation occurred in both areas.

# Lachlan Supercycle

## Benambran Cycle

### Lachlan Orogen

Rollback of the proto-Pacific plate after the Delamerian Orogeny produced a new plate boundary ~1000 km to the east of the 'cratonised' Delamerian margin. Sea-floor spreading at a high angle to this boundary generated a ~1000 km long convergent margin that led to the formation of the intraoceanic Macquarie Arc, possibly on a fragment of the old rifted margin. For most of its 50 m.yr life, this arc developed in response to W-dipping subduction. I do not recognise any other arc or subduction system. The Wagga Basin represents a back arc basin to the Macquarie Arc. The expected volcaniclastic forearc basin and accretionary complex outboard of the arc are absent; they have been replaced by craton-derived quartz rich turbidites of the Adaminaby Group that was assembled off Antarctica and transported north along a strike-slip plate boundary in the Late Ordovician.

### New England Orogen

Three elements of Ordovician convergent margin tectonism occur along major faults in the New England Orogen. Fragments of Ordovician intermediate arc volcanics occur in fault blocks west of the Peel-Manning Fault System. Meta-igneous blueschist knockers occur in serpentinite melange of the Peel-Manning Fault and indicate formation in deep levels of an accretionary complex. High-level accretionary complex rocks occur at Pt Macquarie (Och *et al.* 2007). I suggest that all three units have Lachlan connections, with the missing accretionary complex rocks outboard of the Macquarie Arc now exhumed along major faults in the New England Orogen.

### Thomson Orogen

Work by the Geological Survey of Queensland indicates that ~480 Ma Ordovician felsic volcanic rocks of unknown tectonic affinity occur in drill holes beneath the Adavale Basin (Draper 2006). Felsic volcaniclastic rocks of island arc tholeiite affinity also occur in the eastern part of the orogen, in the Anakie Inlier (Withnall 1995).

### North Queensland Orogen

Several lines of evidence argue for one or more Ordovician continental margin arcs developed over a W-dipping subduction zone in the North Queensland Orogen. These include:

- ~480 Ma felsic volcanics of the Seventy Mile Range Group (Paulick and McPhie 1999) and the 471 Ma Balcooma Volcanics (Fergusson *et al.* 2007) both of which are inferred to have accumulated in a back arc basin behind an E-facing arc.

- Late Ordovician volcanics (Everett Ck Volcanics & Carriers Well Formation) with calc alkaline and tholeiitic chemistry developed in a back arc basin (Withnall and Lang 1993).

- Ravenswood Batholith, with ages from 490 to 463 Ma, and subduction signatures that may represent the roots of a continental margin arc (Kreuzer 2005).

**Benambran Orogeny**

The Ordovician was a period of Gondwana-wide plate activity and deformation. In the Lachlan Orogen, the Benambran Orogeny (phase 1 ~443 Ma, phase 2 ~435 Ma) was caused when subduction outboard of the Macquarie Arc was blocked, causing the arc to collide with its backarc basin (Glen *et al.* 2007). Major deformation was preferentially partitioned into Ordovician turbidites. The Ordovician turbidites of the Castlemaine Group that host the gold of central Victoria were assembled off Antarctica and deformed in that setting Glen. The North Queensland Orogen underwent ?localised deformation in the Middle Ordovician with more regional deformation in the Late Ordovician–Early Silurian

**<u>Tabberabberan cycle</u>**

**New England Orogen**

After the Benambran Orogeny, roll back of the proto-Pacific plate generated a new plate boundary to the east. Silurian to Devonian intraoceanic volcanic arcs related to this plate boundary occur in northern New England Orogen in the Mt Morgan area Murray and Blake and in the southern New England Orogen (Offler and Gamble 2002), flanking the Peel-Manning Fault System between Nundle and Glenrock. Multiple arc-back arc systems may be present, since an inferred Middle Devonian arc system between Yarras and Pt Macquarie in the southern New England Orogen (Aitchison *et al*. 1992) overlaps in time rifting of the arc in the Glenrock area. East-and W-dipping dipping subduction has been inferred for all regions, but W-dipping subduction fits better the relationship with accretionary complex rocks of the Woolomin Formation east of the Peel-Manning Fault System

**Lachlan Orogen**

In a regime of W-dipping Silurian-Devonian subduction, all the Lachlan Orogen would occupy an extending back arc region. This is consistent with formation of rift basins, extrusion of felsic and mafic volcanics and emplacement of S and I-type granites. I don't recognise any internal arcs or subduction zones.

**North Queensland Orogen**

A back arc basin setting is also inferred for this orogen, with deposition of Chillagoe Formation and the overlying the Hodgkinson Formation in the Hodgkinson (sub) province and with deposition in smaller basins to the southwest in the Broken River (sub) province all occurring west of an W-dipping continental margin arc (Bultitude *et al*. 1993, Vos *et al.* 2006);

**<u>Kanimblan Cycle</u>**

This cycle commenced with formation of rifts occupied by A-type volcanics and intrusions, before being dominated by deposition of largely fluviatile sediments over a large area. Deformation and basin inversion in the Early Carboniferous (~340 Ma) were followed by post-tectonic emplacement of I-type granites in the region between Gulgong and Goulburn.

**Hunter-Bowen Supercycle**

The Hunter-Bowen Supercycle is largely manifested in the New England Orogen and is essentially the product of W-dipping subduction from the Late Devonian through to the Middle Triassic. This period of ~140 m.yr. was interrupted only in the Early Permian by major extension. Several cycles can be recognised.

**Cycle 1**

Cycle 1 reflects Late Devonian convergence, marked by the onset of W-dipping subduction that was reflected by development of a continental margin arc (Baldwin Arc in NSW) in the west that is no longer preserved: instead we see arc-flank andesitic rocks in both the northern and southern New England Orogens. These rocks pass east into a forearc basin (Yarrol and Tamworth troughs respectively) and then across major faults into accretionary complexes. Back arc basins include the Drummond Basin as well as small basins in the North Queensland Orogen

**Cycle 2**

Cycle 2, Carboniferous convergence, is reflected by felsic volcanism in the Currububula Arc in the southern New England Orogen and by granites of the Connors and Auburn arches in the northern New England Orogen. Forearc basins also show a changeover to felsic detritus, although arc fringe deposits of the Campwyn Terrane to east of the Connors Arch are dominated by mafic to intermediate volcanism (Henderson *et al.* 1998) Carboniferous accretionary complex rocks occupy the largest area of the southern New England Orogen, but allowance has to be made for latest Carboniferous–Early Permian oroclinal folding that has doubled up the width of the complex and which was part of the deformation that terminated cycle 2.

**Cycle 3**

Cycle 3, Early Permian extension, led to generation of rift basin volcanics at the base of the Bowen, Gunnedah and Sydney basins as well as rift basins in the southern New England Orogen. Extensional faults and exhumation of Delamerian cycle serpentinites occurred at the same time.

**Cycle 4**

Cycle 4 marked a return to W-dipping subduction from late Early Permian to Middle Triassic times. Ignimbrites I-type subduction-related granites mark the re-establishment of a continental margin arc. The extrusion above, and intrusion into, older, cycle 1 and 2 accretionary complex rocks reflects plate boundary roll back (eg Jenkins *et al.* 2002) Progressive uplift of the New England Orogen by underthrusting converted the Bowen, Gunnedah and Sydney basins into foreland basins, filled with orogenic detritus and containing rich coal deposits.

The Triassic to Permian Gympie Terrane is a key but small component of cycle 4 and is interpreted as an intraoceanic island arc that was accreted to the east Gondwana margin in the Middle to Late Triassic (Sivell and McCulloch 2001). This deformation migrated westwards into the foreland basins to the west as part of a foreland propagating fold thrust belt.

## Implications

Plotting the location of arcs reveals major differences between the northern and southern Tasmanides. In the southern Tasmanides, arcs and their proxy fore arc crust, have migrated eastwards with time from the Delamerian Orogen into the Lachlan Orogen and into the New England Orogen. (A caveat here: how do we restore the boninitic forearc crust along the Peel-Manning Fault System?) This migration is best measured by the increasing distance between successive arcs and Precambrian continental crust of cratonic Australia.

In contrast, in the North Queensland Orogen, arcs show less sign of migration and are practically stacked one above the other, remaining close to Precambrian cratonic Australia. Several implications follow:

- These differences in arc migration indicate changes in time in the location of boundary between the proto-pacific plate and the Australia part of Gondwana.

- As a result most of the southern Tasmanides (that part east of the Adelaide Rift Complex) was built on oceanic substrate. (Again another caveat: what lies beneath the allochthonous Bendigo terrane of central Victoria?). In contrast. The northern Tasmanides was built on a basement of Precambrian continental crust.

- The southern part of the Tasmanides shows the character of a growing accretionary orogen. This growth was episodic, most of it reflecting migration of the plate boundary after the Delamerian Orogeny (500-490 Ma), and again after the Benambran Orogeny (443- 435 Ma). From the Late Devonian to the Triassic, the arc was more or less located along the western margin of the New England Orogen. This contrasts with the North Queensland Orogen, where the arc was more or less anchored in time from the Cambrian through to the Triassic.

- This bipolar character of the Tasmanides has in turn further implications. Firstly, it reflects segmentation of the proto-Pacific plate. Secondly, it asks the question how the changeover from an accretionary to non-accretionary orogenic belt was achieved Answers must come form the region of the Thomson Orogen that is effectively hidden beneath the Eromanga Basin? Is there a major continental fracture zone along the northern margin of the Thomson Orogen, or within the Thomson Orogen? Or did the whole Thomson Orogen develop during anticlockwise rotation of the Anakie Inlier away from the Precambrian craton about a pole of rotation to the north, in a north Fiji Basin type model? If so, there must be a major hard-linked continent-scale cross structure along the southern edge of the Thomson Orogen. Is this the structure imaged by the recent seismic reflection program across the Thomson-Lachlan boundary (see Glen et al. this volume).

- The economic implications of such structures are yet to be fully assessed

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# THOMSON-LACHLAN SEISMIC PROJECT – RESULTS AND IMPLICATIONS

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**Key Words:** Thomson Orogen, Lachlan Orogen, gravity modelling, deep seismic profiling, Mt Jack High, Nelyambo Trough.

## Introduction

A collaborative high resolution seismic reflection survey was carried out by DPI and the pmd*CRC and Geoscience Australia in September 2005 to investigate the nature and location of the east-west boundary between the Thomson and Lachlan orogens and mineral potential north and south of the boundary (Figure 1). The rationale behind the project and the seismic acquisition were described in Mines and Wines 2006 (Glen et al. 2006).

## Pre-project geology

The geology of the Lachlan Orogen south of the seismic lines has been established from mapping in the Cobar region 100 km to the south. Here there is a three-fold stratigraphy that is divided into basement (Ordovician turbidites and Silurian granites), Early Devonian sediments ± volcanics deposited in rifts and on shallow water marine shelves, and Late Devonian fluviatile cover rocks (Glen et al. 1996).

In contrast, the geology of the Thomson Orogen in New South Wales is obscured by Mesozoic cover of the Eromanga Basin that has a thickness of 0-300 m. The sparse information that is available comes from old petroleum holes and mineral exploration holes, the latter indicting the presence of mafic- intermediate volcanics around Louth and sedimentary rocks to the south and west.

## Background geophysical framework

The gravity data of the Thomson Orogen is dominated by a major east-west trending gravity high, with a line of smaller ovoid lows in the north (Figure 1). The gravity data of the immediate Lachlan Orogen is dominated by a major gravity low that corresponds with the Nelyambo Trough, an element of the Devonian Darling Basin that is flanked to the southwest by the discontinuous WNW-trending Mt Jack (gravity) High. The boundary between the E-W gravity high and the Nelyambo Trough low coincides with the inferred Olepoloko Fault and is used as the approximate boundary between the Lachlan Orogen and the Thomson Orogen west of Bourke.

The image of total magnetic intensity (TMI) shows a major change in character of the magnetic signature between the north (several isolated magnetic highs that may be correlated to deep seated magnetic bodies and volcanics) and the south (moderate anomalies) of the Thomson-Lachlan boundary. A prominent feature on the magnetic map is a band of NW-trending narrow anomalies (?over volcanic rocks) that swing into the Olepoloko Fault suggesting an apparent left-lateral displacement. North-trending (and folded) magnetic highs around Louth reflect largely buried volcanics drilled by exploration companies.

## Crustal architecture and stratigraphy

### Thomson Orogen

*Lower and middle crust*

Interpretation of seismic data suggests that the lower crust consists of curviplanar bands of highly reflective material up to 6 km thick. Of variable persistence, these are interlayered with

similar thickness bands of lower reflectivity. The middle crust (<~25 km up to ~10 km) consists of less persistent but shorter length bands up to ~ 3 km thick anastomosing around less reflective packets. These are cut by north and south-dipping faults (Figure 2).
Gravity modelling suggests that both the middle and lower crust contribute to the prominent, long wavelength, E-W gravity high. We have been able to model this regional gravity high as a three layer sandwich, with dense rock (2.70g/cc) high in the crust (from ~9 to 20 km) overlaying a slightly more reflective (denser) thin 6 km thick layer (2.71 g/cc) above a very dense lower crust with a density of 3.04 g/cc. A prominent horizontal seismic reflection at depth of 48 km is interpreted as the Moho.

*Upper crust*
Based on existing drill holes, coupled with some field mapping in southern part of the orogen, the main components of the upper crust include:
A volcanic and volcaniclastic mafic–intermediate package near Louth with ocean island basalt (OIB) affinity (Dadd 2006). Gravity and aeromagnetic data suggest that the distribution of these volcanics can be extended westwards. From gravity modelling, we infer the volcanics and volcaniclastic sediments correspond to local short wavelength anomalies and occur as N-dipping bodies extending down to 10 km. This volcanic package is as yet undated. Brunker (1968) cited a suggested Silurian fossil age based on J. W. Pickett, but this age is uncertain (J. W. Pickett pers. comm. 2007). Preliminary zircon data suggest a Neoproterozoic to Cambrian age for gabbro northeast of Louth and a possible Ordovician age for volcaniclastic sandstone at Louth.
Sedimentary rocks occur as background to Thomson Orogen and flanking the Louth volcanics. They correspond (non uniquely) to gravity lows. Some of these sediments are distal turbidite packages in fault contact with the volcanic package. Shales from the turbidite package contain Late Ordovician graptolites at Louth (Brunker 1968) based on fossil identifications by G. H. Packham and J. W. Pickett. Cleaved sedimentary rocks (dark grey shales and grey fine grained siltstones and sandstones) intersected by Compass Resources (2006) contain pyrite and pyrrhotite veins.
A NE-trending magnetic zone extending for ~24 km east of Bourke reflects andesitic volcanics drilled by Newcrest Mining (Hay 2006). They have a calc alkaline, arc signature (Burton 2007). Their age is as yet unknown.
Late Devonian strata in Paka Tank Trough, (Alder 1999).
Granitic intrusions seen on Bourke map and also, inferred from gravity data. Near Doradilla, one granite is Triassic in age (Burton 2007).

Seismic interpretation indicates that on a whole of crust scale, the upper crust of the Thomson Orogen is effectively non reflective, but in detail it consists of short length discrete reflections. A probable broad antiform lies immediately north of the Olepoloko Fault. Farther north lie a series of inferred N-dipping faults that cut these reflections and which sole out at just below a depth of 12 km. In contrast, S-dipping faults dominate in the northern part of the section. A triangle zone down to 9 km in the middle of the Thomson Orogen correlates with volcanics inferred from gravity modelling and extrapolation of drill hole data.

**Lachlan Orogen**
*Lower and middle crust*
There is a highly reflective lower crust under the Lachlan Orogen, between 18 and 33 km. It is characterised by ~ 3km thick packets of moderately continuous, strong reflections anastomosing around less reflective zones of similar thickness (figure 2). Based on gravity modelling, this reflective lower crust has an assumed density of 2.79g/cc that could correspond to mafic granulites. Underlying poorly reflective material is inferred to lie below the Moho which is essentially flat lying.

*Upper crust*
Interpretation of the seismic data suggests a three-fold upper crust that we have divided into basement, rifts and fluviatile cover, consistent with three-fold subdivision in the Cobar region.
Basement: poorly reflective, with discrete short length reflections inferred to be Ordovician turbidites. These are cut by dipping, more reflective zones inferred to be faults.
Rifts: Wedge-shaped packets of reflections in the seismic reflection data, about 3 km thick have been interpreted as (?)Early Devonian rifts on all lines. They are bounded by largely S-

dipping reflections that are interpreted to be fault margins (figure 3). Stacked rifts have been interpreted in the eastern two-thirds of line 1. A thin zone (up to 0.5 km thick) of slightly wavy continuous reflections above these inferred rifts and below inferred fluviatile rocks is interpreted as a sag phase of basin formation. Densities of 2.57 g/cc for the rifts and 2.60 g/cc for the sag were used for the gravity modelling: both elements contribute to the gravity low associated with the Nelyambo Trough.

Particularly reflective areas in the south of line 3 and southwest of line 1 are inferred to reflect the presence of S-dipping igneous rocks lying at depths between 2-6 km (line 3) and 4-6 km (line 1). These have a modelled density of 3.04g/cc.

Mapping has identified shallow water sediments, tentatively correlated with part of the Cobar Supergroup, just north of the inferred gravity defined northern boundary of the Nelyambo Trough: these sedimentary rocks might be part of the sag phase.

Fluviatile cover: This is expressed by parallel continuous (tram track) reflections, that are correlated with the Mulga Downs Group from field mapping both in the Nelyambo Trough and on the Mt Jack High. Combining seismic lines 1 and 2 gives a complete section through the Nelyambo Trough, allowing internal subdivisions into mudstone-rich and sandstone-rich packets.
The thickness of the Mulga Downs Group in the Nelyambo Trough is 6-7 km in the west, and thins towards the northeast down to 1.3 km. This sedimentary package is cut by northeast dipping thrusts, and contains broad folds, some of which display growth and are thus syn-sedimentary in timing. An average density of 2.45 g/cc was assigned for gravity modelling.

Structures

***Olepoloko Fault***

This fault was named by Stevens (1991) and located from gravity data. The interpretation of seismic data shows that the Thomson-Lachlan boundary is a major planar fault dipping to the north at ~ 45° and cutting through the entire crust, separating thick crust of the Thomson Orogen to the north (Moho at ~ 48 km) from thinner but more reflective lower crust of the Lachlan Orogen to the south (Moho at 32 km).

***Mt Jack High***

The Mt Jack High is identified from the regional gravity data as a ~ 20 km wide WNW-trending zone that separates gravity lows that correlate with the Nelyambo Trough to the northeast and the Lake Poopelloe troughs in the southwest. The high itself actually consists of two segments separated by an intervening low which is still higher than the flanking troughs. The gravity response of the Mt Jack high would indicate the presence of rift-related igneous rocks in the rift package (line 1 and 3).

Mapping has identified conglomerate and sandstone correlated with Mulga Downs Group on the Mt Jack High.

***Mt Jack Fault Zone***

Seismic data indicate the presence of the Mt Jack Fault Zone that lies approximately parallel to, but northeast of, the Mt Jack (gravity) High. From southeast to northeast, the Mt Jack Fault Zone consists of a well defined back limb dipping at ~ 35° SW, a broad 6- 7 km long hinge zone measured on top of sag layer, and a short northern antiform that is cut off by 60° SW-dipping Mt Jack Fault that is interpreted to be a thrust. The southwest main antiform is dominant and correlates with a mapped broad anticline with ESE plunge ~50 km long that has an irregular WNW-trending axial trace. Correlation of stratigraphic units at the top of sag phase suggests ~3 km of vertical displacement in line 1 but only 1.5 km in line 3. Antithetic NE-dipping thrusts are present, as are some folds with stratal growth.
The Mt Jack Fault coincides with inferred older edges of rift basins that thicken to the southwest and northeast.

**Implications**

The Thomson-Lachlan boundary is the Olepoloko Fault, a ~planar 45°N-dipping fault that offsets the Moho. Last movement is Carboniferous or younger. Exhumation of the Thomson

Orogen in the hangingwall of this fault is consistent with the local presence of metamorphic kyanite and sillimanite. Curvature of aeromagnetic linears in the Thomson Orogen into the fault suggests a left-lateral component of movement.

The east-west gravity high in the Thomson Orogen is due to high density rocks that sit higher in the crust than rocks of similar density south of the Olepoloko Fault in the Lachlan Orogen.

Differences in character of the lower crust – more reflective under Lachlan, but thicker under the Thomson Orogen - confirms a major difference between the two orogens. We do not as yet know whether the thicker Thomson Orogen crust reflects tectonic stacking or magmatic underplating or a combination of both.

The Nelyambo Trough is as structural basin bounded by thrusts on each side. It contains up to 6-7 km of sediments of Mulga Downs Group and 4 km of rift sequence.

Modelling of the Mt Jack (gravity) High indicates the presence of dense, igneous rocks emplaced in rift package during rifting.

The Mt Jack Fault Zone consists of a SW-dipping thrust with folds and back thrusts developed in the hangingwall. The frontal Mt Jack Fault dips to the southwest and marks the southwestern edge of Nelyambo Trough and may have been developed by the reactivation of older faulted rift margins. The depths of these rifts appear to shallow to the northwest.

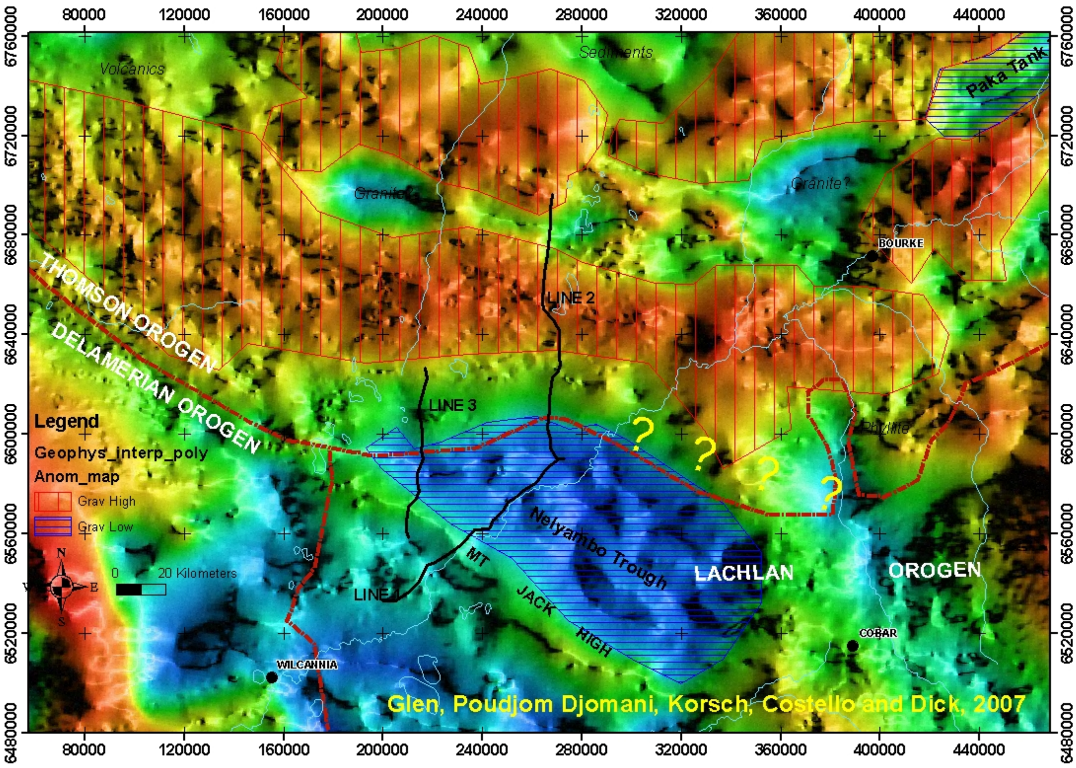


Figure 1. Location of the Thomson-Lachlan seismic lines (black lines) superimposed on a colour image of the Bouguer gravity data. The thick dashed line is the approximate boundary between the two orogens, interpreted from drill hole, gravity and magnetic data. Question marks denote areas where the boundary is not yet finally resolved.

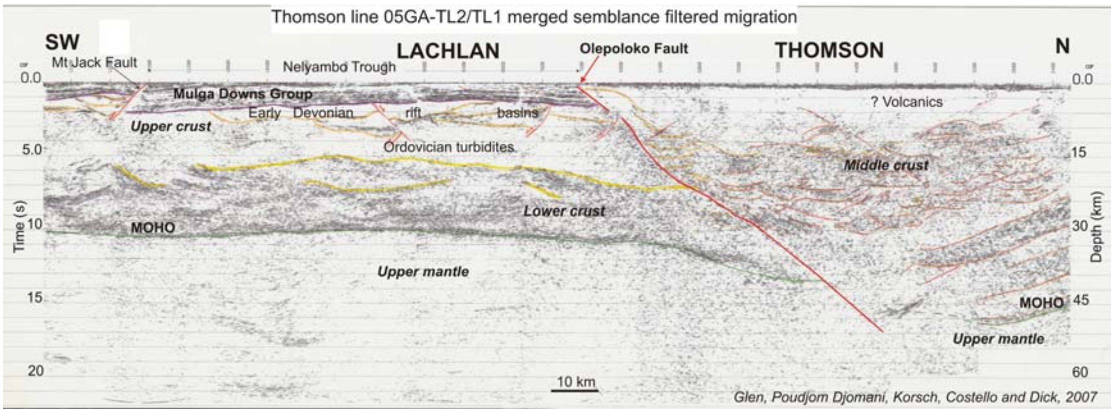


Figure 2. Seismic interpretation of combined lines TL1 and 2. This 22 seconds migrated section shows the subdivisions from the upper mantle through to the upper crust. Refer to the text for more details.

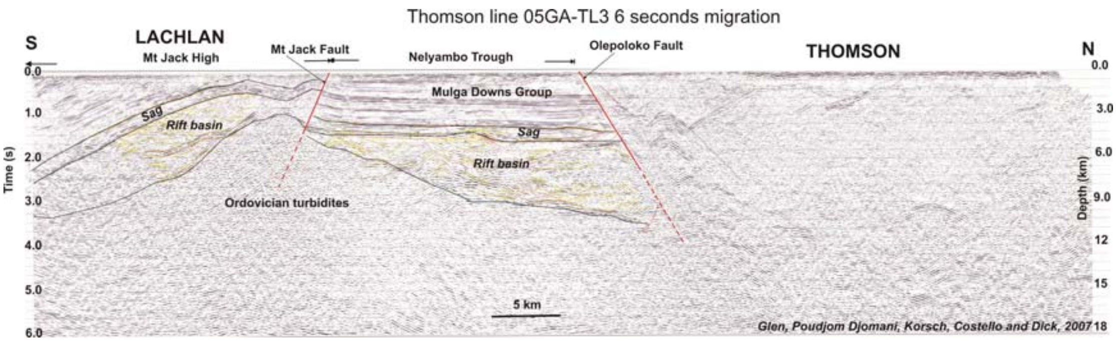


Figure 3. Seismic interpretation of migrated line TL3, down to 6 seconds. Refer to text for more details.

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# DEPOSITIONAL SYSTEMS, CRUSTAL STRUCTURE AND MINERALISATION IN THE THALANGA PROVINCE NORTH QUEENSLAND.

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**Key words:** Thomson Orogen, tectonics, volcanic hosted massive sulphide, back-arc extension, crustal structure

**Introduction:**

VHMS style mineralisation occurs in several deposits in the Seventy Mile Range Group (Berry & others, 1992) and equivalents in the northern Thomson Orogen in Queensland (Figure 1). The Thomson Orogen is an Early to middle Palaeozoic orogen which underlies about 50% of Queensland (Murray & Kirkegaard, 1978; Wellman, in Bain & Draper, 1997). The development of the Thomson Orogen in Queensland is poorly understood as most of the rocks are overlain by thick sedimentary basins of the Great Artesian Basin. Outcrop of the orogen occurs mostly in Eastern Queensland in the Anakie, Charters Towers and in Eastern Georgetown regions.

This paper reviews at the early Palaeozoic development of the Orogen particularly in the Charters Towers region in north Queensland, where it is possible to compare coeval processes at different crustal levels in the same system. Subsequent deformation has "tilted" the crust to reveal these different crustal levels.

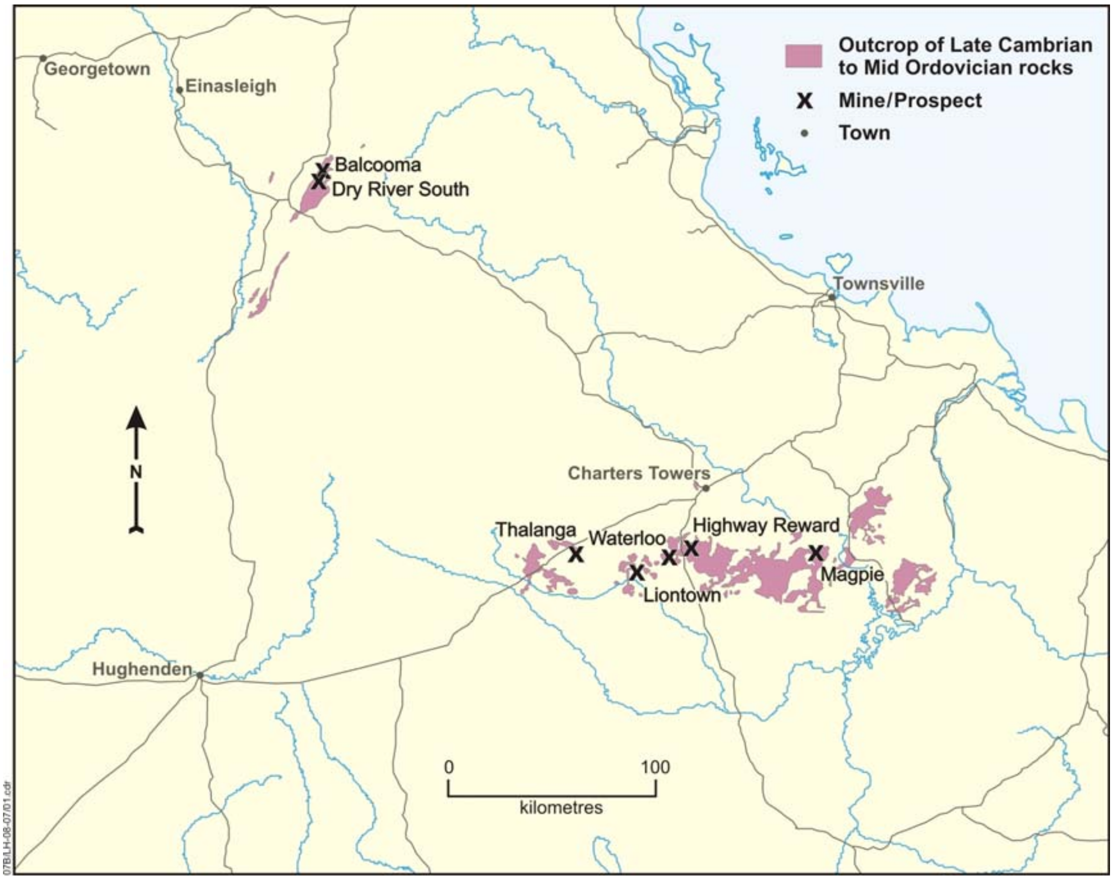

**Figure 1** Map showing the distribution of Late Cambrian to Middle Ordovician rocks in north Queensland and their relationship to mineralisation.

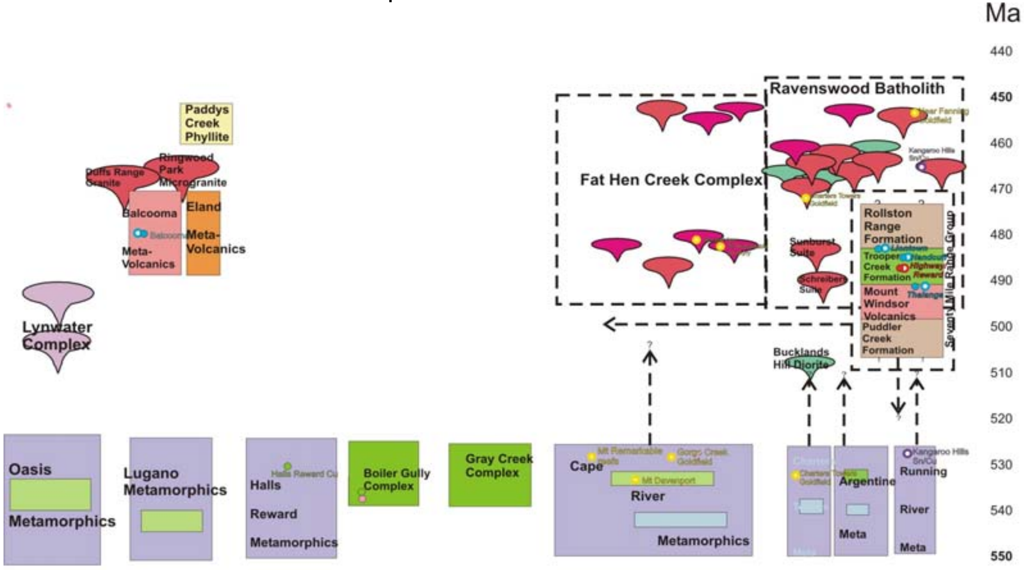


**Figure 2** Time space plot of the northern Thomson Orogen in the Charters Towers and Eastern Georgetown regions.

**Thomson Orogen:**

The Thomson Orogen in Queensland comprises sedimentary and volcanic rocks from late Neoproterozoic to mid Palaeozoic (Murray & Kirkegaard, 1978). They lie to the east of the Tasman Line which marks the eastern extent of the Australian Precambrian craton. Late Neoproterozoic to Middle Ordovician rocks in the Thomson Orogen can be subdivided into two broad sequences - late Neoproterozoic to Middle Cambrian and Late Cambrian to Middle Ordovician.

***Late Neoproterozoic to Cambrian sedimentation:***

The earliest sedimentation in the Thomson Orogen occurred between the late Neoproterozoic and Middle Cambrian (Figure 2). Rocks deposited in this episode are widespread and are characterised by distinctive detrital zircon populations (Fergusson & others, 2001; Hutton & others, 1998; Fergusson & others, 2007a). These populations are dominated by 1000 – 1200Ma zircons with smaller peaks of several older populations. Some have peaks in the 600-800 Ma and 800-1000Ma ranges. The presence of similar detrital zircon populations suggests a common source.

***Late Cambrian to Middle Ordovician sedimentation and volcanism:***

Within the exposed part of the Thomson Orogen, the Late Cambrian to Middle Ordovician sedimentary and volcanic rocks are limited to the Charters Towers and Eastern Georgetown regions (Figure 1) (Bain & Draper, 1997). These two provinces represent the only outcrop in Queensland of an extensive deposition system which extended from the Australian craton in Central Australia to outboard of the eastern margin of the craton (Fergusson & others 2007a).

In Queensland, this system records a range of depositional environments from continental in the west to marine in the east (Fergusson & others, 2007a). Many of the detrital zircon populations present in the late Neoproterozoic to Middle Cambrian are also present in the younger rocks indicating either recycling of the older sediment or a similar source. The younger rocks do however, have a population of detrital zircon between 500-600Ma. While some researchers look for an Australian source (Fergusson & others, 2007a), others see a more widespread distribution of similar detrital zircon populations on several continents and postulate a superfan derived from a collision zone between East and West Gondwana (Squire & others, 2006).

In north Queensland, deposition of Late Cambrian to Middle Ordovician sequence is represented by the Seventy Mile Range Group in the Charters Towers region (Henderson, 1986; Berry & others, 1992) and Balcooma Metavolcanic Group in the eastern Georgetown region (Huston, 1990; Withnall, 1989; Withnall & others, 1991). These rocks were deposited in a marine setting (Berry & others, 1992; Monecke & others, 2006), off-shore from the then eastern margin of East Gondwana, (Fergusson & others, 2007a). In New South Wales at this time, mafic volcanics are interpreted as being formed in a continental margin volcanic arc (Glen & others, 1998). Although no rocks in north Queensland can be interpreted as a volcanic arc, the interpreted setting of the Mount Windsor Volcanics as a back arc (Stolz, 1995), is consistent with the regional setting.

**Stratigraphy of the Late Cambrian to Middle Ordovician volcanic and sedimentary sequences.**

The Seventy Mile Range Group comprises four formations, the Puddler Creek Formation, Trooper Creek Formation, the Mount Windsor Volcanics and the Rollston Range Formation (Henderson, 1986, Berry & others, 1992). These have been assigned to the Thalanga Province (Bain & Draper, 1997) (also referred to as the Mount Windsor Province in Berry & others, 1992). The base of the lowest unit, the Puddler Creek Formation is not exposed. This formation comprises continentally derived siltstone, sandstone and greywacke, intruded by numerous mafic dykes. The age is not known precisely, nor is its relationship to the older (?) Cape River Metamorphics. The overlying Mount Windsor Volcanics is a thick sequence of rhyolitic to dacitic volcanics, volcaniclastic rocks and minor andesite deposited in a marine environment. Some of the rhyolites are extensively altered, particularly in the vicinity of the Thalanga VHMS deposit (Paulick & others, 2001). The Trooper Creek Formation, which overlies the Mount Windsor Volcanics, records a change from dominantly felsic magmatism to intermediate to mafic volcanism. Berry & others (1992) recognised growth faulting during deposition of the Trooper Creek Formation, mainly from rapid thickness variations in the sequence. This faulting is considered to be formed during the back-arc extension, during which VHMS mineralisation was emplaced. The youngest unit, the Rollston Range Formation, comprises volcaniclastic sandstone and siltstone (Henderson, 1986). A Late Cambrian to Middle Ordovician age is assigned on the basis of graptolite and trilobite faunas (Henderson, 1986). Henderson suggested that the contact between the Mount Windsor Volcanics and the Trooper Creek Formation approximated the Cambrian to Ordovician boundary. However an unpublished U/Pb SHRIMP age of ~479 Ma for the Mount Windsor Volcanics suggests that they too are Early Ordovician (Hutton & others, 1997).

In the eastern Georgetown region, a fault bounded belt of early Palaeozoic, partly mylonitic metamorphic rocks crops out between the Palaeoproterozoic Einasleigh Metamorphics of the Etheridge Province and the late Neoproterozoic or Early Cambrian Halls Reward Metamorphics. Because of lithological similarities to the Seventy Mile Range Group in the Charters Towers region, the rocks are also assigned to the Thalanga Province (Bain & Draper, 1997). The early Palaeozoic metamorphic rocks include the Balcooma Metavolcanic Group and the Eland Metavocanics.

The Balcooma Metavolcanic Group is a sequence of rhyolitic metavolcanics (volcaniclastics and possibly lava), metasediments (mica schist and quartzite), and minor mafic volcaniclastics and lava. Isotopic dating indicates a Late Cambrian or Ordovician age for metamorphosed porphyry considered to be related to the metavolcanics (Withnall & others, 1991). The rocks occur in two main areas. The best preserved sequence is in the north and hosts the Balcooma, Surveyor and Dry River base metal deposits (probable VHMS) (Huston, 1990). The sequence was metamorphosed in the lower to middle amphibolite facies and is multiply deformed. The Balcooma Metavolcanics are probably equivalent to the Mount Windsor Volcanics in the Charters Towers Region

The Eland Metavolcanics are a sequence of metamorphosed andesitic to basaltic volcaniclastic rocks, but also include minor marble and metachert. The rocks have a strong, commonly mylonitic foliation with a strong stretching lineation. The unit was metamorphosed in the greenschist facies, and the rocks are now predominantly fine-grained chlorite-actinolite-albite schist and greenstone. Many outcrops are unbedded and could have been either lavas or very thick volcaniclastic deposits. However, some outcrops are clearly clastic with elongate, deformed lithic clasts, and others with well-developed layering defined by different proportions of feldspar phenocrysts or alternating pale and dark green bands, were probably bedded volcaniclastic sediments or tuff. The Eland Metavolcanics may be equivalent to the Trooper Creek Formation in the Charters Towers Region.

**Structure and Metamorphism and granitoid emplacement during the Late Cambrian to Middle Ordovician:**

The structural history of the Cape River, Balcooma and Mount Windsor areas has been discussed by Berry & others (1992), Withnall & others (1997a,b), Hutton & others (1997), and Fergusson & others (2005, 2007b).

Within the Cape River Metamorphics, three major deformations are accompanied by cleavage development (Withnall & others, 1997a,b; Fergusson & others, 2005). The dominant fabric is an S2 cleavage, which is steep to vertical and comprises tight to isoclinal folds. The presence of biotite growing in the S2 fabric indicates that cleavage development was synchronous with metamorphism. Metamorphic grade associated with D2, increases deeper in the metamorphic pile reaching a maximum of middle to upper amphibolite grade around the Fat Hen Creek Complex (Fergusson & others, 2005), where low degrees of partial melting and high grade metamorphism produced hybrid magmatites comprising both, melt-derived and metamorphic mineralogy (Hutton & others, 1998; Hutton, 2004). The S2 structures were originally flat lying, before being steepened into their present steep orientation during D3. Flat lying structures during D2 are interpreted as forming during an extensional structural regime (Fergusson & others, 2005), whereas the D3 deformation is considered contractional.

The age of D2 and D3 are best bracketed by ages of the magmatites in the Fat Hen Creek Complex. S2 structures are recognised in some of the Fat Hen Creek magmatites but not in the younger ones (Fergusson & others, 2005). Ages of magmatites range from ~493Ma to ~455Ma, indicating that the extensional D2 event occurred during the Early Ordovician, followed by compression during the Middle Ordovician.

Three deformations are recognised in the Seventy Mile Range Group (Berry & others, 1992; Hutton & others, 1997). As in the older Cape River Metamorphics, the dominant fabric is considered to be S2.

The Ravenswood Batholith (Hutton & others, 1994, ; Hutton & others, 1997) comprises granitoids ranging in age from ~490Ma (Late Cambrian) to about 407Ma (Devonian). In the southern part of the batholith, immediately adjacent to the Seventy Mile Range Group, the I-type, calc-alkaline Schreibers Granite is dated at about 490Ma (Hutton & others, 1994; Hutton & others 1997), which is, within error, synchronous with the adjacent volcanic rocks in the Seventy Mile Range Group. The exact relationship of the granite to the volcanics is not known due to poor outcrop, but they are now adjacent to each other and probably formed in close proximity. This suggests that the granite may have had some influence on mineralisation within the Seventy Mile Range Group.

As noted above, the Late Cambrian to Early Ordovician S-type granites of the Fat Hen Creek Complex about 50km farther west were generated during middle to deep crustal metamorphism and partial anatexis . This metamorphism was thus synchronous with volcanism in the Seventy Mile Range Group and Balcooma Metavolcanic Group, and also with the emplacement of middle to upper crustal I-type granites and VHMS style mineralisation. This juxtaposition of surficial volcanism and back-arc extension, middle to upper crustal granitoid emplacement, and middle to lower crustal high-grade metamorphism, all occurring during Early Ordovician extension, provide a rare opportunity to link upper, middle and lower crustal processes during the same event in close proximity.

**VHMS mineralisation:**

Volcanic hosted massive sulphide (VHMS) deposits occur at several places within the Late Cambrian to Middle Ordovician volcano-sedimentary rocks in the Thomson Orogen in north Queensland (Figure 1). VHMS deposits in the Thalanga Province are classified as "Kuroko type" based on their interpreted position in a back-arc setting. Throughout the province, the deposits occur within mafic to intermediate volcanics, or underlying felsic volcanics, which were deposited in an extensional setting (Berry & others, 1992). The following is a brief description of deposits in the Thalanga Province:

The **Thalanga** deposit has altered rhyolite of the Mount Windsor Volcanics in the footwall and dacite dominated volcaniclastic rocks of the Trooper Creek Formation in the hanging wall. It has a stratiform tabular geometry, underlain by disseminated and stringer mineralisation and minor stockworks, encased in a quartz-sericite-pyrite±chlorite alteration halo. The alteration is metamorphosed to upper greenschist facies yielding a biotite-muscovite-chlorite-pyrite rock (Paulick & others, 2001). The ore comprises sphalerite, pyrite galena, and chalcopyrite, with variable barite. Reserves at Thalanga were of 6.35Mt of Zn-Pb-Cu-Ag rich ore (Table 1).

**Liontown and Handcuff**, (Table 1)are also tabular bodies, but occur within the Trooper Creek Formation with Liontown being near the contact with the overlying Rollston Range Formation (Hutton & others, 1997). Both deposits are zinc-rich and also associated with quartz-sericite-pyrite alteration.

**Waterloo and Magpie** are lens-shaped bodies within the Trooper Creek Formation and are characterised by cordierite-andalusite hornfels facies metamorphism. Other deposits in the belt occur in greenschist to subgreenschist facies metamorphism. The deposits are interpreted to have formed at or near the sea floor in a moderately deep to deep marine environment (Monecke & others, 2006). Deposition of the sulphides was accompanied by emplacement of an explosive dacitic cryptodome which was also subject to hydrothermal alteration associated with the mineralisation.

**Highway and Reward** are pipe-like bodies (Large, 1991) within the Trooper Creek Formation. Primary mineralisation is copper rich with gold grades up to 6g/t (Hutton & others, 1997). Both occur in rhyolitic to rhyodacitic lavas and volcaniclastic rocks with quartz-sericite-pyrite alteration in both deposits, with some chlorite-anhydrite alteration at Highway. Until 2005, the Highway-Reward mine produced 1047.6kg Au, 172,235t of Cu, 1137t of Pb, 2866t of Zn, and 7394.8kg of Ag.

The volcanic-hosted massive sulphide deposits at **Balcooma, Surveyor 1** and **Dry River South** (Huston & others, 1992; Withnall & Grimes, 1995) occur at about the same stratigraphic level in the Cambrian to Ordovician Balcooma Metavolcanic Groups. These deposits are similar in age and character to deposits at Thalanga and elsewhere in the Seventy Mile Range Group in the Charters Towers region (Bain & others, 1990; Morrison & Beams, 1995).

The Balcooma copper-zinc-lead massive sulphide deposit is hosted by a metapelite lens within a meta-arenite sequence. Several lenses of felsic volcaniclastic rocks also occur within the sequence, which has been intruded by felsic sills. Huston (1990) and Huston & Taylor (1990) considered at least three distinct mineralised 'horizons' (two lead-zinc and one copper) to be present. The central copper 'horizon' contains massive pyrite-chalcopyrite and magnetite, within an envelope of variably chloritised, staurolite-bearing metapelite adjacent to a folded quartz-feldspar porphyry body. Copper mineralisation is invariably associated with the porphyry, which is not chloritised and cuts the mineralisation. The upper and lower, zinc-lead-dominated 'horizons' consist of massive sphalerite-galena-pyrite-chalcopyrite, associated with pyritic quartz-muscovite schist which is interpreted as metamorphosed quartz-sericite alteration. Gahnite-bearing quartzite, associated with some of this alteration type, is interpreted as an exhalite. Evidence from mineral textures supports the interpretation that the deposit is a strongly deformed massive sulphide deposit of the volcanogenic type (Huston, 1990).

| **Deposit** | **Tonnage of ore** | **Pb** | **Zn** | **Cu** | **Au** | **Ag** |
|---|---|---|---|---|---|---|
| Thalanga | 6.35Mt | 3.9% | 12.3% | 2.2% | | 99g/t |
| Liontown | 1.8Mt | 2.2% | 6.16% | 0.48% | 0.9g/t | 29g/t |
| Handcuff | 1Mt | 0.2% | 7.4% | 0.4% | 0.2g/t | 8.8g/t |
| Waterloo | 372,000t | 2.8% | 19.7% | 3.38% | 2g/t | 94g/t |
| Highway/ Reward | 3.7Mt | minor | minor | 5.6% | 0.25g/t | minor |
| Balcooma, Surveyor 1, Dry River (Polymetallic ore) | 3.877Mt | 3.9% | 8.94% | 1.1% | 0.74g/t | 81g/t |
| Balcooma, Surveyor 1, Dry River (Copper ore) | 2.342Mt | 0.14% | 0.34% | 3.44% | 0.44g/t | 18g/t |

**Table 1:** Resources in VHMS deposits in the Mount Windsor Subprovince (source of figures from http://www.portergeo.com.au/database; and Queensland Minerals)

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# MINERAL HILL – A MINING CENTRE RENAISSANCE

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**Keywords:** Mineral Hill, Hera, copper, lead, zinc, gold, production, development

## ABSTRACT

Subsequent to its takeover of Triako Resources Limited last year (Triako), CBH Resources Limited (CBH) commenced a review of the Triako assets including the Mineral Hill operation (on care and maintenance) and the Hera base and precious metal deposit.

Mineral Hill displays similarities to low sulphidation epithermal Au and deeper sulphide Cu-Au intrusive related deposits. At least four main styles of Cu-Au mineralization have been identified to date; vein/lode, breccia/vein-network, disseminated ‘shear’ hosted Au-Ag and skarn Cu-Au. Most production to date has been derived from the steeply west-dipping vein/lode deposits of Jacks Hut, and the Eastern and Southern ore zones. Both the vein/lode and breccia/vein-network styles are zoned from Cu-Au to Pb-Zn-Ag within the same controlling feature(s) representing episodic deposition evolution in response to temperature decrease and possible wall rock interaction.

At Mineral Hill, previous modern exploration and production focussed on the Cu-Au sections of the polymetallic system. Following the depletion of the developed Cu-Au ore zones and the continuing low metal prices, the mine closed, leaving behind some Cu-Au resources and substantial, but poorly tested Pb-Zn-Ag potential. Recent strong base metal prices and CBH’s focus on metals such as Zn has resulted in a reassessment of potential operating scenarios. Work has centred on the Iodide and Parkers Hill deposits looking at both underground and open cut options. At current metal prices good tonnages of Cu-Au and Pb-Zn-Ag mineralization may be defined which could justify the reopening of the mine and the possibly expanding the mill from 200,000tpa to 400,000tpa. Initial scoping study figures are encouraging and drilling to confirm the dimensions and grade of the Parkers Hill resource and to provide metallurgical samples has commenced. A decision to reopen the Mineral Hill operation is expected later this year.

The Hera deposit is being evaluated as an additional feed source for the Mineral Hill mill. A revised resource has been calculated totalling 2.2Mt @ 3.4g/t Au, 4.2% Zn, 3.1% Pb, 0.2% Cu and 18g/t Ag. Various development options are being investigated that include an initial exploration decline into the deposit, followed by full scale development and mining. Approvals are now in place for the exploration decline which is expected to commence following the completion of planned infill surface drilling targeting the central high grade Au section of the deposit.

Should Hera go into production, it would form an important additional ore source for the Mineral Hill plant, potentially extending the life of the operation by a number of years. A decision on the development of this deposit is also expected later in 2007.

## INTRODUCTION

CBH Resources is a mid-sized base metal mining company that has grown strongly over the last four years from its humble origins as an opal explorer to now be included within the ASX300.

The company secured its first zinc property, the CML7 lease, site of the new Rasp mine development at Broken Hill in 2001. In 2003 it then purchased the Endeavor Mine at Cobar and in 2005, the Sulphur Springs Cu-Zn deposit in the Pilbara, WA. Recently the company completed a takeover of Triako Resources Limited to gain control of the Hera Pb-Zn-Au deposit near Nymagee and the Mineral Hill operation near Condobolin NSW. The acquisition also delivered the large Sorby Hills Pb-Zn-Ag MVT style deposit near Kununurra, WA.

CBH aims to markedly expand its production over the next 3 years. A key part of this growth is the possible reopening of the Mineral Hill operation and the development of Hera (Figure 1).

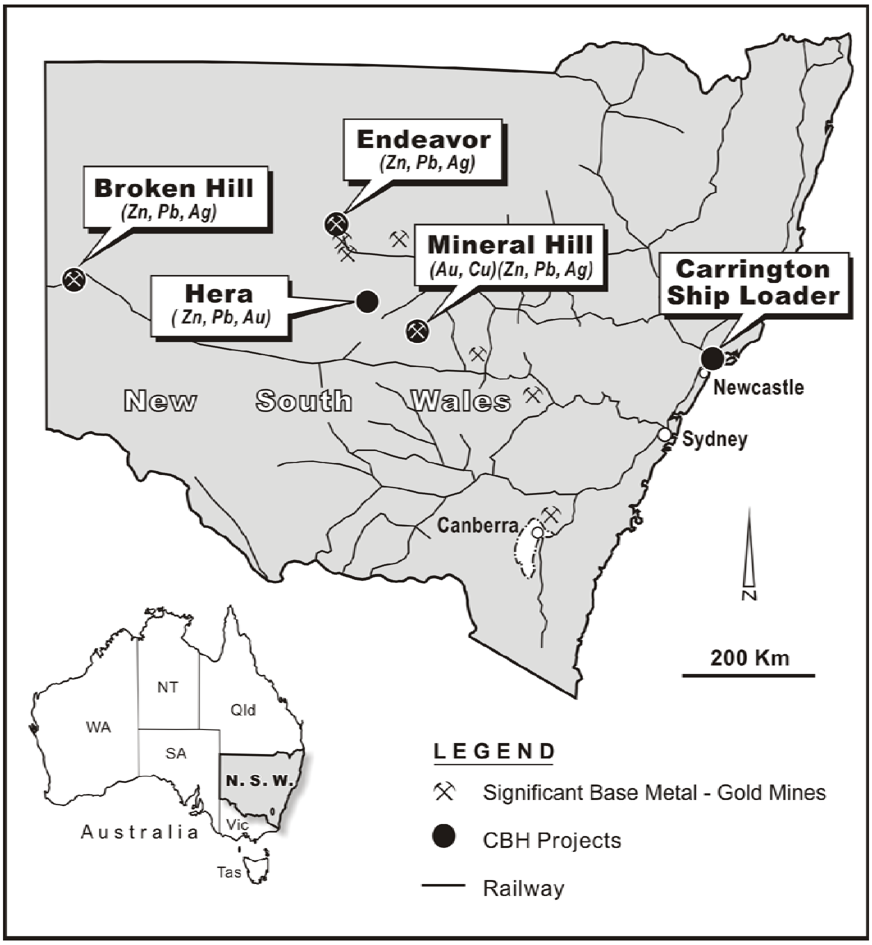


**Figure 1 – Project Locations**

**MINERAL HILL**

The Mineral Hill Mine is located 65 kilometres NNW of Condobolin and 180 km SSE of Cobar in the Central West of NSW. Copper mineralisation at Mineral Hill was first recorded in 1908, but the majority of early mining was carried out over the period 1911 to 1925. Mining during that time, and sporadically through to the 1950s concentrated on the production of Ag and Pb from secondary mineralisation, producing 14,300t @ 24oz/t Ag and 19% Pb, mainly from the Iodide mine (Pittman, E.F., 1913).

In 1989 Triako commenced modern operations with a 200,000tpa concentrator/CIL plant. The mine produced 2.1Mt @ 6.5g/t Au and 1.14% Cu for 360,000 oz Au and 20,400t of Cu in concentrate before being placed on care and maintenance in late 2005. Production had centred on the Cu-Au rich parts of the Mineral Hill system, and had ceased in response to decreasing reserves and the persistent low metal prices up until that time. At the time of closure Mineral Hill published resources were at Parkers Hill and the Southern Ore Zone (SOZ) (total inventory of 377,600t at 4.5g/t Au and 2.7% Cu).

**Geology**

Mineral Hill lies within a north to northwest-trending structural zone (the Canbelego – Mineral Hill Belt) where volcanism and widespread intrusive activity occurred during Siluro-Devonian extensional tectonics associated with the formation of the Cobar Basin.

At the mine, the oldest rock unit recognised is the Ordovician Girilambone Group, a sequence of deep-water turbidites unconformably overlain by the Silurian I-type, felsic to intermediate Mineral Hill volcanics (and sediments), which are in turn overlain by debris flow deposits of the Talingaboolba Formation.

In the immediate mine vicinity, the sequence has been folded into a southeast-plunging anticline, the north-eastern limb of which is displaced by the Parkers Hill Fault. A number of low angle, west-dipping faults have been identified (e.g. Q fault) interpreted to predate a series of northwest-trending, more steeply west-dipping block faults which offset portions of the Mineral Hill anticline and appear to partially bound regions of mineralization (e.g. Parkers Hill).

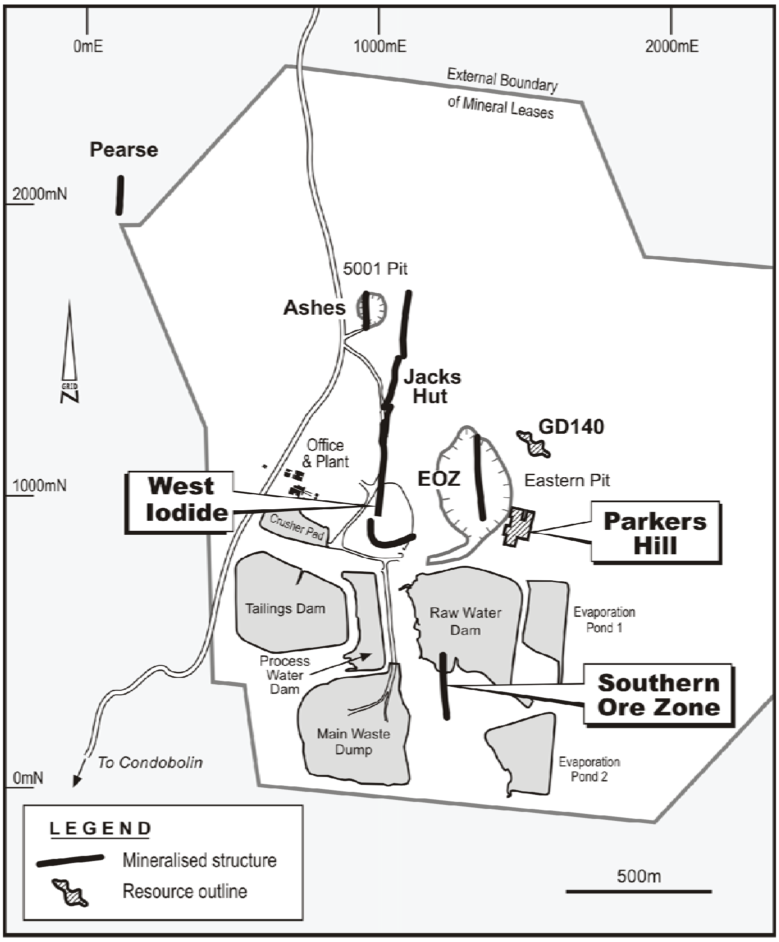


FIGURE 2 – MINERAL HILL MINE INFRASTRUCTURE AND KEY PROSPECTS

Mineralization at Mineral Hill displays similarities to low sulphidation epithermal Au and deeper sulphide Cu-Au intrusive related deposits (Corbett, 2002). At least four main styles of Cu-Au mineralization have been identified to date; vein/lode, breccia/vein-network, disseminated shear hosted Au and skarn Cu-Au.

- Vein/lode – The dominant Cu-Au ore sources occurring as discrete, steeply west-dipping, en-echelon structures within a north-northwest corridor. Cu-Au mineralization hosted within volcanics consists of pyrite-chalcopyrite and fine gold as a late vein phase associated with intense chlorite-quartz-sericite wallrock alteration. Sediment-hosted mineralisation consists of a more replacement (rather than infill) style, dominated by pyrite-chalcopyrite-magnetite-hematite-chlorite. Deposits are generally narrow (<5m), and up to 500m in strike length with a resource size generally less than 1Mt. The main mineralised structures of this style are Jacks Hut, Eastern Ore Zone and the Southern Ore Zone (Figure 2).

- Breccia/vein-network – This style of mineralization is primarily restricted to the Parkers Hill deposit and consists of pyrite-chalcopyrite-chlorite as infill matrix to chloritised wallrock and early quartz vein clasts. A strongly dilatant environment is evident in which repeated activation of the structural regime has resulted in episodic deposition of complex, banded and cross-cutting quartz-sulphide veins with locally highly disrupted orientations. The steeply west dipping Parkers Hill zone is up to 50m wide (highly variable) and can be traced for approximately 150m along strike.
- Disseminated shear hosted Au-Ag – Consists of disseminated to shear-hosted, very fine grained pyrite-arsenopyrite-stibnite-electrum with little or no base metal sulphides and associated illite-chalcedony-carbonate-kaolin alteration. The main mineralised structures are Pearse, Pearse South and Mount Marshall Northeast.
- Skarn Cu-Au – Pyrite-chalcopyrite bearing skarns with heterogeneous Au values present where carbonate rich sections of the Lower Sediments abut known structures such as the Q Fault. No economic material has yet been identified.

Both the vein/lode and breccia/vein network styles can be zoned from Cu-Au to Pb-Zn-Ag within the same controlling feature(s) representing the deposition evolution in response to temperature decrease and possible wall rock interaction (Corbett, 2002 and Morrison, 2005). Pyrite and chalcopyrite are initially joined by galena, sphalerite, bornite and tetrahedrite-tennantite, with increases in As, Sb and Ag and concomitant decreases in Au and Bi. In more 'distal' areas, Cu and Au values are negligible.

Oxidation extends from 45m to 100m below the surface and has generated a wide variety of secondary minerals including chalcocite, covellite, digenite, malachite, azurite, cerussite, anglesite, and pyromorphite. Below the oxide zone is a zone of mixed primary/oxide (supergene) mineralisation between 10m to 40m thick.

## Reactivation Proposal

Recent strong prices and CBH's focus on base metals has resulted in a reassessment of the possible operating scenarios at Mineral Hill. As discussed, previous exploration and production focussed on the Cu-Au sections of the deposit, with little attention directed at base metal mineralisation, despite the indications of good Pb-Zn-Ag potential.

An evaluation of a restart of the operation has commenced, reconfiguring and possibly expanding the mill to initially treat Cu-Au and Pb-Zn-Ag ore from both underground and open cut sources. It is proposed to redevelop the mine in two stages, firstly as a 200,000t/a operation treating ore from underground resources and, subject to further successful exploration, expanding the mill to 400-500,000 t/a and developing a large open cut.

The Mineral Hill plant is generally in good condition and the site remains fully permitted for a 200,000t/a underground operation. Reactivation will involve reconfiguring the plant to treat Pb-Zn-Ag ore, re-establishing mine services and developing new stoping areas.

Three main areas have been identified for production, West Iodide, the Southern Ore Zone (SOZ) and Parkers Hill.

### West Iodide

West Iodide lies within the largest identified mineralised structure in the field. Previous production was derived from the Jack Huts Cu-Au mine in the north and the Iodide Pb-Zn-Ag mine to the south. Drilling has identified strong base metal mineralization within the 300m wide gap between both mines including intersections such as 10m @ 3.4% Pb, 7.4% Pb and 18g/t Ag and 8.8m @ 2.0% Pb, 9.0% Zn and 89g/t Ag (Figure 3). Significantly, these intersections lie just south of the Jacks Hut decline, and should further planned drilling confirm minable ore blocks, these could be accessible with relatively minimal capital expenditure to supply the revamped plant.

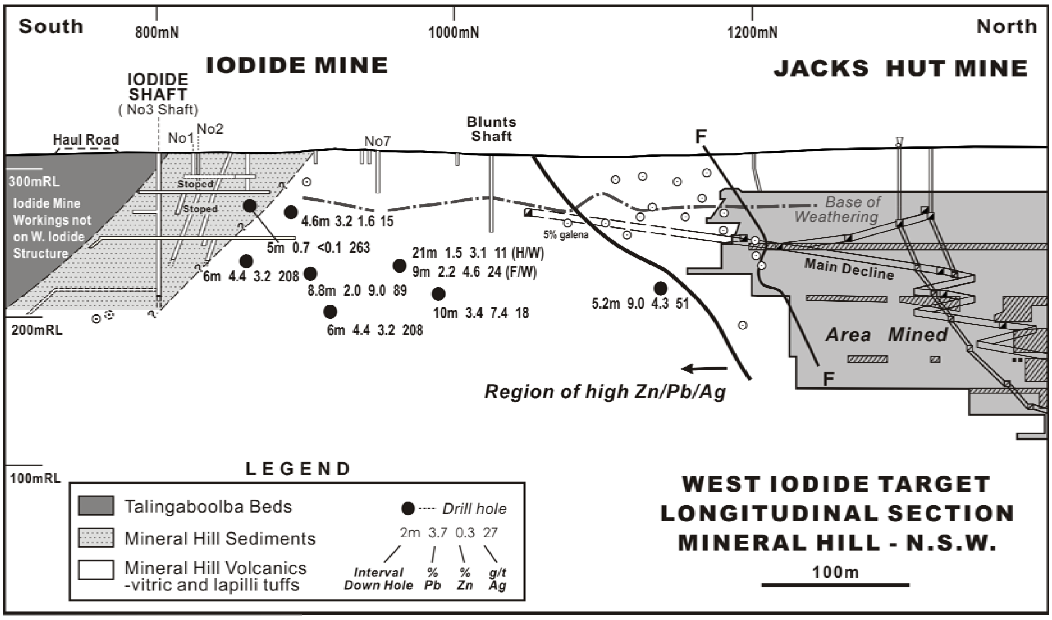


**Figure 3 – West Iodide Project**

### Southern Ore Zone

Decline development accessed and allowed mining of the upper parts of a complex vein/lode Cu-Au system at the southern end of the field. Modest tonnages of high grade Cu-Au resources (120,600t @ 7.2g/t Au and 1.0% Cu) remain to the north and below the current mine workings and it is intended to develop these as a production source.

### Parkers Hill

Previous exploration and development at Parkers Hill defined a high grade Cu (Au) resource (previously estimated at 146,000t @ 0.7g/t Au and 5.4%Cu) from 80m to 130m below the surface in the centre of a large mineralised breccia/vein-network zone. Mineralization consists of a high grade Cu (+_Au) core grading to Cu-Pb-Zn and then to Pb-Zn-Ag dominant material where controlling structures pass through the Mineral Hill sediments.

Recent work has focussed on resource estimation, preliminary metallurgical assessments and evaluation of bulk underground mining and open cut options. Exploration is targeting >1.0Mt of sulphide material that could be mined from Parkers Hill and which may justify at least doubling the mill capacity, providing lower cost structures for the operation. Initial results (based on sparse drilling) have been positive and indicate that an open cut could generate strong cash flows based on the expansion of the resource (at lower cut-off grades), particularly up dip and to the east where there is evidence from old drilling (e.g. GD95) for additional Pb-Zn dominant material.

In addition, work by Triako defined a substantial Pb (Ag) oxide resource that blankets the deposit and which would be mined as part of the sulphide operation. Earlier metallurgical studies indicated that a +30% Pb concentrate could be generated from mining the higher grade section of the oxide blanket which would greatly enhance the economics of an open cut.

As part of the mine feasibility studies, a large drilling programme has now commenced to confirm the resource and provide metallurgical and geotechnical information. Initial studies are expected to take about 4 months and should drilling results from the Iodide and Parkers Hill prospects reach expectations, a decision to reopen the mine at the 200,000t/a rate is expected by end 2007.

## HERA DEPOSIT

Hera was also acquired as part of the Triako takeover. The deposit is located approximately 150km south of Endeavor, or 90km north-north-west of Mineral Hill and was discovered in 1999 by Pasminco who considered it too small before selling it to Triako in 2003. Following several drilling programmes, Triako commenced mine feasibility studies and planning approvals for an exploration decline into the deposit.

## Geology

Hera is located near the south-eastern margin of the Cobar Basin, a fault bounded deep-water basin formed during widespread back-arc extension of the Lachlan Orogen. Locally, mineralization is hosted within the folded and cleaved, monotonous turbiditic sediments of the Amphitheatre Group.

Mineralisation at Hera comprises several steeply west dipping, sub-parallel lenses of intense quartz-sulphide veining, and clast- to matrix-supported breccias containing pyrrhotite, sphalerite, galena, chalcopyrite, gold and occasionally pyrite. Typical zoning and alteration in the Main Lens resource is a strongly silicified central breccia healed with massive sphalerite and galena surrounded by sericite altered host rocks with intense to moderate sulphide veining passing outwards into milky quartz veins then a wide zone of disseminated and veined pyrrhotite (Collins et al, 2005). Coarse visible Au is not uncommon and Au mineralization is believed to have been deposited after base metal sulphides, utilizing the same pre-existing structures/pathways for fluid access.

Drilling, geological and geostatistical work has clearly highlighted the complex and heterogeneous distribution of Au, and to a lesser extent, base metal sulphides within the deposit. Within the Main Lens at least 3 distinct zones of elevated gold have been defined, the largest and highest grade of which is associated with an east-west oriented fault that offsets the Main lode by about 15m. Outside the Main and Far West lenses, there is no strong relationship between base metal grades and Au content. Other lenses within the Hera system can be high Pb-Zn, low Au (e.g. Western Lens), or conversely, high Au, base metal poor (e.g. 1530 lens).

## Resources and Development

Recently, a re-estimation of the resource was completed, utilizing a number of new holes and a revamped geological model generated since the last published estimate in 2005. Total Indicated and Inferred Resources are now estimated at 2.2Mt @ 3.4g/t Au, 4.2% Zn, 3.1% Pb, 0.2% Cu and 18g/t Ag of which about half is hosted within the Main Lens.

At present, Hera has a strike length of about 600 metres and a vertical extent of 350 metres. Good potential exists to expand this to the north, particularly around the high-grade Far West lens.

The deposit is blind with the top of known sulphide mineralization approximately 80 metres from the surface. Recent drilling has discounted the open cut potential and confirmed the presence of spotty visible gold within the central section of the Main Lens. Infill drilling is still progressing with the aim of firming the resource model within the Main Lens as a precursor to mine development.

Development options are currently under review, based on an initial exploration decline into the deposit, followed by full-scale development and mining. All approvals are now in place for the exploration decline which may commence following the completion of the infill surface drilling targeting the high grade gold areas of the deposit.

Should Hera go into production, it would form an important additional ore source for the Mineral Hill plant, extending the life of the operation by a number of years. Initial production estimates are for production at 200 to 250,000 t/a dependent on the future conversion ratio of resources to reserves. A decision on the development of this deposit is also expected later this year.

## CONCLUSION

Mineral Hill and Hera are an important part of the company's future growth plans in NSW. Work programmes and mine feasibility studies are well advanced to assess the viability of these projects. Should drilling and feasibility studies prove successful, decisions to reactivate the Mineral Hill plant and commence an exploration decline into Hera should be made by the end of 2007. Anticipated production levels for both projects would yield Cu-Au and Pb-Zn-Ag concentrates in excess of 35,000t/a Zn metal equivalent.

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# THE COWAL GOLD CORRIDOR – OPENING OTHER DOORS

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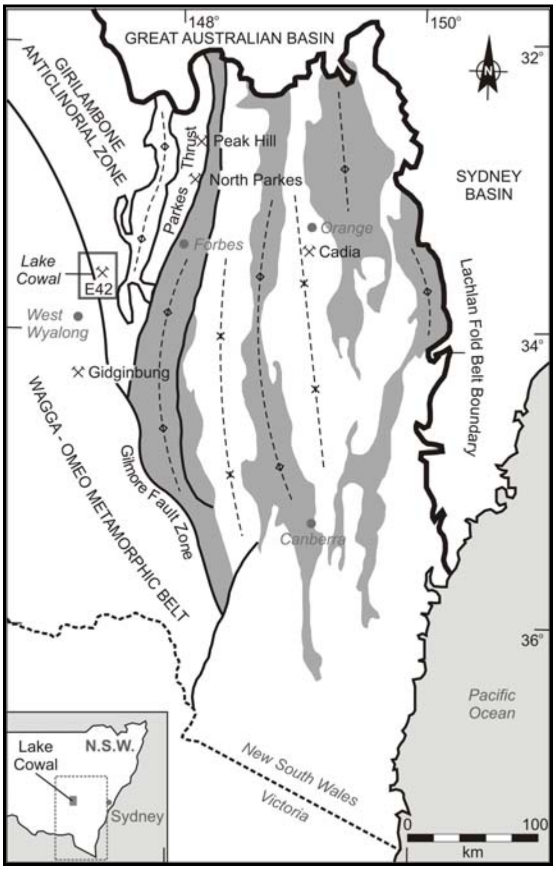
**Key Words:** epithermal, low sulphidation, carbonate-base metal gold system, supergene mineralisation, Cowal, E41, E42, E46.

## Introduction

The Cowal Gold Corridor, is a NS trending zone within the Barrick Cowal Gold Project, that contains three structurally controlled magmatic arc epithermal vein gold deposits (E41, E42 and E46) of Ordovician age. The deposits were discovered in 1988 on the western edge of Lake Cowal, approximately 35 kilometres NNE of West Wyalong in central NSW. The mineralisation style is considered to have affinities with low sulphidation carbonate-base metal gold systems forming between porphyry and epithermal environments (Corbett and Leach, 1996). The E42 deposit is currently being mined by open cut methods. As of December 2006, the E42 Proven and Probable reserves totalled 78.6 Mt at 1.26 g/t Au for 3.19 million contained ounces. Current production at E42 is approximately 240 000 ounces per annum. The E41 and E46 gold deposits are located approximately 1km south and north of the E42 pit respectively, and are currently under further evaluation for their resource potential.




## Regional Geology

The Cowal Gold Project is located within the western portion of the Girilambone Anticlinorial Zone, which is a structural unit of the Lachlan Fold Belt separated from the lower Palaeozoic Wagga-Omeo Metamorphic Belt by the large crustal scale Gilmore Fault Zone (Figure 1). The Cowal deposits occur near a splay of this structure and near the western margin of the 40 kilometres long and 15 kilometres wide Ordovician Lake Cowal Volcanic Complex. The Volcanic Complex contains calc-alkaline to shoshonitic high-level intrusives hosted in epiclastic volcaniclastic sediments and lavas of andesitic to dacitic composition.

**Figure 1:** Location map and regional geological map of the Lachlan Fold Belt (after Suppel and Scheibner, 1990).

**Gold Corridor Geology**

The Cowal Gold Project area is almost totally covered by Quaternary lacustrine sediments. As such, regional geology has been largely defined by interpretation of regional magnetics and drill hole geology.

The project area is characterised by a strong linear NS fabric within the aeromagnetics on the western side of the Ordovician volcanic complex. The Cowal Gold Corridor occurs in this area and hosts all the currently known economic gold deposits within the Cowal Gold Project. The corridor is approx 15 kilometres long and 3 kilometres wide with economic gold mineralisation confined to date to the northern 4 kilometres of the corridor (Figure 3). The corridor is bounded on the western side by the NS orientated Booberoi Fault and on the eastern side by a subsidiary parallel structure within the volcanic complex. Both these structures are identified in the magnetics as linear aeromagnetic lows.

The deposits are aligned NS along the corridor separated by a regular spacing of approximately 1 kilometre. All three deposits are closely spatially associated with the Muddy Lake diorite/gabbro sill (6kms long, approximately 1km wide and 350m thick) that occurs within and is aligned sub parallel to the corridor. The sill is fractionated producing a suite of rocks varying from mafic diorites to monzodiorite to quartz monzonite in composition. Age dating indicates these intrusives are related to the middle to late Ordovician Phase 2 intrusions of Glen et al (2003). The sill intrudes a sequence of comagmatic variably reworked coarse to fine grained volcaniclastics, with some interbedded flows and flow breccias of trachyandesite composition. This sequence overlies a finer grained sequence consisting of volcanic siltstones and mudstones. At the southern end of the Gold Corridor occurs a large granodiorite complex (5km diameter) that hosts porphyry Cu mineralisation (E39 and E43 prospects). Age dating indicates this intrusive is Late Ordovician in age and related to the Group 3 porphyry intrusives of Glen et al, 2003.

**Structure**

The Benambran Orogeny produced a broad anticlinal structure within the Cowal Volcanic Complex creating relatively open folds, plunging shallowly to the NNW. The folds are displaced by a number of NS striking reverse faults (both steep E and W dipping) which were active through the Benambran and later during the Tabberabberan Orogeny. SE-NW directed compression during the late early Silurian part of the Benambran Orogeny resulted in a sinistral strike-slip system dominating and this event was responsible for the structures controlling the Cowal gold deposits (SRK, 2005). Post mineralisation thrusting occurred during the Tabberabberan Orogeny along NS and NE trending faults.

A NW-SE structural trend is clearly evident at the E42 and E46 deposits as well as throughout the volcanic complex. This direction is a long-lived structural trend in the Lachlan Fold Belt that may have been active during volcanic deposition focussing Ordovician calc-alkaline and alkaline intrusions into the upper crust from lower crustal or upper mantle sources. The sinistral strike-slip deformation along the NS structures creates dilational sites for ore deposition on the NW structures. However, at E42 intersections of early NW (related to the Marsden Lineament) and later NS structures appear important in the location of this gold deposit.

This structural connection is best evidenced by studying the orientations of faults and dykes. Pre, syn- and post- mineralisation dyke swarms (dominantly intermediate and mafic including lamprophyric) occur within mineralised zones and follow the above structural directions. Studies of these fault/dyke zones thus have direct implications for understanding the structural controls and targeting depositional sites and channel-ways for mineralising fluids.

**Ore Deposit Types**

Three distinct deposit types occur within the gold corridor:

- Supergene Oxide Zones  Variable development of gold enriched supergene blankets occur at the base of Quaternary transported lacustrine cover, saprolite-saprock transition and at the base of oxidation. These flat lying blankets can be up to several hundred metres wide and 1m to 15m thick. They average between 1-2 g/t Au and are interpreted to have formed as a result of remobilisation of gold during weathering processes in association with water table fluctuations. More extensively developed oxide blankets occur above the E41 East Pod (Figure 2), E42 and the E46 West Pod. The oxide blankets at the E42 deposit constitute 15% of the ore reserve.

- Sheeted Vein Systems  In several deposits namely E42 and E41 (East Pod), the two largest individual deposits, gold occurs dominantly in thin quartz veins in a moderately dipping sheeted vein system (Figure 2). These extensional veins are generally less than 1cm in width and are composed of combinations of quartz, carbonate and adularia together with pyrite and base metals namely sphalerite, galena and chalcopyrite. They generally lack prominent alteration selvages. The sheeted veins dip moderately to the SW in the E42 deposit and to the SSE at the E41 deposit. At the E41 East Pod these veins occur dominantly within volcaniclastics but at the E42 deposit sheeted veins occur within a variety of rock types including volcaniclastics, lava and diorite.

The sheeted vein deposits are thought to have formed within competent lithologies where an inflection in a controlling fault has generated a zone of increased fracture density. Steeply dipping narrow (<1m) normal faults acting as feeder structures to the sheeted vein style mineralisation and can host high grade quartz sulphide breccias (QSB) lodes. These QSB's are poddy and discontinuous formed by repeated episodes of brecciation and mineralisation.

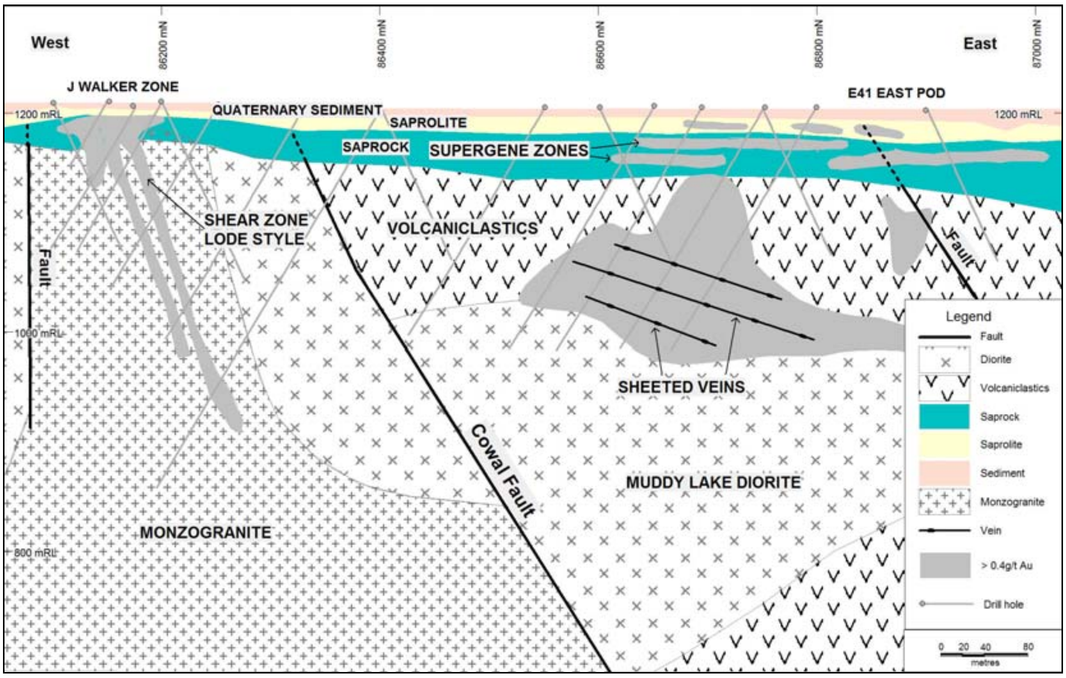



**Figure 2:** Schematic section of styles of mineralisation at E41

- Shear Zone Lode Style  Two pods of mineralisation namely the J Walker zone (Figure 2) and the E46 East Pod occur as steeply dipping shear lode style mineralisation. These lodes in general parallel the NS structures controlling the gold corridor and dip steeply to the east or west. Both deposits have strike lengths of approx 600m and widths from 1-25m. Mineralisation consists of veining, disseminations and replacements within high angle ductile to brittle-ductile shear zones. Some patchy extensional veining occurs within more competent units, marginal to the shear zones. Strong to intense sericite ± silica ± pyrite alteration is associated with the shearing and mineralisation overprinted by ankerite as a final alteration. Overall grades are 0.5-2 g/t within disseminated and stringer pyrite zones but high grade narrow lodes of QSB can have visible gold and average several ounces Au. QSB's are more prevalent at the E46 (East Pod).

**Alteration**

There are three assemblage stages of alteration throughout the deposit:

1) **Calc-Potassic** This high temperature alteration phase in the Cowal deposits is of limited extent but observed in the early hydrothermal alteration of the diorite sill producing actinolite–magnetite–albite-chlorite assemblages. Actinolite, magnetite and chlorite have pseudomorphed former mafic minerals within the diorite. Garnet is also associated with this alteration assemblage (Zukowski, 2007).

2) **Propylitic** Propylitic alteration assemblage which includes chlorite-epidote-calcite occurs as a background incipient and select pervasive style of alteration in all rock types throughout the Gold Corridor. Advanced propylitic is a transition development stage of propylitic producing black chlorite ± calcite ± pyrite ± hematite ± leucoxene ± K-feldspar ± sericite assemblage. This alteration occurs as veinlets, clots and disseminations in close proximity to mineralised structural fluid conduits such as shears and dilational veins.

3) **Phyllic** The phyllic alteration assemblage is dominated by sericite ± silica and carbonate. The carbonate composition changes from calcite in the propylitic stage to ankerite within the phyllic (sericite-carbonate) zone. Sericite pervasively bleaches and destroys original rock texture and overprints all earlier alteration types. At the E42 deposit sericite forms an overlying thick blanket within the Upper Volcaniclastic Unit. This alteration style is also associated with fault zones, dykes, tectonic and hydrothermal vein breccias. It can also form as a vein selvage style of alteration. Phyllic alteration is a dominant alteration assemblage present in the E46 deposits and the E41 J Walker Zone and shows a strong spatial association with Au mineralisation in these deposits.

Late stage alteration minerals include ankerite, carbonates, epidote, chalcedony and prehnite.

**Ore Genesis**

Gold mineralisation at Cowal is structurally controlled and deep epithermal in character. Deposits are formed as a result of interplay between structure, rock competency and chemical reactivity. The structure and mineralisation crosscuts all major rock types including the diorite sill and granodiorite, apart from some post mineralisation dykes. All three Gold Corridor deposits are associated with second and third order NS structures related to the Gilmore Suture and Booberoi Fault and intersecting NW structures.

Despite variation in deposit styles, the main phase of gold mineralisation is always paragenetically late occurring predominantly within fractured pyrite in close association with base metal sulphides (sphalerite, galena and chalcopyrite) and gold and silver tellurides. According to the magmatic arc Au-Cu mineralisation classification (Corbett and Leach, 1996) the Cowal deposits can be classified as a carbonate-base metal gold system.

This paragenetically late gold mineralisation appears to be intimately associated with the late stage overprinting sericite-ankerite alteration possibly as a result of rapid exhumation of the system. Microscopic studies indicate that the carbonate-base metal-gold event overprints early sheeted quartz ± carbonate – pyrite veins with both quartz and pyrite structurally deformed and the base metal-gold mineralisation occurring predominantly within fractured pyrite. QSB's also exhibit similar mineralogy and can contain high gold grades because they occur in narrow fault structures that have undergone several episodes of brecciation and mineralisation.

The alteration paragenesis changed from a dominant chlorite assemblage to a dominant sericite ± silica ± ankerite assemblage, causing cementation of ductile structures and brittle deformation in the form of brecciation and fracturing during late-stage mineralisation development.

The majority of volcanic and intrusive rocks at Cowal have been classified as calc-alkaline but the hydrothermal phases appear to have alkalic affinities developing deep epithermal style mineralisation. This finding is supported by age dating, sulphur isotope results and presence of tellurides, hematite, gypsum and extensive carbonate alteration associated with mineralisation.

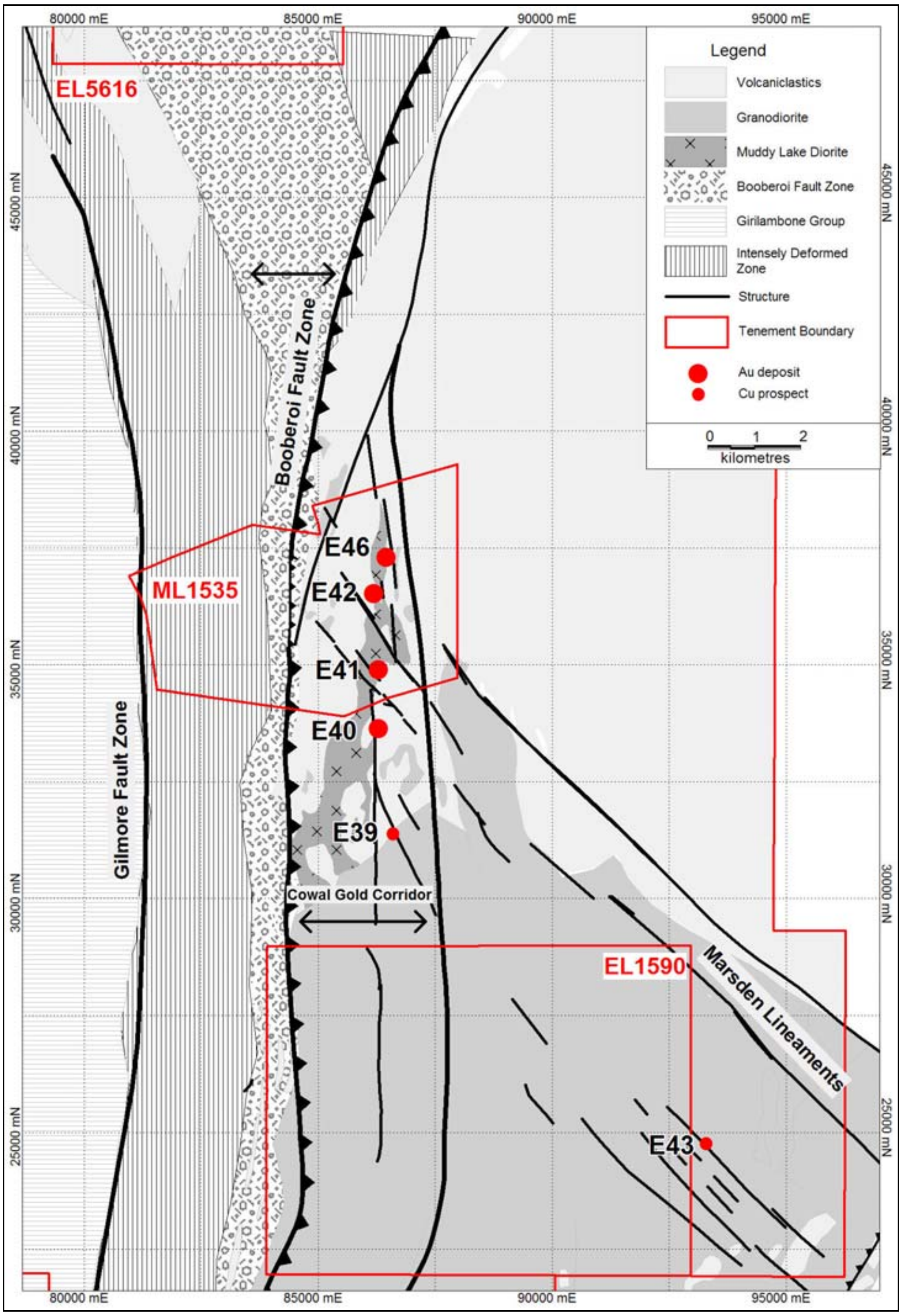



**Figure 3:** Local Geology of the Cowal Gold Corridor

## Acknowledgements

The management of Barrick Gold of Australia thank SMEDG-AIG-DPI for the permission to present this paper. The authors acknowledge the invaluable input made by the many past and present geoscientists who have contributed to the understanding of the Cowal gold deposits.

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# MINERALISATION STYLES AT THE CONRAD SILVER MINE

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**Key Words**: Conrad, silver, lead, zinc, copper, tin, indium, veins, mine, drilling

## Abstract

Conrad was a substantial silver mine in the past, and Malachite Resources NL is currently conducting resource drilling and pre-development studies with a view to putting the mine back into production. This paper details the current state of understanding of the main mineralisation styles at Conrad (ie. quartz-massive sulphide vein style and greisen style) based on old mine records and recent drilling data.

## Introduction

The Conrad silver-rich polymetallic vein system is located in the Palaeozoic New England Fold Belt of New South Wales approximately 20km south of the town of Inverell (Figure 1). The Conrad mine and environs are held under mining leases and exploration titles by Malachite Resources NL, which is conducting drilling programs and associated pre-development studies with a view to putting the mine back into production. The information on which this paper is based comes from historical mine records as well as from the assaying and geological logging of around 6,000m of drill core.

## Project History

The Conrad mine was the largest silver producer in the New England region of New South Wales, with about 3,500,000 ounces (108,500 kg) of recorded silver production, together with by-product lead, zinc, copper and tin. The mine produced approximately 175,000 tonnes of ore at an average grade of 600 g/t (20 oz/t) Ag, 8% Pb, 4% Zn, 1.5% Cu and 1.5% Sn, which at today's metal prices has a silver-equivalent grade of approximately 2,000 g/t Ag (65 oz/t). The vein system was worked continuously underground over a strike length of about 1.5km and to a maximum depth of 260 m, with four shafts and seven main production levels.

The Conrad lode was discovered in weathered massive sulphide outcrops in 1888. Underground mining commenced in 1891 and continued until 1912, when the mine closed due to industrial relations problems relating to management's intention of paying the workforce under individual work contracts rather than the wages system that existed at the time. During this first phase of mining the main metals recovered were silver, lead and tin, with sulphide concentrates produced by simple gravity methods, some of which were smelted on site. The second phase of mining activity commenced in 1947 when Broken Hill South Limited optioned the property, deepened the Conrad shaft, developed two additional production levels, conducted metallurgical testwork, and built a flotation mill. Broken Hill South operated Conrad as a lead mine from 1955 to 1957 (essentially as a satellite operation to their flagship South Mine at Broken Hill), with a cut-off grade of 8% Pb during a period of booming lead prices following the Second World War. The mine finally closed when the lead price collapsed in 1957, and the workings have been flooded since then.

The only recorded modern exploration at Conrad prior to Malachite acquiring the property in 2002 was an IP geophysical survey and four short core holes drilled on the southeastern extension of the vein system in 1969. Since commencing exploration in 2003, the company has completed over 50 drill holes from surface (mainly core but some reverse circulation percussion holes). Drill hole targeting has been based in part on the results of both surface and down-hole electromagnetic geophysical surveys, as the Conrad lodes are strongly conductive due to their massive sulphide character.

## Geological Setting

The Conrad district lies in the Central Block of the southern New England Fold Belt. Intrusive rocks comprising the Early Triassic Tingha Monzogranite and Gilgai Granite underlie the Conrad district (Brown, 2006). The former is a porphyritic hornblende-biotite monzogranite, while the latter is an equigranular to porphyritic biotite leucomonzogranite. These rocks form a roughly circular, composite pluton of about 70km diameter, which intrudes low grade metasedimentary rocks of the Early Carboniferous Sandon Beds to the north and south, S-type granitoids of the Bundarra Plutonic Suite to the west, and felsic volcanic rocks of the Late Permian Wandsworth Volcanic Group to the east (Brown and Stroud, 1997). The Gilgai Granite, which has intruded the Tingha Monzogranite, is the main unit of interest as it is a highly mineralised, fractionated I-type pluton. The Gilgai Granite is associated with a large number of disseminated and vein-type cassiterite and polymetallic sulphide occurrences with diverse metal associations (Sn, Pb, Zn, Cu, Ag, As, Mo) in the region. District-scale zoning in the distribution of the deposits is evident: silver and base metal-rich lodes occur within 4 to 6 km of the western margin of the composite pluton, while tin-rich lodes occur largely near the centre (Brown and Stroud, 1993).

The Conrad mine occurs at the northwestern end of a northwest-southeast striking fault zone, which transects the Tingha Monzogranite and Gilgai Granite on the western side of the composite pluton. The host structure can be recognized as an aeromagnetic lineament and traced over a strike distance of at least 7.5 km (Figure 1). Similar parallel structures occur nearby and may host similar lode systems.

The Conrad vein system differs from the majority of the polymetallic deposits in the district in its comparatively large size, style of alteration, ore mineralogy, and particularly in the persistence of the mineralisation both along strike and at depth (Brown and Stroud, 1993). The lodes are hosted by coarse grained, feldspar and biotite-bearing leucomonzogranite intruded by a finer grained, less porphyritic to equigranular microgranite phase of the Gilgai Granite.

Historic mining at Conrad was developed on a set of narrow sub-vertical fault-filling fissure veins (Figure 2), with underground hand-held mining exploiting only the central high grade core of each lode, which mine records indicate averaged 0.6m wide. Recent drilling by the company has confirmed the presence of a lower grade mineralised envelope to many of these high grade cores.

## Mineralisation Styles

Two styles of silver-rich polymetallic mineralisation are developed at Conrad: (1) the quartz-massive sulphide veins which have been mined historically, and (2) the recently discovered greisen-hosted zone.

<u>Massive sulphide veins</u>

The three main lodes (Conrad, King Conrad and Allwell's) consist of varying proportions of vein quartz and massive to semi-massive sulphides, commonly with the greater part of the quartz forming a central core to each vein. Late stage carbonate has been noted filling the central section of the quartz core in some sections of the lodes. All three lodes dip sub-vertically.

Sulphide mineralisation is represented by argentiferous galena, sphalerite, chalcopyrite, arsenopyrite, pyrite, pyrrhotite, cassiterite, stannite, and minor bismuthinite, tetrahedrite, marcasite and molybdenite are noted in the mine records. These sulphides are generally developed in irregular bands and massive coarse grained aggregates with minor quartz, sericite, and chlorite gangue. The sulphide banding and symmetrical zonation appear to be best developed in the King Conrad lode. In addition to the five metals recovered historically (Ag, Sn, Cu, Pb and Zn), recent assaying of drill samples has detected significant levels of indium. The mineralogical host of indium has not yet been determined, but the very high correlation between zinc and indium in drill core assays supports the view that sphalerite is the host, either as an included mineral phase or in solid solution.

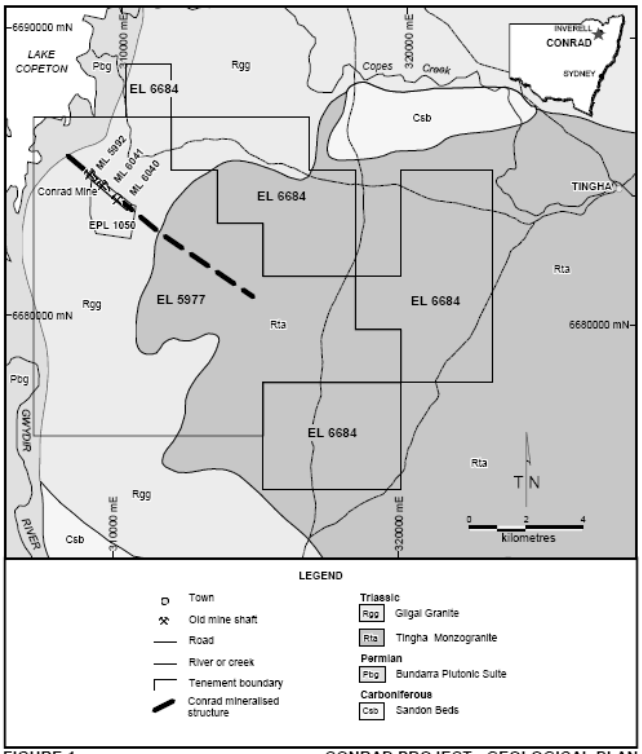


FIGURE 1 CONRAD PROJECT - GEOLOGICAL PLAN

Phyllic alteration represented by an assemblage of quartz, sericite/muscovite, chlorite and pyrite surrounds the main lodes in narrow, irregular envelopes extending up to several metres into the granite wallrocks. Commonly these envelopes carry significant disseminated and veinlet argentiferous base metal mineralisation.

The Conrad lode is the largest of the three main lodes, and the majority of the historic mining has taken place on this lode. It has a strike length of 1,500m and a variable width, with recent drilling intersecting true widths of up to 1.2m across the high grade core, enclosed by lower grade mineralised envelopes up to 6.3m in true width. It has been mined locally to a maximum depth of 260m, and is open along strike and down-dip.

The King Conrad lode forms a splay off the Conrad lode near its northwestern end (Figure 2), has a strike length of 400m, and is open to the northwest and down-dip. It has been mined only in the 200m section nearest to where it joins the Conrad lode, but only to a maximum depth of 120m. Recent drilling has intersected true widths of up to 0.9m across the high grade core, enclosed by lower grade mineralised envelopes up to 8.4m in true width. Grades in the lode increase as it approaches the intersection with the Conrad lode. It is characterised by symmetrical sulphide and quartz zonation within the lode itself, as it has a comb-structured quartz core enclosed on each side by banded massive sulphides. Typically the outer margins of the King Conrad lode consist of arsenopyrite and minor galena, grading into a mixed polymetallic sulphide zone adjoining the quartz core. The mixed sulphide zone includes variable amounts of galena and sphalerite with minor pyrite, chalcopyrite, pyrrhotite, cassiterite and stannite. Chalcopyrite commonly occurs at the boundary of the mixed sulphide zone and the quartz core, and locally replaces sphalerite. Polished section studies of drill core samples indicate a paragenetic sequence in which arsenopyrite was the first mineral to precipitate, followed by cassiterite, and finally the mixed polymetallic sulphides precipitated, partly overgrowing and replacing the earlier formed minerals.

Allwell's lode was the smallest yet the highest grade of the three massive sulphide lodes mined historically, consisting mainly of galena and sphalerite. It has a strike length of about

70m and is open down-dip. Recent drilling suggests that it is a splay off the King Conrad lode, and may cross the northwestern extension of the Conrad lode (Figure 2).

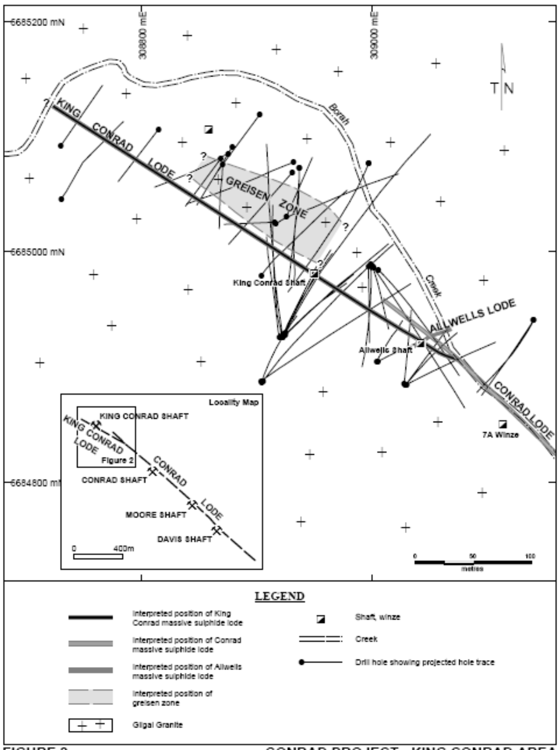

FIGURE 2 CONRAD PROJECT - KING CONRAD AREA

Greisen Zone

This zone was discovered during the company's 2006 drilling program. Although it extends to surface, due to its mineralisation style and lower grade it was not mined, and was probably not known, during previous mining eras. It has a strike length of 150m, a width of about 50m, and is open at depth (Figure 2). The Greisen zone consists of coarse aggregates of quartz and muscovite replacing granite, and hosts the same range of base metal sulphides as occurs in the massive sulphide lodes, but occurring in disseminated, veinlet and locally massive forms.

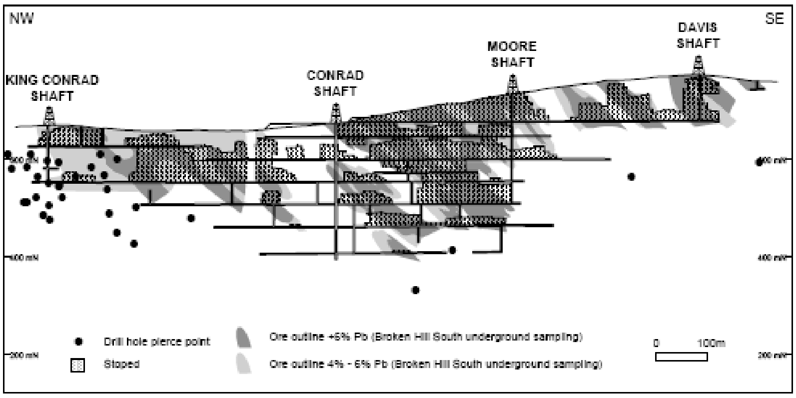

FIGURE 3 CONRAD MINE LONGITUDINAL SECTION

**Lode Metal Associations**

The lodes generally consist of similar sulphide mineral assemblages, and patterns of metal zonation within a lode or between lodes probably exist but have not yet been confirmed. However a review of the geochemical correlation coefficients for drill core assays within the Conrad lodes suggests some mineralogical contrasts between the lodes (Table 1).

| Lode | Strongest Correlation | Likely Mineral Host |
|---|---|---|
| King Conrad<br>(53 samples) | Sn-Cu (0.92)<br>Zn-In (0.90)<br>Pb-S (0.86)<br>As-Sb (0.85)<br>Ag-Cu (0.79)<br>Ag-Pb (0.78) | Stannite<br>Sphalerite<br>Galena<br>Tetrahedrite/Tennantite<br>Tetrahedrite<br>Galena |
| Conrad<br>(15 samples) | Sn-Cu (0.98)<br>Zn-In (0.96)<br>Mo-Co (0.88)<br>Sn-In (0.86)<br>Cu-In (0.83)<br>Ag-Cu (0.81)<br>Ag-Sn (0.81)<br>Ag-Pb (0.63) | Stannite<br>Sphalerite<br>?<br>?<br>?<br>Tetrahedrite<br>?<br>Galena |
| Greisen<br>(377 samples) | Ag-Sb (0.96)<br>Ag-Cu (0.95)<br>Cu-Bi (0.93)<br>Ag-Pb (0.92)<br>Sn-Pb (0.91)<br>Sb-Pb (0.91)<br>Sb-Cu (0.90) | Tetrahedrite/Silver sulpho-salts<br>Tetrahedrite<br>Tetrahedrite/Silver sulpho-salts<br>Galena<br>?<br>?<br>Tetrahedrite |

**Table 1 Conrad Project - Drill Sample Correlation Coefficients**

The association of silver and tin seen at Conrad is a characteristic of the granite-related mineralisation in the Inverell district. For example, the company has found silver in the tin-bearing greisen lodes at Newstead (approximately 30 km northeast of Conrad in the Elsmore area).

**Ore Controls**

The Conrad vein system is hosted by a homogeneous body of granite, and the principal control on the lodes are the faults hosting the Conrad, King Conrad and Allwell’s lodes. Although the lodes themselves are quite extensive within the plane of each fault, a very regular pattern of ore shoots exists within the lodes where mining has taken place, as demonstrated by underground sampling by Broken Hill South (Figure 3). These shoots consist of higher grade mineralisation that plunge to the southeast within the plane of the fault. It is believed that these shoots are controlled by local jogs in the strike and dip of the fault plane (and hence the lode), as no secondary structures which cross-cut the main faults (and would be expected to control the plunge direction of an ore shoot) have been reported in the mine records, mapped on surface, or detected in drill core. Figure 3 also shows the distribution of the company’s drill hole intersections in the massive sulphide lodes.

The Greisen zone strikes sub-parallel to the King Conrad lode, and is located along strike from the northwestern end of the Conrad lode (Figure 2). It is believed to be controlled by a broad set of fractures parallel to the fault hosting the King Conrad lode, and the fluids which formed it may have used the fault hosting the Conrad lode as a conduit.

**Conclusions**

The Conrad vein system is hosted by granite and consists of silver-rich polymetallic lodes occurring as both quartz-massive sulphide veins and broader greisen zones. These lodes occur along major faults, and the higher grade sections of the massive sulphide lodes occur in a regular set of ore shoots which are believed to be controlled by jogs in the strike and dip of the faults.

The zoned massive sulphide veins indicate a paragenesis from early arsenopyrite at the margins of the veins, through a zone of mixed silver-rich base metal sulphides, to a late central quartz core, suggesting multiple phases of ore deposition.

**Acknowledgements**

This paper is based on the valuable contributions made by a number of current and former Malachite geologists to the current understanding of the mineralisation at Conrad. These include Brad Wake, Brett McKay, Garry Lowder, Bianca Pietrass-Wong, Mark Derriman and Oliver Bayley, and the figures were drawn by Chris Bannerman.

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# CHARACTERISTICS OF PORPHYRY COPPER-GOLD MINERALIZATION IN THE GIDGINBUNG VOLCANICS.

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**Key Words**

Porphyry copper-gold, Ordovician, Gidginbung Volcanics,

## Introduction

Six porphyry copper-gold systems have been identified in the Gidginbung Volcanics, namely the The Dam, Estoril, Monza, Culingerai, Mandamah, and Yiddah prospects. Only one has a calculated JORC compliant resource, The Dam 28 Mt @ 0.6 g/t Au, 0.4% Cu, and none are considered economic at this stage. They form a distinctive style which is somewhat different to the much studied Northparkes and Cadia systems.

This group of porphyry copper-gold deposits has received negligible academic study in comparison with the other productive porphyry regions in the East Lachlan, due in part to the lack of an economic resource. Detailed study has been restricted to the high sulphidation gold deposit at Gidginbung by Allibone (1995), an oxide resource of 700,000 ounces mined until 1996.

## Geology

The Ordovician aged Gidginbung Volcanics form a NNW striking linear belt 50 kilometres in length on the western margin of the Eastern Lachlan Fold Belt, where it abuts the Gilmore Fault Zone (Figure 1).

Post Ordovician thrusting produced four north south striking parallel belts of Ordovician volcanics in the Temora region, the Gidginbung, Belimebung, Boonabah and Currumburrama Volcanics. All four volcanic belts are poorly explored due to the lack of outcrop and relatively thick transported cover sequences. The units east of the Gidginbung Volcanics are interpreted to be Ordovician in age although very little is known about these units, as they neither crop out and there is limited age control to fully identify them. The areal extent of all these volcanic belts is defined by positive magnetic anomalies, and their boundary relationships are unknown. The volcanic belts form part of the Narromine-Junee volcano-plutonic belt in the Eastern Lachlan Fold Belt. The Ordovician volcanic belts are separated by Silurian sediments of the Yiddah Formation.

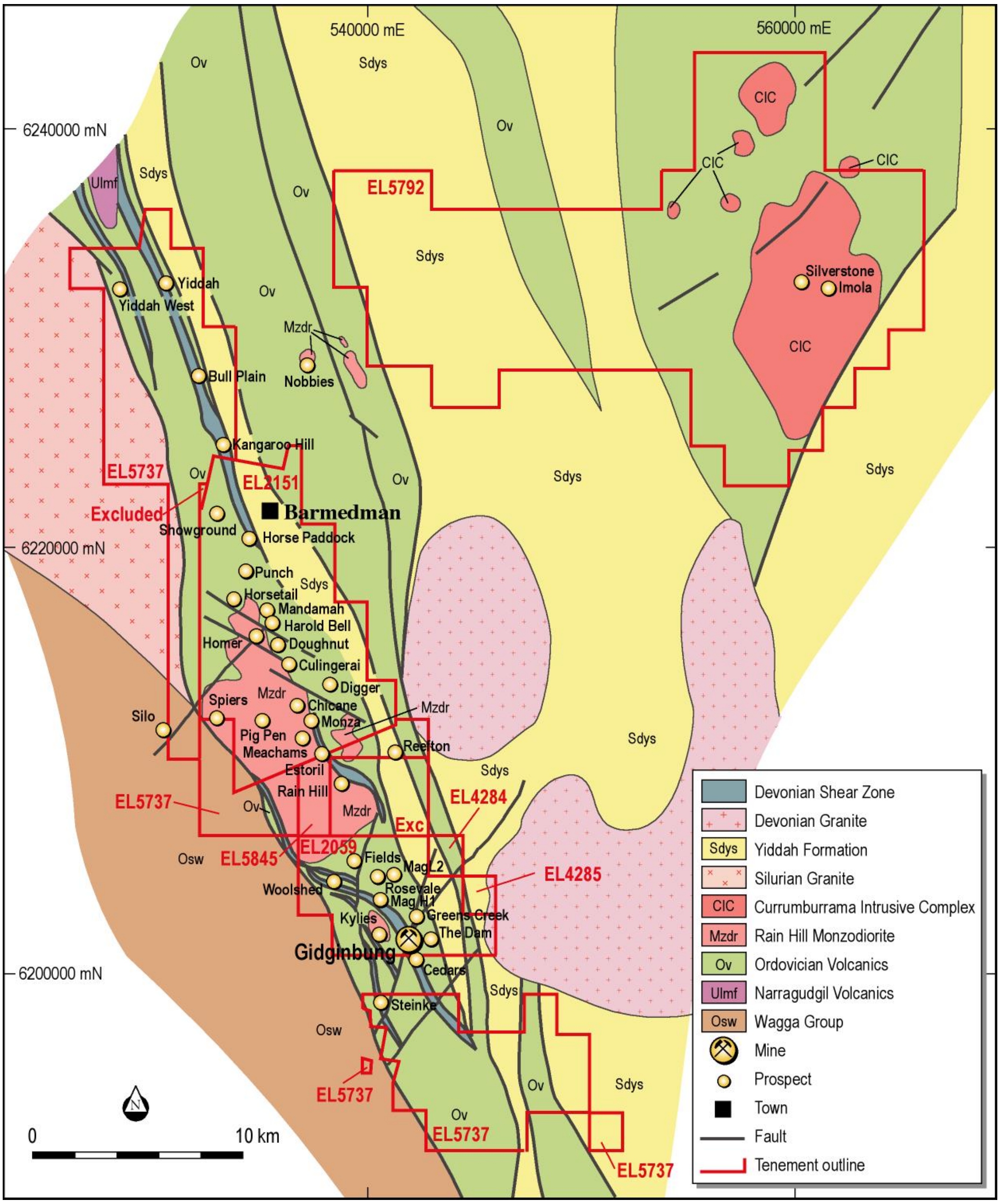
The Gidginbung Volcanics crop out at only two restricted silica altered locations, at the Gidginbung Mine and Yiddah, otherwise the volcanic belt is completely covered by Cainozoic alluvial clays.

Rock units identified to date include andesitic, ultramafic, and basaltic volcanics and volcaniclastics which are intruded by diorite to monzodiorite and gabbro stocks and plugs. Extensive tectonic activity has occurred subsequent to the emplacement of the magmatic belt forming an attenuated band of volcanics with only the Rain Hill Monzodiorite (RHM) being more resistant to the shearing.

The more felsic trachyandesite, latite and trachyte volcanics which occur within the other main porphyry copper-gold districts at the Wombin Volcanics, Lake Cowal Volcanics and the Forest Reefs Volcanics are absent in the Gidginbung Volcanics. Also absent are the monzonite and syenite intrusives which are characteristically associated with porphyry mineralization in these other districts.

The Gidginbung Volcanics is host to the Gidginbung Au mine which produced 700,000 ounces of gold until 1995. This unit also hosts six identified porphyry copper gold prospects at The Dam, Estoril, Monza, Culingerai, Mandamah, and Yiddah, some of which are advanced prospects with significant diamond drillhole intersections.

**Figure 1. Gidginbung Volcanics geology and prospect locations**




Recent dating by Lawrie et.al. (2007) has given an Early Silurian age of 436 ± 3.1 Ma for dykes at Mandamah and Gidginbung and also for hydrothermal zircon related to the high sulphidation gold mineralisation at Gidginbung. This date compares well with 435.0 ± 1.1Ma SHRIMP date of magmatic zircons from a subvolcanic intrusion at the Gidginbung gold deposit by Perkins (1990). Perkins (1995) also dated alunite and illite associated with the Gidginbung high-sulphidation alteration by argon-argon techniques which gave Devonian ages of 417.3 ± 2.0 to 401.2 ± 2.0. It is suspected that these ages reflect resetting during the Devonian deformation event which overprints the gold deposit.

Whole rock geochemistry on the Gidginbung Volcanics does not display the strongly alkaline very high K to shoshonitic chemistry of the units associated with porphyry mineralization at Northparkes and Cadia. The volcanics range from low K calc-alkaline for the ultramafic to mafic units to medium K calc-alkaline for the andesitic units. Intrusive units range from low to medium K calc-alkaline for the diorite and quartz diorite sills and plugs to high-K calc-alkaline for the monzodiorite intrusives.

**Alteration and Mineralisation**

The Gidginbung Volcanics, and to a lesser extent, the surrounding Silurian sediments are a very well mineralised group of rocks with numerous gold and copper occurrences distributed throughout the entire belt. Mineralisation styles can be broadly grouped into three main types

1. High sulphidation epithermal gold; Gidginbung
2. Porphyry copper-gold; Mandamah; The Dam, Estoril, Culingerai, Monza, Yiddah
3. Mesothermal vein gold; Reefton, Barmedman.

The main targets for previous companies were porphyry copper-gold deposits and high or low-sulphidation epithermal Au deposits. The mesothermal reef Au occurrences which occur mainly within the Silurian Yiddah Formation sediments are of less interest, as they all appear too small to support a significant gold mining operation.

Porphyry copper-gold mineralisation is hosted within the volcanic stratigraphy of andesitic volcanics and early quartz diorite stocks and sills. Of the six systems described here only two, Estoril and Culingerai, have intrusives which can be said to be causative and are spatially and temporally related to the copper-gold mineralisation. These are distinctive pink porphyritic monzodiorite dykes which are spatially and likely to be temporally, related to copper mineralization. The dykes have similar composition and appear to have a single phase intrusive history. This is in direct contrast to the Northparkes systems, which are extremely polyphasal and have multiple intrusive histories (Lickfold et.al. 2003).

Alteration zonation of the Gidginbung porphyry systems displays the classic potassic-phyllic-propylitic zones characteristic throughout the porphyry spectrum. All of the porphyry copper-gold deposits described in this paper display identical alteration zonation patterns. There is an inner potassic core of hematite+magnetite+chlorite+albite+sericite+K-feldspar±secondary bioitite. This grades out to magnetite+chlorite+albite+sericite±actinolite within the copper mineralised zone. Further out is an assemblage of albite+sericite+chlorite and finally to a sericite+chlorite+epidote propylitic facies. Finally a structurally controlled strong white sericite+pyrite event postdates and overprints all previous alteration events. This final event is attributed to Devonian aged deformation which is widespread within the Gidginbung Volcanics.

The alteration zones related to porphyry mineralisation are extremely restricted and extend for only 50 metres from ore grade copper-gold mineralisation. This restricted alteration halo is characteristic of the alkaline porphyry systems of the south west pacific.

The widespread hematite alteration which produces distinctive red rocks in the Cadia and Northparkes systems is poorly developed in the Gidginbung Volcanics. Nevertheless porphyry mineralisation always shows some incipient hematite alteration in the core of the deposits.

Vein paragenesis can be grouped into two distinct chalcopyrite bearing stages. The first and most economically significant is an early high temperature quartz+magnetite±K-feldspar±pyrite±chalcopyrite assemblage which forms seam veins typical of porphyry copper-gold deposits. Magnetite, K-feldspar and sulphides form the “seams” parallel to the vein margins. This first stages has alteration selvages of magnetite+hematite±K-feldspar. Chalcopyrite often appears texturally late within these veins, at this stage it is unknown whether this is a primary feature suggestive of late timing of copper introduction, or whether post mineral deformation has remobilised the chalcopyrite.

The second main vein stage is comprised of quartz+carbonate+chlorite±chalcopyrite. All mineral species in this vein stage are coarsely crystalline with the chlorite particularly coarse and chalcopyrite forming large clots. The chalcopyrite in this vein stage appears to be remobilised, possibly from the first vein stage.

Chalcopyrite is the dominant copper species in all the six prospects described here, with rare bornite identified at Mandamah and The Dam. Molybdenum is present in all six porphyry copper-gold deposits described here and in all cases corresponds poorly with gold and copper. In most cases molybdenum occurs on the margins of the best copper-gold grades. It is uncertain whether this is due to different timing or temperature gradients affecting the deposition.

Most of the six porphyry copper-gold prospects described here have close to ore grade intersections, a list of some of the better drillholes is shown below.

| | |
|---|---|
| The Dam | 167m @ 1.0 g/t Au, 0.7% Cu |
| Estoril | 150m @ 0.3 g/t Au, 0.2% Cu |
| Monza | no RC or diamond drilling to date |
| Culingerai | 50m @ 0.8 g/t Au, 0.5% Cu |
| Mandamah | 206m @ 0.5 g/t Au, 0.4% Cu |
| Yiddah | 146m @ 0.1 g/t Au, 0.4% Cu |

### Structure

Strong volcanic belt parallel shearing during the Devonian has overprinted the Late Ordovician-Early Silurian porphyry mineralisation causing attenuated mineralised envelopes. This shearing has destroyed coherent mineralised zones making the discovery of mineable ore lenses difficult. Exploration is now focusing on the more intact systems.

### Metal Zonation

Gold copper ratios within porphyry copper-gold deposits often display increasing gold in the core of the systems, as described by House (1994). The systems within the Gidginbung Volcanics are no different with increasing metal grade and increasing gold copper ratios in the core of the systems. This zonation is useful to find higher grade portions of the deposits.

Zinc haloes are common with most porphyry copper systems, such as at Northparkes (Heithersay 1995), and likewise are present in these systems. The porphyry deposits within the Gidginbung Volcanics have a pronounced zinc halo in geochemical bedrock drilling.

### Distribution

Typically the porphyry systems are clustered, with four forming a linear trend immediately east of the Rain Hill Monzodiorite. The relationship of the Rain Hill Monzodiorite with the mineralised systems is uncertain, however it seems likely that the porphyritic monzodiorites which are related to mineralisation are apophyses of the RHM parent stock in the same way that the mineralised monzonites at Northparkes are related to the parent stock at E31. However the fact that no porphyry systems are seen on the other margins of the Rain Hill Monzodiorite margin brings doubt to this assertion.

### Exploration Strategies

Goldminco Corporation holds the majority of the Gidginbung Volcanics and continues to explore for an economic porphyry copper-gold deposit.

As with all the Ordovician porphyry copper-gold systems in the Eastern Lachlan Fold Belt, the Gidginbung systems are oxidized with abundant magnetite addition during early phase alteration, making them good magnetic targets. Post mineral shearing with associated sericite pyrite alteration is magnetite destructive and these anastomosing zones have left kernels of intact porphyry related magnetite chlorite alteration, giving excellent ovoid shaped aeromagnetic anomalies. Therefore detailed aeromagnetics is the first exploration tool employed.

Due to the extensive transported cover sequences, grid based aircore drilling to obtain geochemical and geological samples is the other main exploration tool. Metal mobility within the cover sequences create exploration challenges. Gold is mobile within the saprolite and often forms concentrations at the interface between the in situ upper saprolite and the overlying transported clay. This mushroom like blanket anomalism can complicate finding the source of the gold. Copper is depleted in the upper saprolite, as so requires drilling to hard refusal to avoid overlooking basement copper anomalism.

The use of IP electrical geophysics which is helpful in defining pyrite haloes in porphyry systems is of little use in the Gidginbung Volcanics as the transported clay is conductive and masks the underlying basement.

The Gidginbung Volcanics are highly mineralised with new discoveries continuing. The most recently identified is the Monza prospect, and it is only a matter of time before an economic system is discovered.

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# BALLARAT GOLDFIELDS: FROM MODEL TO MILL

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**Abstract**
Brownfield exploration within the Ballarat goldfields is a process that comprises exploration drilling, 3D mapping/modeling and trial mining. Here we examine these processes and note the innovative core logging and underground mapping methods that have evolved over the last four years of this activity. These techniques stem from advances in software integration and data feedback, which are utilised in order to continually improve the geological model.

Keywords: Brownfield exploration, delineation drilling, core logging, underground mapping, software integration, geological model

## Introduction

The Ballarat Goldfield (see fig. 1) ranks as the second largest gold producer in the state of Victoria and is further distinguished as being the largest statewide producer from alluvial sources (total = 408 t, alluvial = 343 t; Phillips & Hughes, 1996). The substantial historical production and particularly the primary/ secondary gold ratio, effectively rates Ballarat as a leading exploration target, despite the city's substantial population and urban development.


**Figure 1.** Location map of Ballarat Goldfields tenements

## Exploration (L2) Drilling

Exploration drilling is a primary means of data gathering due to the limited surface outcrop. To date, 158 km of diamond core has been drilled with most drilling now occurring underground.

Definition of the characteristically vein-hosted/coarse-gold resources is achieved using a hierarchical drill program and interpretation procedure. Initial semi-regional exploration drilling (termed L2) consists of fans spaced at ~ 100m along strike and 20m down-dip. These sections provide medium resolution stratigraphic and structural data that is interpreted using a graphical logging process.

Core logging is conducted on Toughbook computers using Acquire software. Lithological data (i.e. grain size, apparent thickness, α angle and hole orientation) are exported to Microsoft Excel, so as to calculate the true thickness of individual beds, which is then uploaded to Corel Draw to produce a graphical log. This step assists with the interpretation of completed drill sections, which are then registered and digitised in 3D space using the Vulcan software package (fig. 2).

Notable improvements to the geological model stemming from L2 include along strike definition of F1 folds, with the discovery of additional $2^{nd}$ and $3^{rd}$ order folds also made. The number of west-dipping D1 faults has similarly been increased from 7 to 18 and the displacement of these faults also quite well constrained locally (<10m usually).

A significant exception to this pattern is the Blue Whale fault where drilling/modeling and assay data indicates >100m of reverse movement and significant mineralisation. Thus the

Blue Whale fault is inferred from L2 drilling to be a semi-regional structure, intimately related to gold emplacement and conceivably a significant conduit of mineralising fluid.

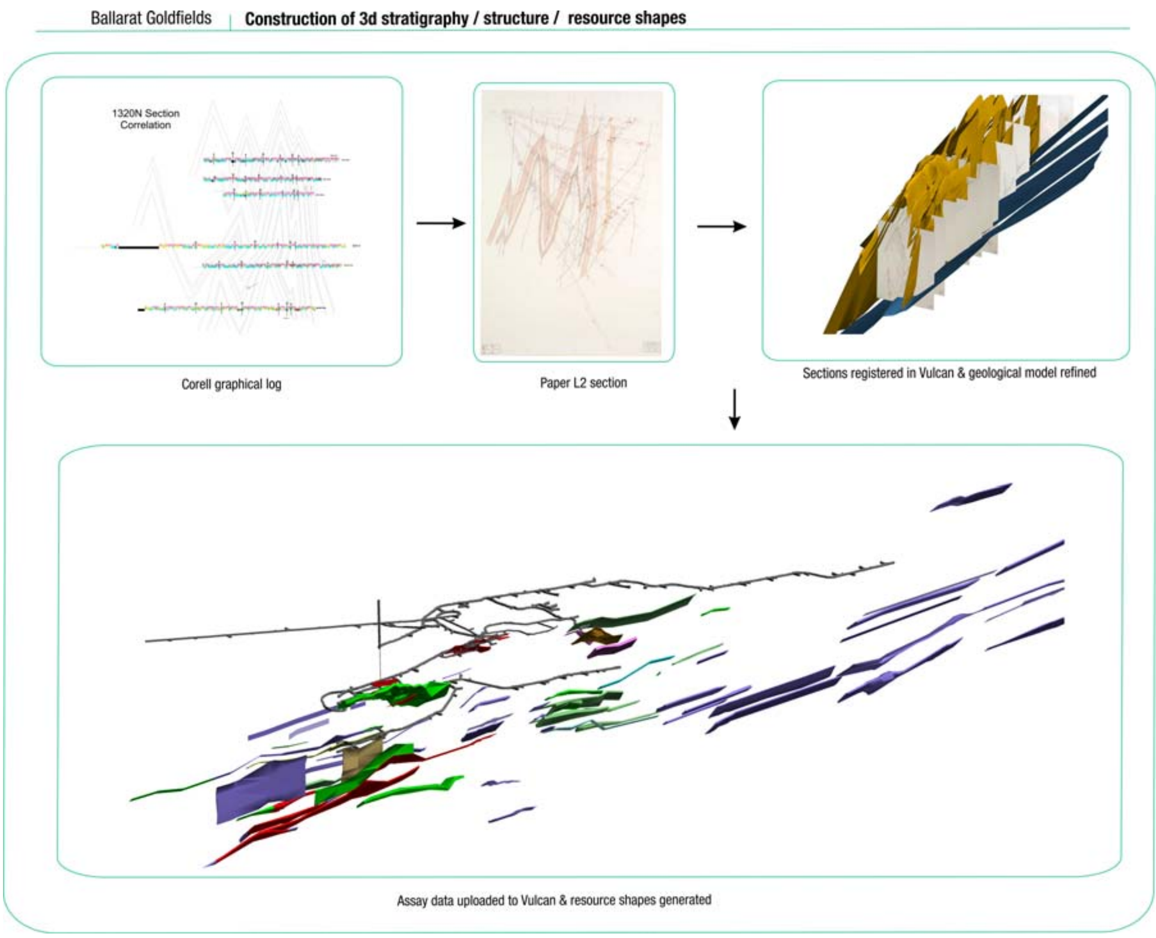


**Figure 2.** L2 exploration drilling / resource modeling process.

### Ore definition

Leachwell assay data of metre-spaced (or composited equivalent) half-core provides the basis for defining resources shapes. To smooth out nuggety distribution characteristics the assay results are standardised using an 85 g/t top cut with a 25% upgrade applied to shapes having a global grade >3 g/t.

L2 blocks are generally reported as Inferred resources according to the JORC code. “Off-section” L2 drilling, which reduces the section spacing to 50m sometimes allows for resources to be classified as Indicated1.

### Stope delineation (L3/L4) drilling

L3/L4 (stope-delination) drilling is an adjunct to actual mining and requires careful consideration of the likely oreshoot morphology and potential extraction method. Ideally, an L3 campaign will precede the access development, which in turn provides a platform for L4; which will determine the subsequent mining plan.

Full core assays of L3 (~30x10m spacing) and L4 (~10x 5m toe spacing) serve to validate targets identified during L2. Indicated2 resource classification is applied where appropriate L3 definition exists; with an eventual upgrade to Indicated3 occurring after L4 is completed.

**Trial mining**

At Ballarat, trial mined headings utilise bolt and mesh ground support in order to expose 3D sections (i.e. crosscuts and drives). Daily face mapping is conducted in these headings whereby a sketch map and digital photograph of each face is taken. The photos are accurately registered in Vulcan 3D space to permit geological model updates (fig. 3).

Walls and backs are mapped in even greater detail. This process uses the Corel Draw import/export function, to produce photographic mosaics draped on “as built” Vulcan strings and survey marks to produce a scaleable, spatially accurate base map. Structural measurements and grab sampling data are then recorded on the base map template, which can be printed from Corel Draw or exported back into Vulcan as required.

Completed mapping of trial-mined sections provide a means for comparison between different areas within the mine. The trends observed from mapping in turn provide a basis for the formation of conceptual models. A new endeavor is the culmination of conceptual and actual models to arrive at a predictive model encompassing all observed geological data and characteristics; i.e. a temporal and spatial (4D) genetic model.
This objective forms the basis of current PhD research, which is expected to model transient deformation and fluid flow relative to the 3D actual model (fig. 3).

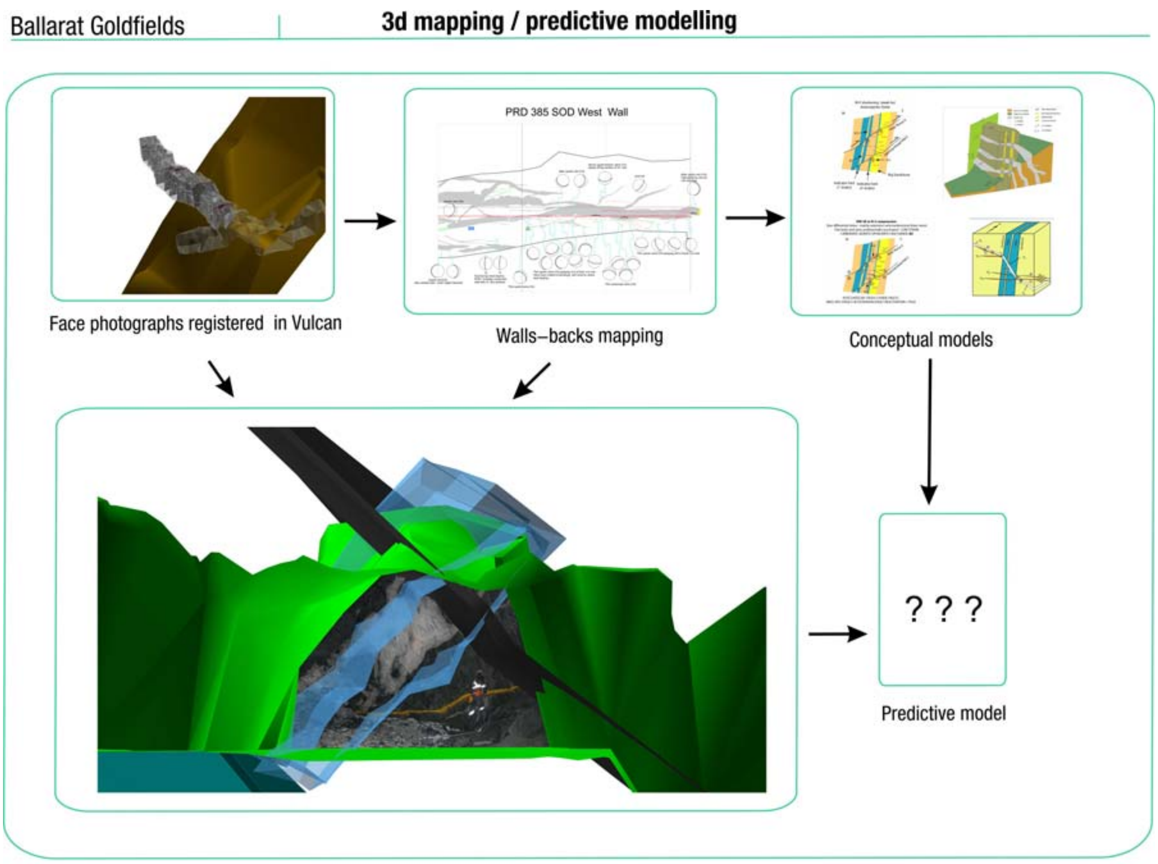


**Figure 3.** Underground mapping / modelling process

**Conclusion**

Delineation drilling and insitu mapping are proving a valuable means of defining gold distribution in narrow vein/coarse gold deposits. Exploration at Ballarat applies these novel methods to achieve a “best practice” level of industry competence. To date the program has extensively revised the known geology and established a substantial resource base within a robust 3D environment.

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# PROSPECTIVITY OF THE GLEN INNES REGION, NEW TECHNIQUES, NEW MINERAL SYSTEMS AND NEW IDEAS.

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**Key Words**: Spatial Data Modelling, Granite Related Gold Mineralisation, Weight of Evidence, New England Fold Belt, Molybdenum, Bismuth.

**Abstract**

Recent research into granite related gold systems has provided new targeting criteria that can be applied to many areas in Australia that have been considered unprospective for gold mineralisation in the past. These new ideas when combined with recently developed spatial data modelling techniques have opened up a number of new areas for exploration in the near surface environment. Exploration targeting was carried out by developing prospectivity models in a GIS database for both Eastern Australia and New Zealand. The GIS database contained a total of 79,000 mineral occurrences, 9,324,000 rock geochemical data analyses, 21,912,000 stream sediment geochemical data analyses, 26,360,592 soil geochemical data analyses, 109,000 drill holes and 2,537,522 km2 of geological information. The models were developed using the Weight of Evidence technique to identify prospective tracts of land for granite related mineralisation for tenement acquisition. The Glen Innes region ranked highly compared to other prospective regions in North Queensland, Tasmania and New Zealand and five tenements were applied for over the most prospective areas. These covered the Kingsgate Leucogranite and its immediate contact zone, including the historic Kingsgate Bi-Mo pipes and the Deepwater greisen. Follow-up exploration including detailed geological mapping, geochemical sampling, geophysics and drilling where carried out in these areas. This work is ongoing, but results at Kingsgate are sufficiently encouraging that a feasibility study has been commissioned. Possibly, more significantly for the region, economic intersections of gold mineralisation were made in the Seven Hills region, confirming the exploration model and the prospectivity of the area for gold. The discovery of a gold greisen association at Seven Hills may also be particularly significant as it is a new variant of the granite gold model. This new style of mineralisation may open up additional new areas for exploration not only in the New England Fold Belt but in other similar geological environments world wide.

## Introduction

There has been ongoing debate in Australia about the problems facing explorers in what is considered a mature exploration terrane and that exploration now has to focus on deeper targets to be successful. The fact that new exploration models that allow the discovery of ore deposits in environments considered to be unprospective in the past can change the perception of exploration maturity has been ignored in this debate. The recent discovery of the Tropicana gold deposit in a new geological setting in Western Australia is a perfect example of how the perception of exploration maturity can be changed. Recent research into granite related gold systems has provided new targeting criteria that can be applied to many areas in Australia that have been considered unprospective for gold mineralisation in the past. These new ideas when combined with recently developed spatial data modelling techniques have opened up a number of new areas for exploration in the near surface environment. The discovery of a new mineral deposit is based on probability of about 1 in 3000, making the discovery of new mineral resources a rare event (e.g., Henley, 1997). Therefore for any company to be successful in exploration they have to be able to increase their chances of success. Spatial data modelling is a rapidly developing predictive technique that is increasingly being used in geology (Bonham-Carter 1994; Partington et al., 2002). There are a growing number of mineral exploration companies who now believe that by using such modern statistical techniques and new ore deposit models it is possible to increase the probability of discovery of new mineral resources (Partington and Sale, 2004; Partington and Mustard, 2005).

A large historic geological database was integrated using spatial data modelling techniques with new information on granite gold mineral systems to develop national and regional scale prospectivity models for the East Coast of Australia and the West Coast of New Zealand to assess the potential for new discoveries of metallic deposits associated with granite intrusions. The modelling highlighted the New England region and locally the Kingsgate Leucogranite in the Glen Innes area as particularly prospective (Figure 1). The area is well known for it's mineral potential, especially for molybdenum and bismuth mineralisation, but the modelling and follow-up fieldwork have identified areas that are also highly prospective for gold, silver, tin, tungsten and basemetal mineralisation. This paper describes the modelling techniques and exploration model used to target exploration in the Glen Innes region, the results of the spatial data modelling and subsequent field checking.

Mineralisation Model

In the last ten years a new, globally widespread, economically important class of intrusion related metal deposit has been recognised (Thompson et al., 1999; Lang et al., 1997; Lang et al., 2000). These deposits have always been recognised for their potential to host tin and tungsten mineralisation, but now are believed to be prospective for other metals, including gold mineralisation. Examples of deposits that belong to the intrusion-related deposit class include: Donlin Creek (10.4 M Oz Au), Vasilkovskoe (9.5 M Oz Au), Pogo (4.9 M Oz Au), Kidston (4.5 M Oz Au), and Fort Knox (4.1 M Oz Au). Recent rises in metal prices mean that these deposits now have the advantage that they have other high value metals associated with gold mineralisation, such as molybdenum, bismuth, silver, tungsten and tin, which can significantly add to the economic value of the mineral deposit.

There is a systematic relationship between degree of fractionation, oxidation state and ore element ratios in these type of granite systems, which can be used to assess the prospectivity for Ag-Au-Bi-Mo-Sn-W mineralisation (Thompson et al., 1999; Lang et al., 1997; Lang et al., 2000; Mustard, 2001; Mustard, 2004; Mustard et al., 2006). This type of mineralisation tends to be associated with granite intrusions that occur in a continental tectonic setting and are Phanerozoic in age (<410 Million years). Importantly, the deposits exhibit a distinctive metallogenic signature, namely Au, Bi, Sn, W, Mo, As, Te, Sb ± (Pb, Cu), with a strong relationship between economic mineralisation such as Au, Sn and W and Bi and a negative correlation with basemetal and particularly copper mineralisation (Mustard, 2001; Mustard, 2004). The intrusions have an intermediate oxidation state which spans the boundary between the ilmenite and magnetite series. The metals of interest are associated with the more evolved phases of igneous suites, granodiorite to granite in composition and specifically associated with late stage vein-dykes, aplites and pegmatites. Also, associated plutons commonly contain textures indicative of the transition from magmatic to hydrothermal conditions (e.g. miarolitic cavities, interconnected miarolitic cavities, unidirectional solidification textures, aplite-pegmatite layers and vein-dykes). Intrusion-related metal deposits can form over a range of crustal depths (1 to 10 km) and at various proximities to the source intrusion (0 to ~3 km). Despite a set of unifying characteristics that define the deposit class as a group and separate them from other magmatic-hydrothermal systems, they can display a wide range of styles, varying from disseminated mineralisation, sheeted vein, flat lying veins, breccia and replacement types. Mineralisation has comparatively restricted zones of hydrothermal alteration and a low sulphide content. The lack of alteration, veining and sulphides makes detection by conventional prospecting very difficult, and many explorers have literally walked over ore-bodies of this type and dismissed the host rocks as unprospective. Spatial data modelling techniques, where individual predictor themes of geology geochemistry and geophysical data are combined into a single prospectivity map, are therefore particularly effective at targeting this type of mineral deposit.

**Prospectivity Modelling**

Spatial data modelling requires a geological database from which predictive evidence for a particular deposit, based on an exploration model, and training data sets can be drawn (e.g., Bonham-Carter, 1994; Partington and Sale, 2004). The relative weights for each predictive map then has to be statistically calculated or inferred from either expert knowledge or a training data set usually based on historical mining data. The geologic predictor themes are then combined according to the weights to predict the location of undiscovered mineral resources (e.g., Bonham-Carter 1994). The simplest type of predictive spatial analysis is where an expert visually inspects a variety of predictive maps and then manually chooses target areas according to subjective criteria. A less subjective approach would be to create maps, on which the chosen input variables are represented by a series of integer values that are then combined together using arithmetic operators. This type of analysis takes no account of the relative importance of the variables being used and the resultant prospectivity map is based on expert opinion. Fuzzy Logic techniques address the problem of the relative importance of data being used, but this technique still relies on expert opinion to derive weights that rank the relative importance of the variable for the map combination. Weights of Evidence, in contrast uses statistical analysis of the map layers being used with a training data to make less subjective decisions on how the map layers in any model are combined (Bonham-Carter 1994; Partington et al., 2002; Partington and Sale, 2004).

The first stage of exploration targeting in this study involved the development of an international scale prospectivity model from a GIS database of known mineral occurrences, regional geology and geochemistry for both Eastern Australia and New Zealand. The GIS database contained a total of 79,000 mineral occurrences, 9,324,000 rock geochemical data analyses, 21,912,000 stream sediment geochemical data analyses, 26,360,592 soil geochemical data analyses, 109,000 drill holes and 2,537,522 km2 of geological information. Digital data were reclassified prior to the prospectivity modelling stage and adapted and combined in accordance with the mineralisation model described above. Polygonal themes of geochemistry, geophysics and geology were developed. Derivative datasets were generated using GIS modelling techniques such as buffering, theme intersections, interpolation using inverse distance weighting or density algorithms. Statistical analyses of all geophysical, geological and geochemical data were completed using probability and percentile plots to identify anomalous populations to allow the reclassification of the data sets. Sixty seven predictive map themes were analysed for their spatial relationship to a training data set using the Weights of Evidence technique. The key geological concepts tested included: relationship to granite lithology, granite texture, granite series, granite age, granite geochemistry, proximity to major faults and relationship to fault orientation, correlation with density of quartz veins, proximity to aplite or pegmatite dykes or veins and correlation with As, Au, Bi, Cu, Mo, Sn, U and W geochemistry. Significant spatial correlations were found between Au, Bi, Mo and W geochemistry, granite geology including composition, type and series, indicators of granite fractionation and with faults and fractures. Permian age I-type leucogranite, adamellite and granite had the best spatial correlations with the training data. The more leucocratic or fractionated the granite the better the spatial correlation as highlighted by maps of granites containing pegmatite, aplite or miarolitic cavities. Other indicators of granite fractionation such as $SiO_2$ content, U content and Rb/Sr ratios also gave significant spatial correlations. The spatial correlation of uranium with the training data possibly provides a good regional scale tool for exploration of this deposit type using airborne radiometric techniques.

A model was then developed using the Weight of Evidence spatial correlation values to identify prospective tracts of land for granite related mineralisation for tenement acquisition. The Glen Innes region ranked highly compared to other prospective regions in North Queensland, Tasmania and New Zealand and five tenements were applied for over the most prospective areas. These covered mainly the Kingsgate Leucogranite and its immediate contact zone, including the historic Kingsgate Bi-Mo pipes and the Deepwater greisen. All the tenements had little or no modern exploration, especially for gold, and importantly no drilling.

**Geological Setting and Mineralisation in the Target Region**

The tenements acquired on the basis of the prospectivity modelling in the Southern New England region cover rocks of the Upper Carboniferous to Triassic New England Batholith that intrudes accretionary prism complexes. The batholith is composed of synorogenic, Late Carboniferous to Early Permian peraluminous S-type granitoids, and post-orogenic Permo-Triassic I-type intrusions. The I-type intrusions form a NNE trending 300 km long by 60 km wide belt. The New England Batholith has been subdivided into the Bundarra, Hillgrove, Moonbi, Uralla and Clarence River suites based on distinct mineralogical, geochemical, isotopic and age criteria. The Moonbi Supersuite (Leucogranites) represent the most significant group of mineralised granites, having produced Sn, W, Mo, Ag, As, Bi, Cu, Pb, Zn, Au, fluorite, beryl and topaz. The Wards Mistake Adamellite occurs extensively throughout the Glen Innes tenements and comprises coarse to medium-grained monzogranite-granodiorite. It has been intruded by the Kingsgate Leucogranite and the Red Range Microleucogranite. The Kingsgate Leucogranite is very coarse-grained, equigranular biotite granite whereas the Red Range Microleucogranite is a fine- to very fine-grained saccharoidal, pink, equigranular microleucogranite, which is believed to be the carapace to the Kingsgate Leucogranite. Mo-Bi-Ag±Au quartz pipes and veins are developed in clusters along the margins of the Kingsgate Leucogranite and the Red Range Microleucogranite and are historically the most significant mineral occurrences in the region.

**Follow-up Exploration**

Prospectivity modelling was successfully used in the initial targeting to reduce the search area so speeding up the land acquisition process, minimising costs and increasing the chances of discovery. However, there is no substitute for fieldwork in exploration. This is especially true in the Glen Innes region due to the lack of modern prospect scale geological, geophysical and geochemical data, which limit the scale at which the prospectivity models can be used. The modelling highlighted the Kingsgate prospect, the Deepwater prospect and a new area in the Seven Hills region as highly prospective for the metals of interest, including gold. Consequently, follow-up exploration including detailed geological mapping, geochemical sampling, geophysics and drilling where carried out in these areas. This work is ongoing, but results at Kingsgate are sufficiently encouraging that a feasibility study has been commissioned. Possibly, more significantly for the region, economic intersections of gold mineralisation were made in the Seven Hills region, confirming the exploration model and the prospectivity of the area for gold.

The Kingsgate Mine, located 20km east of Glen Innes, is the second largest producer of molybdenum in Australia (Figure 1). A total concentrate of 350t molybdenum, 200t bismuth, and 12t wolframite-bismuth was mined during the early 1880’s to late 1920’s. Much of the ore was mined from 54 pipes up to 20m diameter that were worked to a depth generally not exceeding 50 metres. Assays of ore samples in 1884 returned 2.6-69.3% Bi, 12-194.5 ppm Au and 149-4442 ppm Ag. Geological mapping highlighted more than 94 Mo-Bi-rich pipes located along a 4.75 km N-S trending belt. The pipes are hosted in medium-grained biotite granite, with the majority located within 300m from its contact with sediments and plunge 20° to 30° east parallel to an aplite carapace. Rock chip sampling of the pipes returned grades up to 7.3% Mo, 2.2% Bi, 2.0 g/t Au and 100 g/t Ag (Figure 2A). A Scoping Study has been completed, which suggests that the Kingsgate project could be a high grade operation with a low processing rate, a mine life between 5-10 years and an operating cost of $60.33 per tonne of ore processed. Capital expenditure and infrastructure related to development is estimated to be $39.76M. A conservative diluted head grade of 0.23% Mo and 0.23% Bi is being targeted and based on a 250,000 tpa processing operation, a total of 911 tonnes of Mo in concentrate and 698 tonnes of Bi in concentrate would be produced annually. This represents revenue of $158.12 per tonne of ore processed, using the study’s long term assumptions of a US$22/lb Mo concentrate price, US$13/lb Bi concentrate price and a US$0.80 exchange rate.

The Seven Hills prospect lies within the Glen Elgin tenement (EL 6408) approximately 45km northeast of Glen Innes (Figure 1). Geology of the area around the Seven Hills prospect comprises Wandsworth Volcanic Group rocks to the west, Kingsgate Leucogranite in the central parts and Mount Mitchell Monzogranite with inliers of Glen Garry Microleucogranite to the east. Three samples of quartz veins in granite were collected during reconnaissance geological mapping of the tenement area assayed 2.52 g/t Au, 2.43 g/t Au and 2.11 g/t Au. Mapping identified a number of historical sluiced creeks and shafts in an area where there has been no significant modern exploration for gold. The gold mineralisation sampled on the surface is associated with zones of greisen with quartz-sulphide veins forming several broad areas up to 500m by 200m in size (Figure 2B). Several phases of detailed exploration were conducted, including prospect scale geological mapping and rock-chip sampling, soil, auger and costean sampling, geophysical dipole-dipole IP line surveys and RAB and RC drilling that have progressed the Seven Hills prospect to an advanced gold drill target. Geophysical dipole-dipole IP line surveys defined coincident zones of relatively weak chargeability highs (inferred sulphide bodies) and relatively weak resistivity lows (inferred altered zones) that appeared to coincide with mapped anomalous zones of surface geology and geochemistry. Initial shallow RAB results targeting anomalous surface geochemistry intercepted several intervals of high-grade gold mineralisation such as 9m at 12.19ppm Au, including one interval at 32.70ppm Au. Follow-up RC drilling of the geophysical targets was disappointing although sulphide mineralisation was intercepted. The RC drilling of the geochemical targets was more promising with several intersections of up to 11m averaging 2.05ppm Au made. Fresh mineralisation was intersected in a variably hydrothermally altered and mineralised medium to coarse grained, biotite leucogranite. There has been partial to complete replacement of the primary rock by a greisen assemblage of muscovite-sericite, with associated quartz, minor chlorite and sulphides and a trace of rutile. The main geochemical association in the fresh material is Au, Bi, Ag and Te, which is typical of a granite gold system. However the gold mineralisation is also associated with Pb and As, which is not typical.

**New Mineral Systems and New Ideas**

The initial aim of the prospectivity modelling was to use a probabilistic approach to exploration targeting to develop a portfolio of prospects that have an increased probability of discovery and development. The spatial modelling successfully identified a number of targets, reducing the initial search area by several orders of magnitude. The benefits of carrying out spatial data modelling include: Effective data compilation, QC of digital data, Understanding of critical geological factors to be used in follow-up exploration, Ranking of prospects, Prioritising exploration, Exploration budgeting and management, Understanding of risk, and Cost reduction. Geological data have proved to be fundamental predictors of mineral occurrences in all models developed to date. An understanding of the structure and temporal development of the geology of the area is critical, especially at a prospect scale. This means more fieldwork, but specifically targeted at a prospect scale.

The Glen Innes region was identified as particularly prospective for the style of mineralisation and metal assemblages required. Work to date has shown the new ideas coming from research into granite gold systems have opened up old and new areas in Australia that were not considered prospective for gold in the past. More importantly these areas are not under significant depths of cover and therefore represent low cost exploration targets that can effectively be explored using modern geochemical and geophysical techniques. The recent rise in metal prices also means that these ideas can also be applied to exploration for a range of metals including molybdenum, bismuth, tin, tungsten, silver and gold. The discovery of a gold greisen association at Seven Hills may also be particularly significant as it is a new variant of the granite gold model. This new style of mineralisation may open up additional new areas for exploration not only in the New England Fold Belt but in other similar geological environments world wide.

**Acknowledgements**

The authors would like to thank Auzex Resources Ltd. for allowing the paper to be presented. Also we would like to thank the local field crew for their efforts in collecting new field data and to all geologists past and present who have worked in the area contributing to the large body of historical data that allows effective exploration targeting to be carried out.

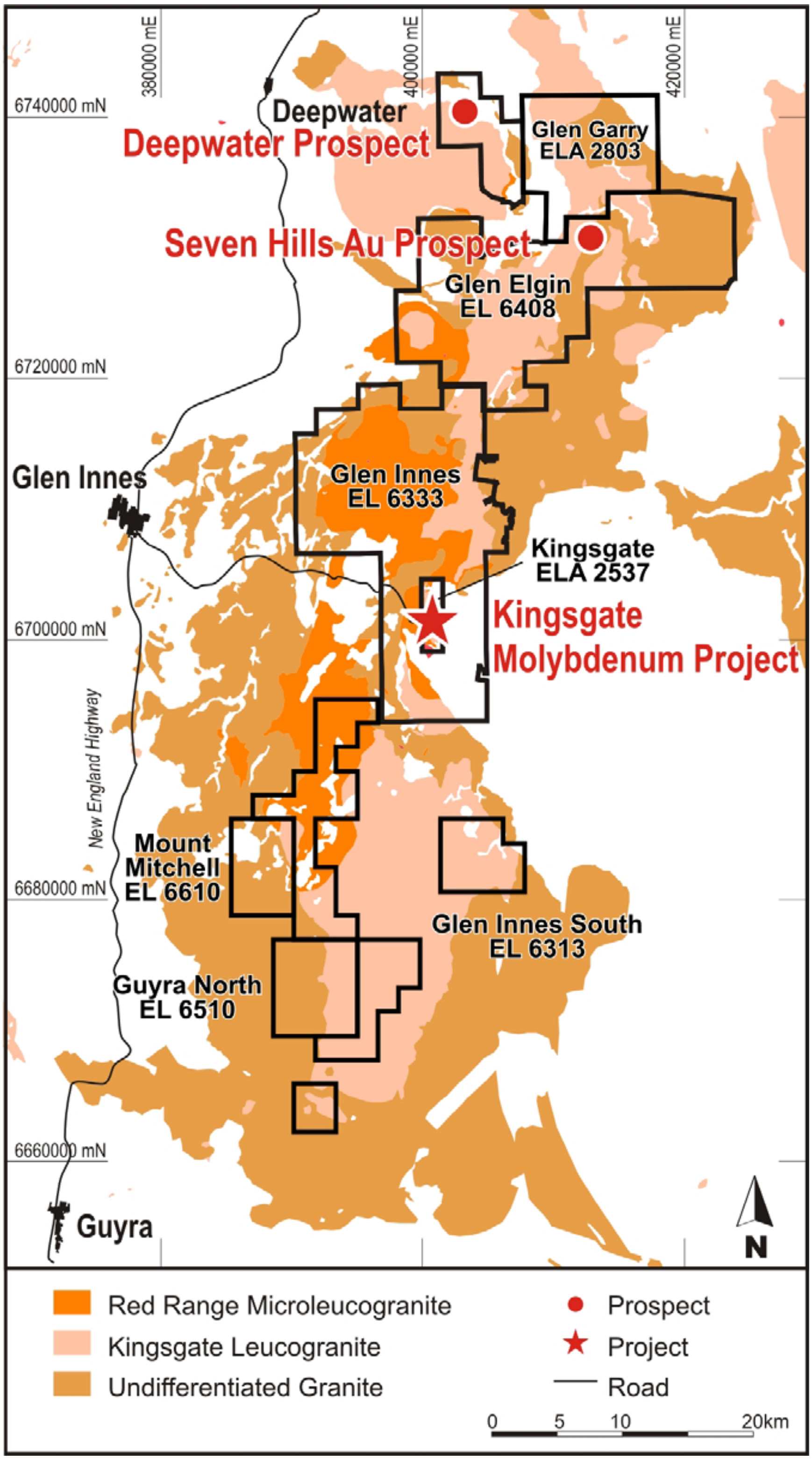


Figure 1. Simplified geology of the Glen Innes region with Auzex Resources Limited tenement holding and key projects.

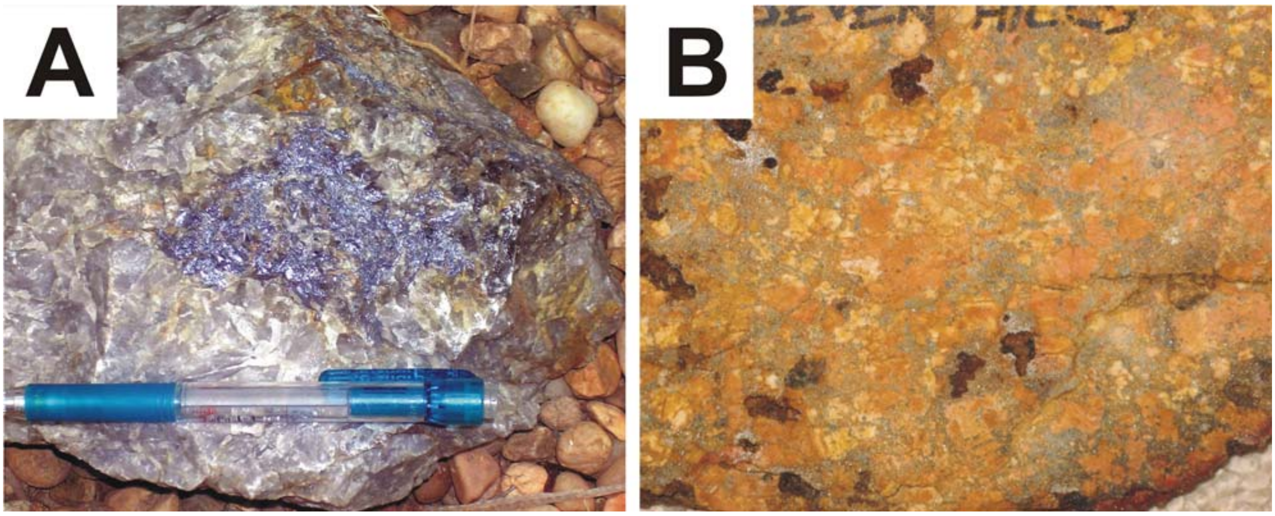


Figure 2A. Quartz pipe material from the Kingsgate Mo-Bi Project containing coarse molybdenum. 2B. Gold bearing greisenised granite from the Seven Hills gold prospect (Field of view 10cm x 15cm).

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# THE WATERSHED TUNGSTEN DEPOSIT: RISEN FROM THE DEAD

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**Key Words:** scheelite, hydrothermal, quartz vein swarms, calc-silicate alteration, albitisation, Far North Queensland

## Details of Presenter

Bruce Pertzel was appointed Principal Geologist for Vital Metals Ltd on its launch as a publicly listed company on the Australian Stock Exchange in October 2005. Prior to this Bruce established a geological consultancy , Pertzel Tahan & Associates, following a ten-year engagement with Endeavour Minerals Limited during which time he progress from Project Geologist to Exploration Manager.

## Abstract

Vital Metals Ltd [Vital} acquired the Watershed scheelite deposit and listed on the Australian Stock Exchange in late 2005.

The deposit was discovered by Utah Development Company Incorporated [UDC] in the late 1970s using stream sediment geochemistry. It is situated in Far North Queensland approximately midway between Cairns and Cooktown at the foot of Cape York Peninsula. The deposit is unique in that it has no direct analogues in published literature. It is a mono-minerallic deposit and unlike similar deposits elsewhere it contains no other metallic minerals usually associated with like deposits such as molybdenum, bismuth, base or precious metals.

The deposit is hosted in multiply-deformed sediments of the Siluro-Devonian age Hodgkinson Formation. A source granite is postulated at depth beneath the southwest of the deposit. Scheelite occurs as both disseminations in calc-silicate and albite-muscovite-biotite altered greywackes (arenites) and in late-stage quartz-feldspar veins. The scheelite is generally coarse grained.

Vital has conducted resource infill drilling since it floated in October 2005 and to date has completed in excess of 16, 000m of diamond core drilling. Vital has re-interpreted the genesis of the deposit to that of a quartz-vein swarm style deposit. UDC had interpreted the deposit to be of a stratabound style. This has meant orientating drill holes to local grid north (at ninety degrees variance to the majority of UDC drilling which was oriented normal to stratigraphy) Vital's vein-swarm normal drill hole orientation has been successful in demonstrating continuity of mineralisation across sections 50 metres apart.

# MT CARLTON PROJECT – DISCOVERY OF THE SILVER HILL GOLD-SILVER-COPPER DEPOSIT

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**Key Words**: Gold, Silver, Copper, High Sulphidation Advanced Argillic, Discovery, North Queensland

## Introduction

Mt Carlton Gold-Silver-Copper Project is located 200 km south of Townsville, and covers the northern margin of the Permian Bowen Basin, in particular the Lizzie Creek Volcanics with minor Back Creek Group sediments.

Four deposits have been found to date. The most recent and most significant of these is the Silver Hill deposit with indicated and inferred resources of 10 million tonnes at 2.4 g/t gold, 41 g/t silver, and 0.35% copper, discovered in July 2006. All four deposits occur within a felsic volcanic unit near the base of the Permian Lizzie Creek andesitic formation, and are localised by a combination of stratigraphic and structural features. The Silver Hill Deposit is a variation on this theme with a more extensive stratabound alteration zone. Although essentially a blind deposit, it is now shown to be the down dip extension of the Herbert Creek East deposit.

Key factors in the discovery were use of surface geochemistry and outcrop alteration as primary targeting tools, high quality data from previous exploration, a stepwise approach to extending the known, time to learn the geology, experienced field crew, increase in metal prices, and a willingness of management to trust the field crew to drill test targets.

## Exploration History

Prospector Butch Firth pegged two mining leases over Mt Carlton Hill to scratch for copper in the 1960's. Half 44 gallon drums of hand picked malachite with high silver and gold credits were taken by landrover to Collinsville for rail to Mt Isa. During 1978 BHP did a JV with the prospector and drilled 12 diamond holes on his ground testing both epithermal and porphyry targets. In 1986 Ashton Mining pegged a large area of Exploration licences in the northern Bowen Basin and Clarke Range area. These tenements were subsequently joint ventured by MIM exploration, who conducted substantial exploration resulting in the discovery of the Herbert Creek East Deposit. Goldfields Australia joint ventured into the the MIM tenements in the late 1990's while exploring for epithermal gold at Crush Creek, and subsequently sold it's equity to Conquest. Conquest purchased 100% of the tenements from Xstrata in December 2003 after the takeover of M.I.M.

Initial 2003 drill programs at Mt Carlton and at V2 prospect were to re-test earlier open-hole percussion data with RC sampling. It was thought that a significant improvement in assays might be achieved, and that drilling near some of the better holes might locate extensions.

The 2003 V2 Hill drill program was to test the intensely silica-pytite altered outcrop (which the author thought had similarity to the Lone Sister high grade gold deposit ) and to follow up previous drill holes intersections up to 9 g/t gold. Five holes were drilled with all intersecting intensely silicified drill bit destroying ground. Three of the holes failed to get to target depth, and the rig caught fire on the second last hole…… however three holes returned 60m intersections of 0.25 g/t gold.

The 2003 Mt Carlton program resulted in some significant improvements in grade over the old open hole data and located a thickening in the main shear zone lode that contained about 1 million tonnes at very moderate grades (Table 1). One of the early puzzles about this structure was that it appeared not to persist into basement, and that intially we were unable to locate this structure north of a vertical dyke that apparently had no significant fault movement.

However our initial focus in 2004 was to explore along the strike of the Mt Carlton shear zone. The area of most interest was a 40 ppb gold in soils anomaly on this structure 500m west, with an MIM drill hole intersection of 10m @ 3.5 g/t gold. To the south of this hole was a silcified ridge of volcaniclastics with dark matrix replacement, but with no gold anomaly. An assayed rock chip returned 426 g/t silver; and the first line of 4 RC holes intersected 3 stacked north dipping lodes (interpreted as shear zones).

In 2005 we located some horizontal stratabound mineralisation on the north side of Mt Carlton, which for the first time resolved part of the “disappearing lodes saga”, and gave us the exploration concept. This stratabound style was later demonstrated to also exist at Silver Hill in April 2006.

In late 2005 a single hole was drilled to test beneath a small vertical vein outcrop of 2,000g/t silver located on a magnetic low fault zone with 600m strike. This outcrop had been previously tested by MIM hole HCEP79 and intersected 5m @ 80 g/t silver. However hole HC05RC13 intersected **7m @ 930g silver.** A detailed 25m spaced RC drill program was designed to follow up a 2005 high grade intersection with the intention to define a small high grade open pittable resource. However the results were substantially below expectation with only a small sub-economic inferred resource of 104,000 tonnes at 80 g/t silver and 0.50 g/t gold outlined.

But, the alteration mapped on cross-section showed that the high grade vein was a structure that released fluids from the permiable stratabound main alteration horizon. And indicated that substantial exploration potential existed in the general area around Silver Hill and the Herbert Ck East Deposit (located 1km north). This concept was supported by previous exploration data, including magnetics which showed a large area of alteration.

The main problem with this concept model was where to drill, as the whole paddock was in theory prospective. As part of the assessment, and in keeping with the objective of “gold-exploration”, it was decided to re-test the V2 Hill gold anomaly where previous drilling had intersected sporadic economic gold values. A set of 4 fences of holes were drilled between Silver Hill and V2 Hill, with the northern most and last few holes of the program intersecting bonanza gold intersections that converted the prospect into a potentially mineable resource. The best of these was 29m @ 12.4g/tAu, 97g/tAg, and 1.46%Cu in hole HC06RC053.

## Geology

The Central North Queensland Goldfields has historical production and current resources totalling 20 million ounces of gold. The largest of these were Charters Towers with 7.1 Moz., Mt Leyshon with 3.3 Moz, and Pajingo with 4 Moz. However the majority of this production has been from the Ravenswood Block and Drummond Basin to the west. The discovery of a significant deposit in the Bowen Basin now provides a major shift in exploration concepts.

From an exploration point of view the most importatin horizon is a sequence of felsic to silicic volcanics that occur near the base of the Lizzie Creek Volcanics and in part unconformably overlies the Early Carboniferous Glen Alpine Adamellite. This volcanic unit is geochemically anomalous in precious and base metals and outcrops over about 25km of strike. All of the 4 deposits discovered to date, and numerous prospects occur within this unit. Unaltered Lizzie Creek Volcanics (rhyolitic ignimbrite) in the Crush Creek area have been dated at 284+/-7Ma (Hutton, in Denaro et al., 2004), and samples of illite from altered wall rocks at the Herbert Creek east deposit have been dated by K-Ar at 266 ± 3 Ma, (Perkins, 1993).

The stratigraphy is fairly flat lying with a gentle southerly dip, although the granite basement has a significant amount of topography. The granite basement is overlain on occaision by rhyo-dacitic volcanics which appear to be of similar age and alteration. This package is overlain by feldspathic tuffs that are often banded with fine lithic fragments. The unit is marked by strong yellow jarosite and occaisional haematite alteration, and outcrops in the silver ridge and western lodes prospect areas. Although this unit is interpreted at Silver Hill and at Mt Carlton to be footwall to the main mineralised sequence, at the western lodes it is silicified and hosts significant silver and gold mineralisation as sulphide replacement of the matrix of volcaniclastic layers.

**The target horizon consists of volcanic breccias and volcaniclastics**, the main part of which has clasts in the 10 – 100cm range. The rock is coarsely quartz phyric and often with visible feldspar laths. With alteration, much of this unit was originally logged as QFP before good drill core was available. The unit has been substantially altered with various zones of silica, alunite, kaolin, sulphide, sericite, and pyrite. The top part often has intense acid leaching with cavities and bladey textures after perhaps enagite or pyrophyllite or gypsum. Above this is often a zone of intense silicification and sulphide replacement, with massive sulphides which are often barren. In some parts of the deposit the top of the volcanic breccia is polymict with some mafic clasts.

**Andesitic volcaniclastics** and tuffs with layers of haematite and chlorite alteration. The unit is punctuated by some sinter horizons. The alteration may be due to primary depositional environment, or to later hydrothermal ground waters.

**Shales and carbonaceous sediments** are present sporadically through out the deposit area, typically in association with khaki andesitic tuffs and fine sandstones or arkose layers. Some of these are obviously lake sediments.

### Mineralisation

Mineralisation styles across the property encompass nearly the full range from porphyry associated stockworks, stratabound replacement, to high sulphidation epithermal veins, and low sulphidation banded epithermal vein systems.

Petrology on drill chips from the 2003 program identified dickite-alunite alteration which clearly indicated a high-sulphidation or acid-sulphate system at V2 Prospect. It was also noted by England (2004) as possible that some or much of the host breccia has a hydrothermal origin like those at Mount Leyshon (Morrison & Blevin, 2001).

At Mt Carlton the mineralisation occurs as matrix replacement, and stockwork sulphide and silica veining within a brecciated shear zone. The zone is 5 -25m thick and has angular to rounded 10-30cm clasts. The zone is east-west striking and dips north at 45 degrees. Best grades are adjacent to a steep basalt dyke which also strikes east-west. Mineralisation north of this dyke is undulating to flat and appears to be stratabound replacive. Dominant ore minerals are electrum, covellite, bournite, tetrahedrite, and some wire gold.

At Silver Hill the mineralisation occurs within an intensely silicified volcaniclastic of dominantly rhyodacitic composition. The unit appears to be a flat lying blanket that was porous, and therefore a favourable host. Two phases of silicification have been identified by petrology that pre-date the copper – silver mineralisation. The timing of the gold mineralisation is not known, but as it has a separate zonation (as at Mt Carlton) it is speculated to be from a separate event. Two high grade zones occur. The first is a gold-copper-silver zone that occurs as matrix fill to breccias and stockwork fractures that appears to be east-west striking and northerly dipping at about 45 degrees – similar to Mt Carlton. The second, is the vertical east-west fault – which hosts high grade silver epithermal veins at Area 39 and in hole HC05RC13.

**Table 1: Mt Carlton Project Total Resources – March 2007**

| | Tonnes | Grade g/t Au | Gold Ounces | Grade g/t Ag | Silver Ounces | Grade % Cu | Copper tonnes |
|---|---|---|---|---|---|---|---|
| Silver Hill Deposit | 9,800,000 | 2.4 | 760,000 | 41 | 12,800,000 | 0.35 | 34,000 |
| Area 39 Silver Hill | 970,000 | 0.15 | 4,700 | 158 | 4,930,000 | 0.12 | 1,100 |
| Mt Carlton | 966,000 | 1.35 | 42,000 | 38 | 1,090,000 | 0.345 | 3,400 |
| Western Lodes | 558,000 | 1.49 | 26,700 | 120 | 2,100,000 | n/a | 0 |
| Herbert Creek East | 351,000 | 2.17 | 24,500 | 4.2 | 47,000 | n/a | 0 |
| Total Resources | 12,600,000 | 2.11 | 858,000 | 52 | 21,000,000 | 0.3 | 38,500 |

Notes: Area 39 and Western Lodes Resources were estimated by sectional polygonal methods. Herbert Creek East and Mt Carlton were estimated by Kriging by Snowdens. Silver Hill Deposit was estimated by Multiple Indicator Kriging by Hellman & Scholfield.

### Key Discovery Factors

These points are not in order of priority. But are simply those ideas that on reflection seem to have been important or to have assisted in the discovery.

Surface Geochemistry
Surface geochemistry has been one of our primary targeting tools, particularly silver geochemistry in bulk cyanide leach soil samples. The silver seems to have a wider dispersion than the gold, and often forms a halo around areas of gold mineralisation. However noteable exceptions are the high grade silver veins zone at Silver Hill, and Silver Ridge prospect which have no significant associated gold.

Alteration and Previous Drill Intersections
The appearance of intensely silica-pytite altered outcrop at V2 Hill, and an area of brecciation and chalcedony on the south side of this outcrop were major reasons for the initial 2003 drilling program and continued enthusiasm in 2004. The similarity in appearance of these rocks (in the authors opinion at the time) to the Lone Sister breccia pipe deposit in central Qld, and previous gold values in drill holes up to 9 g/t were also strong factors that led to the 2003 and 2006 drill programs.

High Quality Previous Exploration
The conduct of good quality exploration and preservation of these records and plans at the Mines Department provided an extensive database and numerous exploration targets. Key amongst these was the large number of drill holes in the Mt Carlton to Herbert Creek area with substantial widths of base and precious mineralisation.

Stepwise Approach
Step wise approach to extending the known, combined with testing a few wild targets. As a small company – small targets are acceptable. This allowed us the scope to continue to test and to discover mineralisation, and importantly gave us the time and means to learn the geology and mineralisation styles.

Time
From our first drill program to the Silver Hill discovery was 3 years. I think it took that long to learn the geology and geochemistry – and to be open to new ideas. In

**Drilling**
To date 65,000 meters of drilling in 600 holes including 8000m of diamond core has been completed on the property, and includes about 12,000 metres completed by previous companies. Without drilling nothing is discovered; at least as far as the market is concerned.

**Change in Metal Prices**
The increase in metal prices has been a significant factor in making lower grade resources potentially economic. It has had a significant bearing on our exploration philosophy and ability to raise capital.

Experience
The field team consisted of three experienced professional staff – a senior field geologist Martin Male, a senior prospector Paul Szabo, and the author (Exploration Manager). The combined exploration field experience of the discovery team was 75 years. All of the crew have a strong bent towards boots and hammer style exploration – ie a belief in looking carefully at rocks and assaying them. We regard this as the cheapest part of our exploration budget.

Both Paul and Martin deserve special mention for their roles. Paul for his bloody minded wish to drill test the high grade silver with hole 13. Martin for his diligent logging of RC chips that identified the stratabound concept at Silver Hill.

Willingness of management to trust the field crew to test targets

Ground magnetics for detailed structure
In Hind sight, although airbourne magnetics provides very clean level data; a number of key ground magnetics targets and structures used in our exploration programs are not visible in our airbourne data (subsequently flown). Both are at 50m line spacing.

**The Exploration Future**

We believe we have identified a new camp or mineral field, with anomalous metals geochemistry and siliceous outcrops spread over 25km of strike. There is potential for discovery of a major resource. This potential has been recognised by Gold Fields Limited, who have entered into a joint venture on the 8 tenements covering 1600 $km^2$ surrounding the 7$km^2$ Mt Carlton Project which is 100% owned by Conquest. Gold Fields can earn a 51% interest in the *Regional JV Area* by completing 150,000m of drilling over a 3-year period. It is also obliged to spend A$5m in the first 12 months of the agreement.

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# HILLGROVE: A NEW START

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Straits Resources purchased 100% of the Hillgrove Gold Mine in March 2004. Since then, Straits has pursued an aggressive exploration program coupled with ongoing care and maintenance activities up until July 2006. In July 2006, Straits committed to spending $30M on pre-mine development and construction of a demonstration process plant, in addition to an ongoing exploration program.

Hillgrove is a historical mineral field where gold, antimony and tungsten have been mined since the 1880's. The deposits are located proximal to and within a 450 metre deep gorge adjacent to the village of Hillgrove. The steep terrain has provided haulage, mining and exploration challenges for current and previous miners.

In summary, the geology of the Hillgrove area consists of Carboniferous metasediments which have been intruded by Late Carboniferous to Late Permian granitoids during several episodes of plutonism, associated with the formation of the New England Orogen. Hydrothermal mineralisation has then been emplaced during the Permian along major northeast trending structures and between these structures via sinistral movement, creating dilatant jog zones. Remnants of tertiary basalt flows and associated alluvium have produced inverted topography in some areas, possibly concealing mineralisation.

The target mineralisation is hydrothermal vein and shear-hosted gold, antimony, tungsten and silver. Several styles of deposit have been targeted. In terms of 'million ounce gold equivalents' the deposit styles targeted are analogous to Eleanora (1 Moz), Comet (0.25 Moz), Enmore (0.4 Moz), Brackins Spur/Clarks Gully (0.4 Moz) or Syndicate (0.75 Moz). There are over 200 gazetted lodes in the Hillgrove area with extensive workings on many of the lode systems. To date, 15 lode systems have been tested. Straits currently have a resource of 1.44 million ounces (gold equivalent) as at 31st of December 2006.

The production target for Hillgrove is to produce 250,000 tonnes of ore per annum and extract 10,000 tonnes of antimony, 21,000 ounces of gold and 300 tonnes of tungsten concentrate (scheelite mineral). Gold and antimony will be recovered using electrowinning technology. Tungsten will be gravity recovered.

Since the last Mines and Wines conference in 2006, the following activities have occurred on site:
Construction of a demonstration process plant capable of producing antimony and gold ingots. The plant also produces a tungsten concentrate.

Construction of a new tailings storage facility.

Construction of a new road and causeway linking the plant with the deposits of Metz Gorge via Bakers Creek.

Pre-mine development of the Syndicate lode including portal development and stripping to allow jumbo and production drill access. Ventilation, water and power upgrades have also been completed. An underground workshop, crib room and rescue chamber have also been established. An entire mining fleet has been acquired.

Infill and exploration diamond drilling of the Syndicate, Eleanora, Golden Gate and Brackins Spur deposits (~13,000 metres). A hole has also been drilled into the gap between Garibaldi and Brackins Spur into the Central Eleanora Structure.

Regional exploration including airborne magnetometer survey and digitising legacy data including streams, soils, drilling and geological mapping. Soil sampling and mapping has commenced on several prospects.

Upgrade to offices, store, laboratory, security, core processing and first aid room.
Establishment of an Emergency Response Team.

Ongoing rehabilitation of environmental damage from previous mining activities.
Personnel numbers have increased from 25 to ~100 people on site.

Mine production commenced in June 2007 with the first delivery of ore to the ROM. The demonstration process plant has undergone commissioning since late August 2007. Production of the first metal is expected at the commencement of Q4 2007.

# LOCKINGTON: A NEW GOLD DISCOVERY UNDER MURRAY BASIN COVER

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**Key words:** Lockington, gold, arsenopyrite, Murray Basin, soil geochemistry, aircore drilling, gravity, turbidites

**Abstract**
A new gold system has been discovered within Ordovician Turbidites under Murray Basin cover at Lockington in north-central Victoria. Depth to weathered basement varies from 40 to over 120 metres, and the nearest outcropping basement is 15 kilometres to the south. Mineralisation is within the interpreted northern extension of the Ballarat-Bendigo gold belt. The area was selected using regional modelling techniques, supported by structural interpretation based on gravity and aeromagnetics data. Soil geochemistry was used to select and prioritise areas for basement sampling using AirCore drilling. Mapping of the basement geochemistry has delineated at least 7 extensive north-south striking mineralised trends within an area 9 kilometres long by 5 kilometres wide.

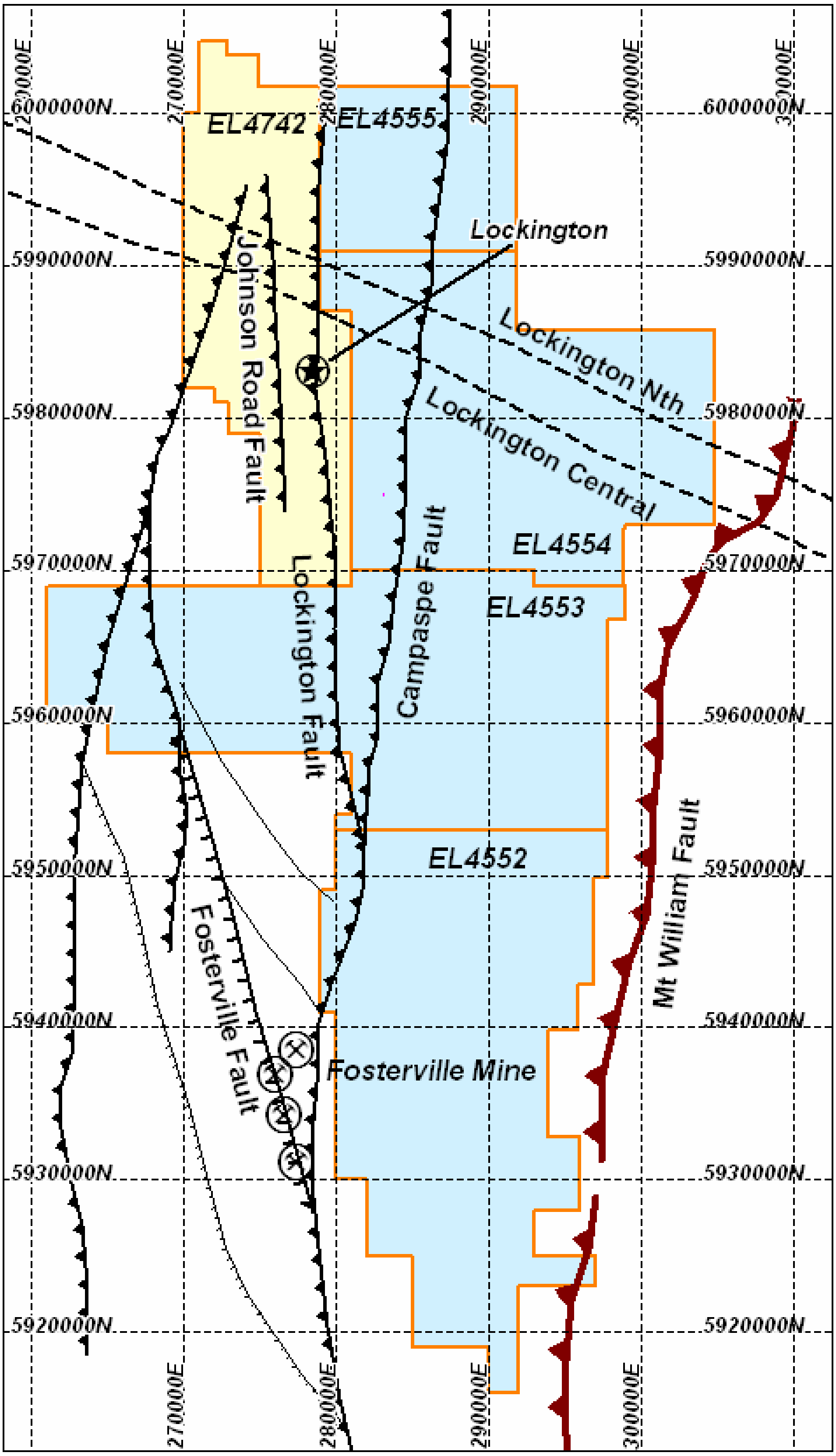
Diamond drilling has identified significant gold intersections in a sediment shale package. Detailed logging of the drill core has led to a comprehensive interpretation of the complexly folded and faulted Ordovician turbidites that host the sulphide associated mineralisation of the Fosterville style, but understanding of the controls on mineralisation is still being developed.

## Introduction
The Central Victoria Project was instigated by Gold Fields Australasia (GFA) in July 2003 and presently consists of a joint venture between GFA and Pacrim Energy Ltd (GFA earning 75% of ELs 4552 to 4555) and one tenement held 100% by GFA (EL 4742). The project is managed by Exploration Management Services (EMS) based in Bendigo, Victoria.
The project targets a plus 5 million ounce Ordovician sediment hosted orogenic gold deposit under shallow cover and along the strike of the Central Victorian gold fields that have produced over 50 Moz. Several deposits of the size targeted include Fosterville, Bendigo, Stawell and Ballarat.

The Project area was selected as no previous gold exploration had been attempted over much of the area, despite its location near the major Bendigo gold deposit. Due to depth of tertiary cover of 30-200m, underground mining operations are the likely outcome of successful exploration.

## Regional studies
The Ballarat-Bendigo gold fields have produced over 50 Moz of gold from areas of outcropping Ordovician sediments, and although most of this area has been lightly explored, the potential for an undiscovered major gold deposit is slim. North of Bendigo however, is very poorly explored due to the thick cover sequence of Tertiary Murray Basin sediments. Major gold deposits in the Ballarat-Bendigo region follow a NNE trend (individual strikes of deposits or lodes are north-south, to NNW striking) which closely parallel the interpreted margin of the Selwyn Block as proposed by Geoscience Victoria (Cayley, et al, 2002). Detailed geophysics data collected by the GSV combined with this research were crucial in identifying key structures and gold targets. Tenements were selected or applied for as land became available north of Bendigo on this north-easterly trend.

A group of prominent north-south structures were interpreted from the regional VIMP gravity data – apparent splay structures from the newly interpreted Campaspe Fault (parallel to the regionally important Mt William Fault) include the Fosterville Fault (associated with mineralisation at the Fosterville Mine) and the Lockington Fault.




Depths to

Figure 1 Regional Structures Fosterville to Lockington basement were estimated from the regional borehole database – contours of basement depths show a prominent topographic ridge extending northwards to Lockington, coincident with the Lockington Fault. Indicative shallow depths along this ridge are conducive to economic AirCore testing of basement.

Targeting was further refined by soil geochemistry. After a trial program using various partial leach methods, samples collected along E-W roadside reserves at 400 metre spacings were submitted for gold and silver (2 kg Bulk Cyanide Leach) and arsenic, antimony and base metals by 50 gm aqua regia and AAS. Gold results highlighted the dispersion in Bendigo Creek, and showed the only 2 known deposits on the southern margin of the tenements. Combined metal results, on the other hand gave low level anomalies in the north of the project area near Lockington. As one of these metal anomalies was coincident with the interpreted Lockington Fault, re-sampling at closer spacing across private land was undertaken to confirm and clarify the anomaly.

While the infill soil data did not show any "classic" anomalies, there was a significant variation of metal values in an otherwise regional flat response. Drill targets were generated by lining up peaks in the metal-in-soil profiles for each of the lines sampled at Lockington South.

**AirCore drilling**

After drilling and confirming that the gold-arsenic anomalies in the Bendigo Creek flood plain were spurious, the AirCore rig moved to test basement beneath the soil geochemistry anomalies south of Lockington. The first hole was sited over the interpreted Lockington Fault close to one of the stronger anomalies, and 20 other holes were drilled on 3 lines, 600 to 700 metres apart with inter-hole spacings of 80 metres. Significant quartz veining and water ingress supported the Lockington Fault interpretation, but otherwise the basement rocks appeared to be barren. Basement depths ranged from 48 to 110 metres, the cover sequence being layered clays and water saturated sands.

| Hole ID | From (m) | To (m) | Thick (m) | Au (ppm) | As (ppm) | Sb (ppm) | Depth to Basement | Line |
|---|---|---|---|---|---|---|---|---|
| 04LOKC001 | 75 | 90 | 15 | 0.53 | 203 | 9 | 54 | 1 |
| 04LOKC006 | 66 | 72 | 6 | 0.74 | 190 | 35 | 66 | 1 |
| 04LOKC006 | 78 | 81 | 3 | 0.15 | 90 | 19 | 66 | 1 |
| 04LOKC011 | 59 | 60 | 1 | 0.12 | 89 | 11 | 59 | 1 |
| 04LOKC011 | 66 | 69 | 3 | 0.13 | 125 | 26 | 59 | 1 |
| | | | | | | | | |
| 04LOKC008 | 96 | 111 | 15 | 0.29 | 148 | 10 | 84 | 2 |
| 04LOKC010 | 78 | 81 | 3 | 0.12 | 72 | 21 | 78 | 2 |
| 04LOKC010 | 96 | 111 | 15 | 1.27 | 290 | 17 | 78 | 2 |
| | | | | | | | | |
| 04LOKC016 | 99 | 102 | 3 | 0.11 | 511 | 1 | 102 | 3 |
| 04LOKC019 | 78 | 84 | 6 | 0.28 | 33 | 5 | 78 | 3 |
| 04LOKC019 | 93 | 99 | 6 | 0.18 | 49 | 3 | 78 | 3 |
| 04LOKC020 | 84 | 87 | 3 | 0.12 | 15 | 15 | 69 | 3 |
| 04LOKC020 | 93 | 99 | 6 | 0.13 | 42 | 13 | 69 | 3 |

**Table 1** **Initial AirCore Results** (June 2004)

Follow up drilling on lines approximately 300 to 400 metres apart north and south of these intersections subsequently defined the Carnie Trend over 3.5 kilometres strike length. Further AirCore drilling over the following 3 years has defined at least 7 mineralised trends within an area 9 kilometres long by 5 kilometres wide south and east of the town of Lockington. The longest mineralised trend is the Main-Lees Trend at 9.0 kilometres with gold intersections up to 130 metres width, open to both north and south. Trends are defined by gold values > 0.1 g/tonne or arsenic > 150 ppm. The highest gold value returned is 7.05 g/t over 3 metres in the Watson Trend, and broad zones of up to 30 metres at 0.8 g/t gold have been recorded.

Total AirCore drilling to date, with regional exploration is 105,645 metres in 1,041 holes. Standard practice is logging and sampling at 3 metre intervals, allowing for rapid drilling and rod change in sometimes difficult conditions. Only basement material is sampled for gold, arsenic, antimony and a select suite of other metals.

**Diamond Drilling**

The first 4-hole diamond drill program hole commenced in June 2005 on the Carnie Trend. The gold mineralisation is associated with pyrite + arsenopyrite mineralisation in sericite altered sandstone-shale packages. Quartz veining need not be present, but where intersected in mineralised zones, is unmineralised but strong arsenopyrite mineralisation is often developed in the immediate wall rock to the veins. While visible gold has been observed (to 2 mm diameter) on rare occasions, overall the mineralisation style is identical to that at Fosterville.

| Hole ID | From (m) | To (m) | Thickness (m) | Au (ppm) | As (ppm) | East | North | Azimuth | Dip |
|---|---|---|---|---|---|---|---|---|---|
| 05LODH001 | 166.0 | 173.7 | 7.7 | 4.24 | 3488 | 278900 | 5981179 | 89 | -60 |
| 05LODH001 | 181.5 | 183.6 | 2.1 | 2.92 | 3352 | | | | |
| 05LODH002 | 259.8 | 261.0 | 1.2 | 2.44 | 3748 | 278849 | 5981176 | 89 | -60 |
| 05LODH004 | 154.6 | 156.4 | 1.8 | 12.04 | 3887 | 278936 | 5980956 | 89 | -60 |
| 05LODH004 | 224.5 | 226.1 | 1.6 | 19.49 | 4064 | | | | |
| 05LODH004 | 270.0 | 282.0 | 12.0 | 2.47 | 2987 | | | | |
| 05LODH005 | 230.8 | 234.9 | 4.1 | 6.28 | 2460 | 279112 | 5981183 | 269 | -60 |
| 05LODH005 | 245.8 | 247.5 | 1.7 | 1.77 | 2224 | 279112 | 5981183 | 269 | -60 |
| 05LODH006 | 280.0 | 282.0 | 2.0 | 2.47 | 3033 | 278763 | 5981174 | 89 | -65 |
| 05LODH007 | 303.2 | 308.9 | 5.7 | 3.15 | 3406 | 279186 | 5981164 | 269 | -55 |
| 05LODH008 | 437.2 | 437.7 | 0.5 | 7.55 | 7810 | 279257 | 5980911 | 269 | -62 |
| 06LODH012 | 161.0 | 162.6 | 1.6 | 1.51 | 1722 | 278965 | 5981892 | 89 | -58 |
| 06LODH012 | 289.6 | 290.2 | 0.6 | 10.40 | 17100 | | | | |
| 06LODH015 | 141.2 | 146.3 | 5.1 | 1.65 | 4083 | 279150 | 5979974 | 89 | -58 |
| 06LODH017 | 301.4 | 302.3 | 0.9 | 3.47 | 6003 | 278836 | 5981903 | 91 | -60 |
| 06LODH017 | 453.0 | 454.6 | 1.6 | 1.54 | 2815 | | | | |
| 06LODH017 | 508.5 | 509.8 | 1.3 | 4.91 | 1705 | | | | |
| 06LODH020 | 203.0 | 204.1 | 1.1 | 2.64 | 3992 | 279604 | 5981442 | 89 | -58 |
| 07LODH022 | 128.4 | 130.9 | 2.5 | 4.17 | 7659 | 278933 | 5980603 | 89 | -57 |
| 07LODH022 | 129.1 | 130.9 | 1.8 | 5.40 | 9778 | | | | |
| 07LODH022 | 132.3 | 134.1 | 1.8 | 2.48 | 5427 | | | | |
| 07LODH024 | 256.9 | 258.9 | 2.0 | 2.50 | 4474 | 279269 | 5980598 | 269 | -55 |
| 07LODH024 | 271.8 | 274.4 | 2.6 | 3.62 | 4999 | | | | |
| 07LODH024 | 279.9 | 283.4 | 3.5 | 4.00 | 4796 | | | | |

**Table 2 Significant diamond drill results**
As at February, 2007

**Other Methods**

As the mineralisation is associated with sulphides from 1 to 2% of the shale-sandstone packages, electrical geophysics methods were considered for better drill target definition. IP was rejected, due to the number of fences (most electric) in the area. CSAMT was trialled, but the results were too noisy and there was no significant depth penetration, although the cover-basement contact was defined fairly accurately. Airborne TEM has closely mapped the cover thickness and palaeochannels further west, and has definite potential as a basement mapping tool.

**Construction of sections**

Most of the gold mineralisation in central Victoria is hosted by shale-sandstone packages in the Ordovician turbidite pile. Sandstones and shales repeat on a regular basis, with individual beds varying in thickness from a few centimetres to 10 metres or more. Facies changes along strike and the development of submarine channel sands and overbank deposits preclude the development of well defined marker beds that can be used to determine where in the overall package a particular drill intersection might be.

GFA and EMS adopted the sequence stratigraphy method of logging turbidites developed by Linex Pty Ltd as an aid to interpreting cross sections. This is based on logging sediment grain size at intervals down to 10 cm (down hole), converting drilled thickness to true thickness based on alpha angles – the resulting graphical logs are then compared across holes and packages of sediments are readily correlated. Loss, or repetition of packages can also be identified, and thus faults interpolated.

This method has proved invaluable in interpreting the structural geology of an area with no outcrop to provide even the most basic of data. Because the beds are laterally continuous, diamond drilling along widely spaced lines can be used to construct a reliable geological framework.

**Discussion**

The Central Victoria Project was initiated using a combination of regional studies and structural interpretation of both magnetic and gravity data. These methods produced broad areas of interest, but on-ground methods were required to define drill targets. Conventional exploration techniques were used, but significantly were applied for the first time in the area. Regional soil sampling identified anomalous multi-element geochemistry south of Lockington, which, after some follow-up sampling, led to the decision to drill three lines of aircore holes to sample the basement. Gold mineralisation under cover at Lockington was located by aircore drilling based on coincident soil geochemical anomalies with prioritised regional structural features. The size of the mineralised halo or footprint at thresholds of >100 ppb gold and >100 ppm arsenic is large, allowing for quite wide aircore drill spacings.

So, if soil geochemistry truly reflected the gold mineralisation in basement rocks, how did the metals move vertically through 50 to 100 metres of unconsolidated wet sands and aquitard clays? Or was it coincidence, and the surface geochemical anomalies are just noise?

Soil sample surveys have been trialled across some of the main basement anomalies by Geoscience Victoria (GSV) and crc-LEME, and 3 metre samples through the cover sequence have been tested for trace elements by GSV. Preliminary results do indicate that soil geochemistry is a valid tool for locating mineralisation under thick sequences of unconsolidated Tertiary cover, under certain conditions.

Gold Fields is continuing to assess the potential of this new gold field.

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Linex Pty Ltd Core logging in central Victoria http://www.linex.com.au/core/contents.htm

# MINERAL SYSTEMS IN THE TASMANIDES: THE GLOBAL PERSPECTIVE

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## Introduction

A major aim of the AGCRC and pmdCRC over the last two decades has been to develop mineral systems concepts that have genuine predictive capacity. The emphasis on understanding "where" the deposit is located underpins the need to think about how ore forming processes operate in space as well as in time. This emphasis on "where is the deposit" led inevitably to a restating of the "source" "transport" and "trap" paradigm of mineral systems. The "5 Question" description of the mineral system explicitly highlights the problem of understanding the system in space and the temporal evolution of the system at all scales. Question 1 asks: "What is the architecture and size of the system?" and question 2 asks: "What is P-T and the geodynamic history of the system. Hence, the source/transport/trap issues addressed by questions 3, 4 and 5 are explicitly linked to the spatial and temporal of the mineral system. Q3: "What is the nature of the fluids and fluid reservoirs in the system?" Q4: "what is the nature of fluid pathways and processes driving fluid flow" and Q5: "what is the nature of chemistry of metal transport". Most of the research has focused at the deposit to district to terrain scale. Arguably, there is a need to ask the "5 Questions" at Earth - scale or at least consider the possibility of needing to work at that scale. This contribution considers some aspects of the tectonics and metallogeny of the Tasmanides from the global perspective.

## Whole-of-Earth Mineral-System Models

The rationale for developing whole-of-earth mineral-system models is to better understand the properties of mineral systems at all spatial and temporal scales through Earth history as well as the links between metallogenesis and other Earth processes. Typical length scales of major mineral provinces are of the order of 100s to 1000s of kilometres across the earth's surface. The major mineral provinces of the Tasman Fold belt System (e.g. the 440Ma metallogenic event of the LFB, the Sn belt of the western Lachlan, the Permo-Carboniferous gold province of North Queensland) are of this scale. Given that aspect ratios (length to depth) of systems can be expected to be of the order of 1:1 then the depth of mineral systems may well be 100s to 1000s of kilometres rather than 10s of kilometres as commonly assumed. The distance from the surface of the Earth to the core is approximately 3000 km making it conceivable that some components in mineral systems may originate in the lower mantle, if not the core of the Earth. Is it actually possible that a mineral-system might extend to these depths? Seismic studies in major mineral provinces have established crustal-penetrating structures and identified architecture in the upper mantle to depths of ~ 100-150 km. Tomographic studies have also established steep structures in the Earth's lower mantle that extend into the upper mantle. If these architectural elements were linked then fluid release from the lower mantle may be possible.

## DEEP EARTH FLUIDS, TECTONISM AND PATHWAYS

If the deep-Earth released fluids into mineral-systems what would be their nature and how could the record of fluid release be established? The occurrence of Si and Fe-silicides inclusions in SiC from the mantle indicates the presence of hyper-reduced, $H_2$ - rich fluids, albeit transiently, in the upper mantle. The density deficiency of the Earth's core points to the core being the dominant reservoir of these fluids. Hydrogen-rich or hydridic fluids have potential to complex a wide range of elements of metallogenic interest (e.g. Ti, V, Cr, Ni, Co, Cu, Pb, Zn, Mo, W, U, Th, Au, PGEs, REEs) at high temperature and pressure, either as hydrides or S, N, C and/or halogen complexes. Hence there is the possibly of transporting a wide range of elements at high temperature and pressure within the mantle and crust by fluids other than silicate melts. Aqueous fluids may dominate processes in the crust but metal transport phenomena in the mantle, in fluids other than silicate melts, are much more likely to be controlled by anhydrous fluids and at depths greater than 300 to 400 km these fluids will be dominated by $H_2$ and $CH_4$ rather than $CO_2$. The "deep-earth" fluids are postulated to contain H, N, C S and halogen (Cl, F) complexes with hydridic complexes such as NaH, $MgH_2$, $AlH_3$ and $SiH_4$ potentially playing a significant role in mobilizing the common rock forming elements.

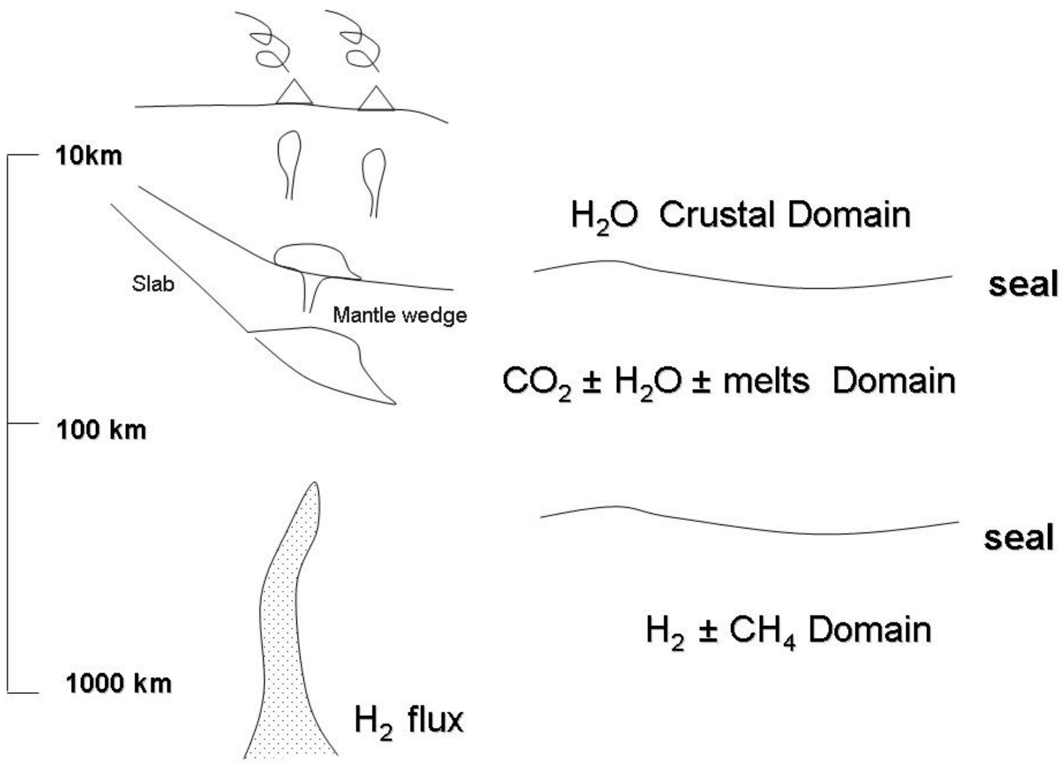


Figure 1: Plumes of hydridic fluids may provide geochemical connectivity between distinct compositional reservoirs in the core/lower mantle and the crust/upper mantle.

Focused domains of Fe - enrichment may create at least transient sources of negative buoyancy that could impact on subduction processes. Most thinking is focused on "top down" mechanisms to drive a cold, stiff, and negatively buoyant lithosphere into the mantle with sources of negative buoyancy and instabilities considered to be within tectonic plates or from surface loading of the plates. "Bottom up" metasomatic loading could provide an alternative mechanism to create at least the transient instabilities required for initiation of subduction. Plumes of hydridic fluids may provide geochemical connectivity between distinct compositional reservoirs in the core/lower mantle and the crust/upper mantle; creating a mechanism to re-enrich the upper mantle in elements depleted by melt production and crust formation through Earth history. The tears in slabs, cross-arc structures and times of plate re-orientation, slab-rollback and slab-foundering are important architectural and dynamic factors that help create pathways fro the deep-Earth fluids into the upper-crust. Arguably, such factors played an important role in the distribution of the major provinces of the Tasmanides. The control of the Lachlan Tranverse Zone on the Ordovician Cu-Au Province and the Cobar Field is one example. The cross-arc structural control on the Permo-Carboniferous Gold Province and associated magmatism is another.

## HISTORY OF EARTH DEGASSING AND FOOTPRINT IN THE CRUST

The history of Earth's degassing may be reconstructed from redox-sensitive indicators of the hydrosphere and reflects the interplay of deep Earth $H_2$ - rich fluids with $CO_2$ ± $H_2O$-fluids of the outer ~200 km of the Earth. There have been 2 major epochs in last 3.0 billion years of Earth history from ~2.4 to 2.0 Ga and ~ 0.9 to 0.6 Ga when the outer shell of the Earth has been largely sealed to advection of green-house gases but open to enhanced diffusive loss of $H_2$ with shorter epochs of advection of $CH_4$ - rich and $CO_2$ - rich gases. Upper mantle shear zones that may have acted as seals to advection of green-house gases from inner Earth are predicted from thermo-mechanical models of the Earth. The most significant epochs of enhanced diffusive loss of $H_2$ in the Phanerozoic occurred at ~ 450 to 400 Ma and ~ 350 to 250 Ma. These epochs overlap with significant metallogenic epochs in the Tasmanides.

The responses to injecting a hydridic fluid, stable at > 600 km within the earth, into crustal rocks ± aqueous crustal fluids will depend on the precise reaction path and P/T conditions. A significant factor will be ratio of alkali and alkali-earth halides to HF and HCl which will control the evolution of acid/base balance of the fluids as they react with crustal fluids and rocks, degrading to aqueous fluids of varying acidity, redox state and salinity. Relatively high halogen to alkali ratios should lead to acid production through dissociation of HCl and HF in aqueous crustal fluids; assuming limited degassing of hydrogen. Loss of hydrogen through degassing, or consumption of hydrogen through reaction with oxidised species or rocks (sulfate and carbonate or $CO_2$) could lead to neutral to alkaline, highly saline, sodic and potentially magnesium, and calcic brines depending on the history of fluid rock reaction. These brines may be sufficiently alkaline to dissolve quartz. These "degraded" hydridic fluids can explain the widespread occurrence of acidic alteration, as well as regional scale sodic-calcic alteration and Mg-metasomatism. Deposit to district mapping of these alteration assemblages will define the pathways and role of deep-Earth fluids in deposit formation in the Tasmanides.