Mines&Wines

2006

Mineral Exploration Geoscience in NSW

EXTENDED ABSTRACTS

CESSNOCK
May 2006

SMEDG

Bibliographic reference
Lewis P.C. 2006 Mineral Exploration Geoscience in New South Wales, Mines and Wines Conference, Cessnock NSW SMEDG

Contact details – see www.SMEDG.org.au

DISCLAIMER

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

Short quotations from the text of this publication and copies of maps, figures, tables, etc (excluding any subject to pre-existing copyright) may be used in scientific articles, exploration reports and similar works provided that the source is acknowledged and subject to the proviso that any excerpt used, especially in a company prospectus, Stock Exchange report or similar, must be strictly fair and balanced. Other than for the purposes of research or study the whole work must not be reproduced without the permission in writing of SMEDG.

MINES AND WINES

MINERAL EXPLORATION GEOSCIENCE IN NSW

CONTENTS

Papers in Order of Conference Presentation **Page No**

ORGANISING COMMITTEE

In alphabetical order:

Glen Coiainz	**Golden Cross Resources**
Kim Stanton Cook	**Golden Cross Resources**
Lindsay Gilligan	**Geological Survey of NSW**
Roger Smyth King	**Contour Graphics**
Peter Lewis	**Geological Survey of NSW**
David Timms	**Golden Cross Resources**
Chris Torrey	**Apex Silver**

PLATINUM SPONSORS

FUGRO
AIRBORNE AND GROUND
GEOPHYSICAL SERVICES

MACQUARIE
BANK

ORTA RECENS QUAM PURA NITES

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

GOLD SPONSORS

CBH Resources

G.o.S
DRILLING

GOLD SPONSORS

encom

H & S Hellman & Schofield

BARRICK
AUSTRALIA

Straits

CSA Mine
CMPL

ALS
ALS Chemex

Supporting Organisations

Rangott Mineral Exploration Ltd

Golden Cross Resources Limited

PREFACE

Kim Stanton Cook

The 2006 Mines & Wines Conference is another link in the relationship linking the NSW DPI and the Exploration and Mining industry in their combined efforts to share data and general information.This collective chain forms part of a long line of seminars and similar cooperative ventures which have provided mineral explorers and producers in NSW the opportunity to showcase their latest updates on project growth and development.

SMEDG & NSWDPI have a long and successful history of collaborative effort in regard to holding Conferences of the calibre which will be achieved, I am sure, by this one
The industry has a number of issues confronting it at this moment in time: we are in boom times, a semi-unusual event but one which some of us are used to and we are aware of what the future holds. The global geopolitical situation may delay the inevitable down-turn but we should prepare for the future. This is a novel idea - we have never prepared before - but why not start now. We have come through the 90's and many major companies, driven by bottom-line considerations or as a result of mergers & acquisitions, have laid off staff to reduce exploration expenditure - as an "unecesssary cost". Now those same companies are driven, by current high commodity prices, to expand their exploration staff and they complain of shortages of personnel. Why can't these companies have their cake and eat it too? They have sown the seeds of their own downfall and should be condemned. Where were the vacation jobs for 2nd and 3rd year geology students? Where were the bursaries to encourage young Australians to enter schools of earth sciences and geology. Where were the complaints and entreaties to governments to support tertiary earth science education? Missing......and not even in action.
"They", the silent ones, must accept responsibility and, if you are not one of them, do something positive. Arrange student employment on your projects that will help those students become better geologists. Support funding, by sponsorship, of SMEDG student field mapping programs so that our profession has a future. Field skills, environmental sensibilities, community awareness, and the ability to blend into and become part of rural Australia are wonderful skills. Can you help a young geologist achieve the level of confidence that so many of us older geoscientists take for granted? No? Then get out of the road and make way. We know who you are!

The Lachlan Orogen: New boundaries, new data, new ideas, new deposits

Dick Glen

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

Introduction: the Lachlan Orogen in a Tasmanide Context

The Lachlan Orogen of NSW, Victoria and northeast Tasmania forms the keystone in our understanding the tectonic and metallogenic evolution of all of eastern Australia. In this paper, I first discuss the Lachlan Orogen within its eastern Australian context, before focusing on its boundaries and then on key tectonic, structural and metallogenic aspects of its formation. In this way I hope to construct plate tectonic and architectural frameworks within which we can place a discussion of mineral deposits.

Palaeozoic to Mesozoic rocks in eastern Australia constitute the Tasmanides, itself part of Gondwana. The Tasmanides record the break-up of the supercontinent Rodinia, from ~750 Ma until ~525 Ma, followed by ~300 million years of largely convergent margin interaction with the proto-Pacific plate until the Late Triassic.

How do we try and describe the geological chaos that eventuates from such plate interactions, especially since we are looking back over 480 million years and lessons from the SW Pacific tell us that arcs are born and die (ie are subducted) in only a few million years. There are two main ways.

The first is to divide the Tasmanides into areal packages. This is conventionally done by subdividing it into a collage of orogenic belts (or orogens, known as fold belts before the importance of linked fault systems was appreciated). This subdivision is a structural one, and is based on estimating the areal extents of deformations of different ages. In this way, the Tasmanides are subdivided into five orogenic belts. In the southern Tasmanides are the Delamerian (=Tyennan in western Tasmania), the Lachlan and the southern New England Orogen. In the north lie the Thomson Orogen, the northern New England Orogen and to the north the North Queensland Orogen. Just to complicate things, an internal Permian-Triassic rift-foreland basin system, the Bowen-Gunnedah-Sydney Basin System, separates both the Lachlan Orogen and Thomson Orogen from the New England Orogen. Using this system of subdivision, rocks of the Delamerian Orogeny were deformed by the Middle-Late Cambrian Delamerian Orogeny, the Lachlan Orogen was deformed at the end of the Ordovician (Benambran Orogeny), as well as in the Middle Devonian (Tabberabberan Orogeny) and also in the Early Carboniferous (Kanimblan Orogeny). Complications occur where orogenies consist of phases separated by sedimentation and/or igneous activity, and where post-orogenic stratigraphic units lie above rocks deformed in these defining orogenies, making it difficult to recognise and interpret boundaries between orogens.

Other problems also arise, from this classification system. For example, how do we classify Cambrian mafic and ultramafic rocks that characterise much of the Delamerian Orogen but which also lie east of the Delamerian Orogen? Outcrops occur in both the New England Orogen (along the Peel-Manning Fault System) and in the Lachlan Orogen, for example in the hangingwalls of the Heathcote, Mt Wellington and Governor fault zones. Because these rocks, as far as we know, were not deformed in the Delamerian Orogeny, we can't put them into the Delamerian Orogen.

The solution lies in sub-dividing the Tasmanides into time packages. The concept of tectonic cycles or supercycles (Glen 2005) gets around this problem by erecting a series of tectonic cycles which are independent of geography. Then, by using the plate tectonic paradigm, we can categorise rock sequences and structures into plate tectonic elements in an individual time slice into (ie a convergent margin consisting of, perhaps, an arc, backarc basin, subduction complex), or extensional margin or strike-slip margin.

A complete tectonic cycle includes sedimentation and igneous activity (either one of, or a combination of, convergent, strike-slip or extensional or intraplate) followed by deformation that commonly appears to reflect the accretion of a terrane, such as an arc or subduction complex, to Gondwana. Each cycle is named after its terminal deformation. Temporally, the Tasmanides comprise three (super)cycles, each encompassing sedimentation and igneous activity, terminated by orogenies. The supercycles are the Delamerian (Neoproterozoic to latest Cambrian), terminated by forearc or arc collision with the craton in the Middle to Late Cambrian (with post collisional granites and molasse), the Lachlan (basal Ordovician to Early Carboniferous and divided into three cycles all terminated by orogenies - the Benambran, the Tabberabberan and the Kanimblan) and the Hunter Bowen (Late Devonian to Late Triassic) terminated by accretion of an intraoceanic arc.

Using tectonic cycles in this way shows that from the Middle Cambrian to the Late Triassic, the Tasmanides evolved by long periods of sedimentation, arc and back arc activity along the east Gondwana margin, coupled with formation of subduction complexes related to generally west-dipping subduction. These were punctuated by the short-lived, ?orthogonal as well as highly oblique accretion of craton-derived turbidite terranes, island arcs and subduction complexes that developed along the east Gondwana margin that also acted to close back arc basins. The proto-Pacific Ocean itself was never closed.

In the Tasmanides, rocks generally get younger from west to east, away from cratonic Australia, so that rocks in the Delamerian Orogen are generally older than those in the New England Orogen. This fits a model in which the Tasmanides grew by the accretion of rock masses at plate boundaries. However, there are two important caveats (Glen 2005): i) there is no sign of accretion in the North Queensland Orogen, where Neoproterozoic to Permian rocks are stacked on top of each other, and remain close to the cratonic margin. This in marked contrast to the southern Tasmanides, where the eastern margin of the Delamerian Orogen lies ~400 km east of cratonic Australia (the Gawler Craton). Rocks in the Lachlan Orogen may lie up to an extra ~700 km farther east and the New England Orogen up to ~300 km farther east again. And these are deformed widths! This important difference between the northern and southern Tasmanides may indicate that rollback of the proto-Pacific plate only occurred in the south, and must reflect segmentation or oblique spreading of that plate.
ii) rollback of the southern part of the proto-Pacific plate is reflected by some of the outboard orogens containing old rocks (eg rocks of the Delamerian supercycle in the Lachlan Orogen and New England Orogen and rocks of the Lachlan supercycle in the New England Orogen). These represent pieces of older cycles rifted off during rollback in the Ordovician and again in the Silurian-Devonian (Glen 2005) and now forming partial basement to the new cycle.

The Lachlan Orogen: boundaries The eastern boundary of the Lachlan Orogen with the New England Orogen is obscured by young rocks of the Sydney and Gunnedah basins. The western boundary with the Delamerian Orogen is controversial and is discussed by Hallett *et al*. (2005) and Hallett (this volume). ~500 Ma white mica cooling ages reported from parts of the Stawell Zone in western Victoria (Miller *et al.* 2005) suggest that the Lachlan-Delamerian Zone boundary lies east of the Coongee Break (east of the Stawell gold mine) and it is here taken to lie along the Avoca Fault, west of the Bendigo Zone. Extensions of the Stawell and Bendigo zones into southwestern NSW have considerable economic implications. The northern boundary with the Thomson Orogen occurs in the Tibooburra-Brewarrina area of far northwestern NSW and is a curvilinear east-west trending, north-dipping crustal scale thrust. Results of seismic reflection profiling across this contact are discussed by Glen *et al*. (this volume).

Before concentrating on the Lachlan Orogen, I must make brief comment on the Delamerian supercycle.

The Delamerian supercycle consists of two cycles. The first cycle records a prolonged rifting event from 750 Ma till ~580 Ma as Rodinia was broken up. The inboard part is largely amagmatic and is represented by the Adelaide Rift Complex. The outboard part is characterised by development of smaller rift basins and a major alkaline magmatic rift system from 600-580 Ma. The second cycle is marked by a switch to convergent margin magmatism in the outboard part of the Delamerian Orogen that began about 525 Ma. This was approximately synchronous with a new rifting event, leading to formation of the Kanmantoo Trough in the inboard part of the orogen. Cycle two is reflected by the formation of mafic to ultramafic boninitic forearc crust in western Tasmania and probable arc rocks as well as forearc crust on the mainland. Both east and west dipping subduction have been proposed and more than one arc may have been developed sequentially. Accretion of arc and forearc rocks occurred around 510-505 Ma and was followed by extension, post-collisional volcanism and then later deformation at the end of the Cambrian.

The Lachlan Orogen: cycles and metallogeny

The Lachlan Supercycle is divided into three cycles – the Benambran, the Tabberabberan and the Kanimblan

The Benambran cycle began with molassic sedimentation on the old Delamerian Orogen, but was mainly characterised by rollback of the southern part of the proto-Pacific plate after the Delamerian Orogeny. A new plate boundary was established about 1000 km east of the old Delamerian margin, and led to the formation of the intraoceanic mafic to intermediate Macquarie Arc opposite a 1000 km long, west-dipping, highly convergent part of the plate boundary. Blueschists associated with this subduction zone now occur as knockers in fault slices in the southern New England Orogen and were probably displaced ~200 km to the north in the end-Ordovician Benambran Orogeny. Ordovician quartz-rich turbidites and shales formed in separate terranes that show differences in lithology, thickness and fauna: one was probably in situ, deposited in a back arc basin, but the others are allochthonous and formed off present-day west Antarctica. One of these, the Bega Terrane, lies east of the Macquarie Arc and was transported northwards along a largely transform plate boundary in the Late Ordovician. It and the Macquarie Arc were accreted by a combination of thick and thin-skinned thrusting and multiple deformation around the Ordovician-Silurian boundary in the Benambran Orogeny. The largely Ordovician oceanic Narooma Terrane was accreted to the Bega Terrane in the Benambran Orogeny as well. MORB-like mafic volcanic + chert terranes represent ocean crust formed during mid-Ordovician seafloor spreading and were imbricated with other terranes during closure of ocean basins in the Benambran Orogeny. The allochthonous Bendigo Terrane also underwent a simple thin-skinned deformation in the Benambran Orogeny (well south of its present position), but only in the western part. In its eastern part, deposition continued into the Early Devonian during northwards strike-slip transport, and was only terminated by accretion at the end of the Early Devonian in the Tabberabberan Orogeny.

Metallogeny

Rocks of the Benambran Cycle contain the two world-class groups of deposits in the Lachlan Orogen: structurally-controlled gold deposits in the Bendigo Zone and porphyry gold-copper deposits (and other styles) in the Macquarie Arc. Although both underwent major mineralising events at ~440 Ma, the terrane model for the Benambran cycle suggests that they formed thousands of kilometres apart. Bendigo zone gold is syndeformational. Porphyry gold copper deposits in the Macquarie Arc formed during critical events in the evolution of the arc, related to interruptions, cessation or restarts of magmatism, not to steady-state subduction. Critically the ~440 Ma porphyries were emplaced during accretion of the arc in the Benambran Orogeny, with control apparently exercised by cross structures (see below).

Tabberabberan cycle

With the exception of the Bendigo Terrane, the enlarged eastern part of Gondwana was in tension from the Early Silurian to the Middle Devonian in the Tabberabberan Cycle. In the southern Tasmanides, crustal extension occurred in a wide developing back arc region that formed as a result of rollback of the southern part of the proto-Pacific Plate. This led to the relocation of a new west-dipping subduction zone and development of an intraoceanic arc and subduction complex, both now preserved in the southern New England Orogen. This Silurian-Devonian extension led to dismembering of the Ordovician Macquarie Arc into several structural belts, formation of sedimentary rift and transtensional basins and emplacement of both I and S-type granitic batholiths. The well known basins like Cobar Basin, Mt Hope Trough, Rast Trough, Cowra Trough, Hill End Trough, Canberra-Yass Shelf etc all formed during this event. Several rift events can be recognised, separated by sag-phase deposition of shales or limestone. Rifting occurred around 430 Ma, at the base of the Wenlock (Early-Late Silurian boundary), and again at around 413 Ma in the middle Lochkovian in the Early Devonian. Rift packages may be separated by provenance changes and/or extensional unconformities. Contractional deformation around the Silurian-Devonian boundary only occurred in basins near the NNW-trending Gilmore Fault Zone and its linked systems.

The Middle Devonian Tabberabberan Orogeny was marked by inversion of sedimentary and volcanic rich rifts, deformation of granitoids and re-deformation and renewed imbrication of older rocks. It was in part driven by changes along there plate margin and in part by the accretion of the Bendigo Terrane.

Metallogeny

The classical structurally controlled deposits in the Cobar Basin and Hill End Trough are hosted by Early Devonian sedimentary rocks, although their formation occurred during basin inversion, either Devonian or Carboniferous. Base metal-rich deposits in Silurian rifts in the eastern Lachlan Orogen seem to be largely structurally controlled and thus inversion related but whether this is Middle Devonian or Early Carboniferous is uncertain. Some mineralisation is syngenetic.

Granite-related mineralisation is often seen as high-risk in the Lachlan Orogen.. Fractionated I-type granites like the Braidwood (containing Dargues Reef) and those of the Boggy Plain Supersuite (eg Yeoval Complex with its large number of small showings) seem to have the most potential. In this context, interpretation of large areas of low-strain high level Early-mid-Devonian igneous complexes under cover north of the Narromine and Dubbo 1:250 000 sheets (Dawson & Glen 2006) increases the potential to find granite-related deposits, especially given their interpretation belonging to the Boggy Pain Supersuite (P. Blevin pers. comm. 2006).

Disseminated fine-gold deposits (‘Carlin-style’) also form exploration targets in carbonate rich basins, especially those that experienced multiple rifting events with associated magmatism and structures perhaps inherited from the Benambran cycle. Fine-grained gold may also occur in clastic sedimentary rocks too.

The Kanimblan Cycle (which overlaps in time with the Hunter-Bowen Supercycle of the New England Orogen) began with limited rifting, with formation of granites and volcanics in small, narrow rifts (A-type in NSW, S- and I-type in Victoria). Extension was rapidly aborted and replaced by deposition of a 3-4 km blanket of continental sedimentary rocks. These rocks extend from the Delamerian Orogen right across the Lachlan Orogen. Deformation occurred in the Early Carboniferous, with emplacement of post-tectonic Early Carboniferous granites.

Metallogeny

I-type Carboniferous granites and adjacent skarns host small deposits. Structurally controlled gold in Ordovician Sofala and Burranah Volcanics, in the eastern, Rockley-Gulgong Volcanic Belt of subduction-related volcanics and in the Silurian Chesleigh Formation at Hill End formed during Carboniferous deformation.

Hunter-Bowen Supercycle and Metallogeny

The Hunter-Bowen supercycle covers the Late Devonian to Late Triassic development of the Tasmanides and is best seen in the New England Orogen. Here two cycles of convergent margin development that led to formation of continental margin arcs are separated by Early Permian extension. In the Late Devonian and the Carboniferous, the outboard part of the Tasmanides developed into a classical convergent margin related to west-dipping subduction. From west to east, this margin consisted of a continental margin arc, a forearc basin and subduction complexes. A feature of the northern New England Orogen was the development of a Late Devonian to mid-Carboniferous back arc basin (Drummond Basin) on continental crust west of the arc. The Drummond Basin was filled by a lower volcanic-rich package, a middle quartz-rich package derived from the craton and an upper volcaniclastic package that is arc-derived. There are Late Carboniferous intrusives. The presence of epithermal deposits like those at Pajingo indicates the prospective nature of this basin, and forces the question whether a similar backarc basin lies in NSW opposite the southern New England Orogen. If so, it lies beneath the Gunnedah Basin, in an area recently interpreted as containing Carboniferous granites (Dawson & Glen 2006).

The Lachlan Orogen: architecture and metallogeny

Much of the architecture of the Lachlan Orogen was set up during the Benambran Orogeny, when Ordovician arc and turbidite terranes were accreted to Gondwana. This accretion was oblique, and resulted in the formation of both thin and thick (ie all of crust) skinned structures. The north-south component of this accretion was accommodated by the formation of cross structures with WNW to east-west trends and by strike-slip movement on the NNW to N-trending thrust faults. (The term ‘thrust fault’ is used here to describe those contractional faults that lie at low angles to the rock envelope. The angle to the present day horizontal, the text book definition of a thrust, is irrelevant in a situation where these faults were passively rotated, along with their enclosing rock packages, during subsequent deformation). Extension in the Silurian to Middle Devonian Tabberabberan cycle was accommodated in the upper crust by formation of major normal and oblique-slip faults that created space for the formation of sedimentary basins. Basin margins provided suitable pathways for fluids during both deposition and inversion, as well as localising deformation during inversion events. It is thus no surprise that hinge areas and margins are the sites of major mineral deposits. It is debateable how many of these basin-bounding structures were inherited from the Benambran Orogeny and how many formed as new structures that cut across the regional fabric.

The recognition that faults and folds form parts of linked systems not only helps explain how deformation (extensional and contractional) was partitioned through the upper crust, but also provides pathways for the migration of fluids up into the upper crust or down into the middle crust. In a structural environment characterised by oblique and strike-slip faults, the presence of jogs, with their potential for dense fracturing and thus greater permeability, provides suitable targets for both magmas as well as ore-bearing fluids.

The Lachlan Orogen: Cross structures

In such an environment of oblique accretion, the presence of cross structures becomes a significant feature of the Lachlan Orogen. On a regional scale are features like the Lachlan Transverse Zone. Restoring the Silurian-Devonian disruption of the Macquarie Arc suggests that this zone developed from a Late Ordovician transform fault lying at high angles to the plate boundary. In the Late Ordovician-Early Silurian, the Lachlan Transverse Zone localised the intrusion and shapes of porphyries such as at Cadia. Smaller WNW-tending structures that seem to localise intrusions and plumbing systems include those at Wyoming (Alkane Exploration Ltd website) and Copper Hill (Golden Cross Resources Ltd website) and Dargues Reef (Moly Mines Limited website). The Lachlan Transverse Zone was then reactivated through to the Carboniferous, controlling and partitioning upper crustal extension and contraction in a subtle way, and extending father west into the Cobar region.

References

DAWSON M. W. & GLEN R. A. 2006. Eastern Lachlan Orogen Geoscience Database, Second Edition (on CD-ROM). Geological Survey of New South Wales, Maitland, Australia

GLEN R. A. 2005. The Tasmanides of eastern Australia. *In*: VAUGHAN A. P. M., LEAT P. T. &PANKHURST R. J. *Terrane Processes at the Margins of Gondwana*, 23-96. Special Publication of the Geological Society, London 246

HALLETT M., VASSALLO J., GLEN R. & WEBSTER S. 2005. Murray-Riverina region: an interpretation of bedrock Palaeozoic geology based on geophysical data. *Quarterly Notes of the Geological Survey of New South Wales,* 118, 1-16.

MILLER J. M., PHILLIPS D., WILSON C. J. L. & DUGDALE L. J. 2005. Evolution of a reworked orogenic zone: the boundary between the Delamerian and Lachlan Fold Belts, southeastern Australia. *Australian Journal of Earth Sciences,* 52, 921-940.

Alkalic porphyry and epithermal deposits - A view from outside the Macquarie Arc

---

David R Cooke[1], Richard M. Tosdal[2], Claire M. Chamberlain[2] and Cari L Deyell[1]

1 Centre for Excellence in Ore Deposit Research, University of Tasmania, Private Bag 79, Hobart, Tas, 7001
[2] Mineral Deposit Research Unit, The University of British Columbia, Vancouver, CANADA V6T 1Z4.

Key Words: alkalic, porphyry, copper, epithermal, gold

Abstract

Alkalic gold-(copper) deposits are of increasing economic significance and are an attractive exploration target. They include some of the world's highest grade and largest porphyry-related gold resources (e.g., Ridgeway: 73 Mt @ 1.76 g/t Au, 0.62 % Cu – 4.1 Moz Au, 0.45 Mt Cu; Ridgeway Deeps: 2.5 Moz Au, 0.28 Mt Cu; Cadia East: 18 Moz Au, 2.9 Mt Cu; Cadia Valley: 281Mt @ 0.64 g/t Au, 0.17% Cu - 5.9Moz Au, 0.48 Mt Cu http://www.newcrest.com.au; Galore Creek, BC: 516.7 Mt @ 0.37 g/t Au, 0.6 % Cu, 4.5 g/t Ag – 6.1 Moz Au, http://www.novagold.net), as well as some of the largest gold accumulations in epithermal settings (Ladolam, ~40 Moz Au; Porgera, ~22.9 Moz; Cripple Creek, ~26.7 Moz; and Emperor ~9.5 Moz).

The alkalic porphyry deposits of the Ordovician Macquarie Arc (Cadia, North Parkes) are NSW's premier gold and copper resources. In addition, Cowal is possibly an example of a deep-level alkalic low sulfidation epithermal gold deposit. A greater diversity of mineral occurrences have been recognized in alkalic provinces elsewhere, and so we review the characteristics and settings of some of the alkalic systems of British Columbia and Papua New Guinea below, in order to stimulate thinking regarding potential new styles of targets and implications for exploration within NSW's Macquarie Arc.

Alkalic Porphyry Deposits

The economic importance of the alkalic class of porphyry deposits to New South Wales is well established with the discovery and exploitation of the Cadia and North Parkes deposits. However, exploration for these targets is difficult because of their small footprint and alteration assemblages that are different in significant details from those characteristic of porphyry Cu deposits associated with subalkalic igneous complexes (Lang et al., 1994, 1995a,b). The alkalic group of porphyry systems are an eclectic group, and styles of mineralisation in the Jurassic oceanic island arc alkalic provinces of British Columbia differ considerably from those discovered so far in NSW.

Mt Polley has proven and probable reserves of 40.98 Mt @ 0.45% Cu, 0.32 g/t Au (0.42 Moz Au), measured and indicated resources (excluding pit reserves) of 79.24 Mt @ 0.35% Cu, 0.29 g/t Au – (0.51 Moz Au) and inferred resources of 27.17 Mt @ 0.30% Cu, 0.29 g/t Au (0.25 Moz Au; http://www.imperialmetals.com). Mineralisation is associated with a monzonitic intrusive complex that appears similar in texture to the Cadia Hill intrusive complex. However, mineralisation at Mt Polley differs markedly from Cadia in that it occurs as several ore zones localised within high-grade magmatic-hydrothermal breccia complexes. Significant breccia-hosted porphyry ore is yet to be discovered in the Macquarie Arc. Mt Polley demonstrates that these alkalic intrusive complexes can produce major mineralised breccia-hosted ore bodies.

Other alkalic porphyry deposits of British Columbia are associated with silica-undersaturated alkalic intrusions that are distinctive in that they lack quartz veins. At Galore Creek, Cu-Au ore occurs in several mineralised zones in association with garnet, anhydrite, orthoclase, biotite and magnetite. Mineralisation is partly hosted within an intrusive complex (monzonite, syenite) that contains approximately 12 discrete intrusive phases, however mineralisation is best developed in the earliest phases and associated volcanic complex, which are pseudoleucite-bearing. The deposit is distinctive in that it contains abundant melanitic garnet as a vein and alteration mineral, and metal zonation is unusual, with a chalcopyrite core passing through a bornite zone to an outer pyrite zone.

The Lorraine prospect in British Columbia contains at least 32 Mt @ 0.66% Cu, 0.26 g/t Au (0.29 Moz Au; 1998 resource estimate – eastfieldgroup.com/eastfield/nr03-09-24.html. The Lorraine region contain some of the most unusual styles of alkalic intrusion-related mineralisation. The ore zones have characteristics that suggest their formation included magmatic-segregation and magmatic-hydrothermal processes, and elevated PGE contents are distinctive. The Lorraine deposits appear to represent the deepest known level of ore formation in the alkalic porphyry environment.

Mt Milligan is a volcanic-hosted alkalic porphyry system of British Columbia that contains measured and indicated resources of 408 Mt @ 0.18% Cu, 0.47 g/t Au (5.6 Moz Au; placerdome.com. Mineralisation occurs in several ore zones that have distinct Cu-Au ratios. Highest copper grades are associated with chalcopyrite-rich potassic alteration. The highest gold grades occur in the 66 zone, where pyrite is the dominant sulfide.

Mt Milligan and Lorraine are distinct from other alkalic systems in BC in that they formed at approximately 180 Ma during accretion of the oceanic arcs to the northern American continent (Fonseca, 2006). The other alkalic systems of BC formed between 210 and 200 Ma in oceanic island arc settings, demonstrating that it is possible for more that one period of alkalic porphyry mineralisation to occur in an alkalic mineral province.

Alkalic Epithermal Deposits

The alkalic epithermal systems have features similar to the "low sulfidation" family of calc-alkalic epithermal deposits. Discriminating features include the presence of roscoelite (e.g., Porgera, Emperor), and anhydrite (e.g., Lihir, Porgera), and negative sulfur isotopic compositions of sulfide minerals (e.g., Lihir). These features are indicative of oxidation states higher than expected for calc-alkalic LS systems, and potentially providing evidence of a greater magmatic contribution to the alkalic mineralising fluids. As with the calc-alkalic systems, alkalic epithermal deposits are best preserved in younger volcanic arcs, although the alkalic systems occur in association with alkalic igneous rocks, implicating anomalous tectonic processes in their formation.

Papua New Guinea is endowed with spectacular porphyry copper-gold and epithermal gold resources, some of which are alkalic in nature. The Ladolam gold deposit on Lihir Island has a resource of 421.8 Mt @ 2.95 g/t Au (40 Moz Au; http://www.lihir.com.pg) is an epithermal system that formed in the brecciated core of an alkalic volcano that was partly inundated by the ocean during sector collapse approximately 0.4 m.y. ago (Carman, 2003). It is the world's largest known low sulfidation epithermal gold deposit. Lihir Island is part of the Tabar to Feni chain of Pleistocene alkalic volcanoes that formed on extensional structures that are arc-normal to New Ireland, but which have been reactivated in a back-arc setting during northwards-directed subduction of the Solomon Sea plate along the New Britain Trench (Carman, 2003). Early, pre-breccia mineralisation is of low-grade Cu-Au-Mo porphyry character, whereas high grade gold ores formed first during the transition from the porphyry to epithermal environments (e.g., breccia-hosted Minifie orebody), followed by the development of late quartz-calcite-adularia stockwork veins (Carman, 2003). Lihir is analogous in some ways to the deeper level breccia-hosted ores of Mt Polley.

Porgera occurs in the highlands of PNG, and as of June 2001, it had reserves and resources of 113 Mt @ 3.5 g/t Au, plus an additional 10.3 Moz Au produced since 1990 (total of 22.9 Moz Au; Ronacher et el., 2004). Porgera has a much larger vertical extent of mineralisation than Lihir and contained spectacular high-grade gold mineralisation associated with the Romane fault. Mineralisation occurred at depths greater than normal for epithermal systems (2 – 2.5 km; Ronacher et al., 2004). Ore formed during the intrusion of a series of alkalic intrusions into reduced carbonaceous wallrocks approximately 6 m.y. ago (Ronacher et al., 2002). Early carbonate-base metal sulfide veins are cross-cut by high grade quartz – roscoelite - pyrite gold veins. The early stage veins are comparable to the late-stage carbonate base metal veins that occur in the North Parkes and Cadia porphyry systems, and are also comparable to the deep epithermal mineralisation that occurs at Cowal. There is no known analogue for the high grade Romane Fault-style mineralisation in NSW.

Conclusions

There is potential for discovery of a greater diversity of alkalic mineralisation styles in NSW, both of porphyry and epithermal character. Epithermal targets are problematic, in that the level of erosion in NSW is such that only deeper styles such as Porgera or Cowal are likely to be preserved. The diverse porphyry-related Cu-Au mineral occurrences of BC are potentially viable exploration targets in NSW, although it is not yet known if silica-undersaturated alkalic complexes formed in the Macquarie Arc.

Acknowledgements

We have initiated an industry-supported research project that is investigating alkalic mineral systems in BC, NSW and PNG. There are a number of PhD and MSc research students who have commenced studies of the deposits mentioned above, and we thank them for their contributions: Adam Bath, Jacqueline Blackwell, Frederico Henriques
, Amber Henry, Paul Jago, Meghan Jackson, Janina Micko, Heidi Pass and Wojtek Zukowski. Thanks also to the sponsors of our research: AngloGold Ashanti, Barrick Gold Corp., Newmont Mining, Placer Dome Exploration, TeckCominco, Amarc Gold, Imperial Metals, Newcrest Mining Ltd. and Nova Gold Ltd. Thanks also to the conveners of the Mines and Wines meeting.

References

Carman, G.D., 2003, Geology, mineralisation and hydrothermal evolution of the Ladolam gold deposit, Lihir Island, Papua New Guinea: Society of Economic Geologists, Special Publication No. 10, 247-284.

Fonseca, A., 2006, Mt Milligan in the regional setting of alkalic Cu-Au porphyry deposits of the Canadian Cordillera: Mineral Exploration Roundup 2006 conference, Vancouver, http://www.placerdome.com/__shared/assets/Mineral_Exploration_Roundup_-_Mt2623.pdf

Lang, J.R., Stanley, C.R. and Thompson, J.F.H., 1994. Porphyry copper deposits related to alkalic igneous rocks in the Triassic-Jurassic arc terranes of British Columbia: Ariz. Geol. Soc., Digest 20.

Lang, J.R., Lueck, B., Mortensen, J.K., Russell, J.K., Stanley, C.R. and Thompson, J.F.H., 1995a, Triassic-Jurassic silica-undersaturated and silica-saturated alkalic intrusions in the Cordillera of British Columbia: Implications for arc magmatism: Geology, v. 23, 451-454.

Lang J. R., Stanley C. R., Thompson J. F. H. and Dunne K. P. E., 1995b, Na-K-Ca magmatic-hydrothermal alteration in alkalic porphyry Cu-Au deposits, British Columbia: Min. Assoc. Can., Short Course 23, 339-336.

Ronacher, E., Richards, J.P., Villeneuve, M,E., Johnston, M.D., 2002, Short life-span of the ore-forming system at the Porgera gold deposit, Papua New Guinea: laser 40Ar/39Ar dates for roscoelite, biotite, and hornblende: Mineralium Deposita 37, 75 – 86.

Ronacher, E., Richards, J.P., Reed, M.H., Bray, C.J., Spooner, E.T.C., Adams, P.D., 2004, Characteristics and evolution of the hydrothermal fluid in the north zone high grade area, Porgera gold deposit, Papua New Guinea: Economic Geology 99, 843 – 867.

CHARACTERISTICS OF PORPHYRY Au-Cu SYSTEMS IN THE ORDOVICIAN MACQUARIE ARC OF NSW

Bruce Mowat, Goldminco, Mitchell Hwy, Orange NSW 2800

Stuart Smith, Oxiana Ltd, 9th Floor, 31 Queen St, Melbourne, Vic 3000

Key Words: copper, gold, porphyry systems, Macquarie Arc, Ordovician

Abstract

The early Ordovician to early Silurian Macquarie arc of the Lachlan Orogen in NSW is Australia's only economic porphyry Cu-Au province. The province is currently host to six active mines with a further two deposits in feasibility stages. An additional seventeen significant porphyry systems exist within the Macquarie arc making a total of twenty five porphyry systems (Smith et al., 2003). In addition a further ten significant Cu and/or Au systems that may be porphyry-related in the broader sense exist (Table 1; Figure 1). Numerous other minor occurrences with porphyry or porphyry-related characteristics occur throughout the arc.

The deposits are not uniformly distributed throughout the volcanic belts and extreme clustering is evident at all scales. The location of the known systems is heavily skewed toward four productive districts. These districts occupy approximately 11% of the explored volcanic belts but contain 92% of the known systems. Two of the districts contain all of the known economic and feasibility stage systems. These districts can be distinguished to a certain extent from much of the remaining Macquarie arc, but no single or combination of features can definitively distinguish them.

The productive Porphyry Districts share many features (in addition to their mineral endowment) that distinguish them from much of the Macquarie arc. Importantly however these features do not uniquely define the productive districts because other areas have been identified that share some of the features but are not yet known to be productive.

One of the most critical and striking aspects of the districts is the abundance of intrusive rocks compared to the Macquarie arc outside the productive districts. The Cadia-Forest Reefs District as we define it has an area of 430 km2 and within this mapped intrusive rocks occupy 51 km2. Therefore approximately 12% of the total area of the Cadia Forest Reefs District is represented by intrusive rocks compared to 3.5% in the Molong Volcanic Belt as a whole.

The Ordovician volcanic belts display compositions ranging from ultramafic to felsic; however the dominant compositions are within the basalt to andesite range (Wyborn, 1992; Wyborn, 1997). Within the Porphyry Districts, compositions are relatively more felsic with a greater representation of andesitic and trachytic rocks.

The association between potassic magmas and mineralization in the Macquarie arc has been discussed by numerous workers (eg Muller et al., 1994; Holliday et al., 2002; Blevin, 2002). Blevin (2002) has highlighted that intrusives of the Goonumbla and Cadia Districts are more K-enriched than the intrusives of the Copper Hill area and supported an association between K-enrichment and mineralisation potential.

The variable K-enrichment is reflected in modal quartz contents with the less K-enriched rocks containing quartz at much lower SiO2 values than the more K-enriched magma suites (Blevin, 2002). Both of the isolated porphyry systems (Cargo and Copper Hill) are characterized by quartz-rich suites (Torrey & White, 1998, Blevin, 2002).

Insufficient published data exists to evaluate the K-enrichment of the other districts and the Macquarie arc as a whole; however it is likely that the intrusive chemistry and degree of enrichment could prove to be one of the most reliable discriminators of productive districts. Another feature of the intrusive rocks that helps distinguish the Porphyry Districts is their distinct

pink to brick red color due to fine hematite dusting. Although rocks of this color occur outside the productive districts, pink to red rocks are overrepresented in the districts.

The JNVB and MVB are highly magnetic and are easily identified on regional aeromagnetic data. However the character of the belts is not uniform and a number of complexes within the belts display anomalous character. All of the Porphyry Districts have the anomalous character; however several anomalous complexes exist that, to date, have not proven to be productive.

The anomalous complexes are characterized by highly complex magnetic signatures ranging from intense highs to deep lows and distinctly curvilinear to blocky patterns. We interpret these signatures to reflect a higher abundance of variably magnetic intrusive rocks and a greater degree of magnetite destructive and magnetite constructive alteration. In those parts of the arc outside the complexes the patterns are dominated by stratigraphic variations in magnetic character.

Gravity data helps to distinguish the Goonumbla and Lake Cowal Districts. Both occur within the major regional gravity high that underlies the JNVB but correspond in part with ovoid gravity lows apparent in published gravity data (Heithersay & Walshe, 1995). Modeling of the Goonumbla gravity data has been interpreted to indicate the presence of a zoned felsic intrusive complex at depth that was the source of the mineralizing porphyries (Clarke & Schmidt, 2001).

Large scale NW-trending cross-structures have been inferred to play a part in localizing K-enriched magmas and mineralization in the Lachlan Orogen (Glen & Walshe, 1999; Glen & Wyborn, 1997; Glen et al., 1998). The most commonly cited one (the Lachlan Transverse Zone) contains the Goonumbla and Cadia-Forest Reefs Districts. Definition of these structural zones is severely hampered by the effects of major post-Ordovician structural events and their applicability to exploration is limited.

The Macquarie arc porphyry Au-Cu systems represent a substantial exploration challenge in an area of increasing exploration maturity. Detailed exploration models that integrate the range of features of the significant systems will increase the probability of success

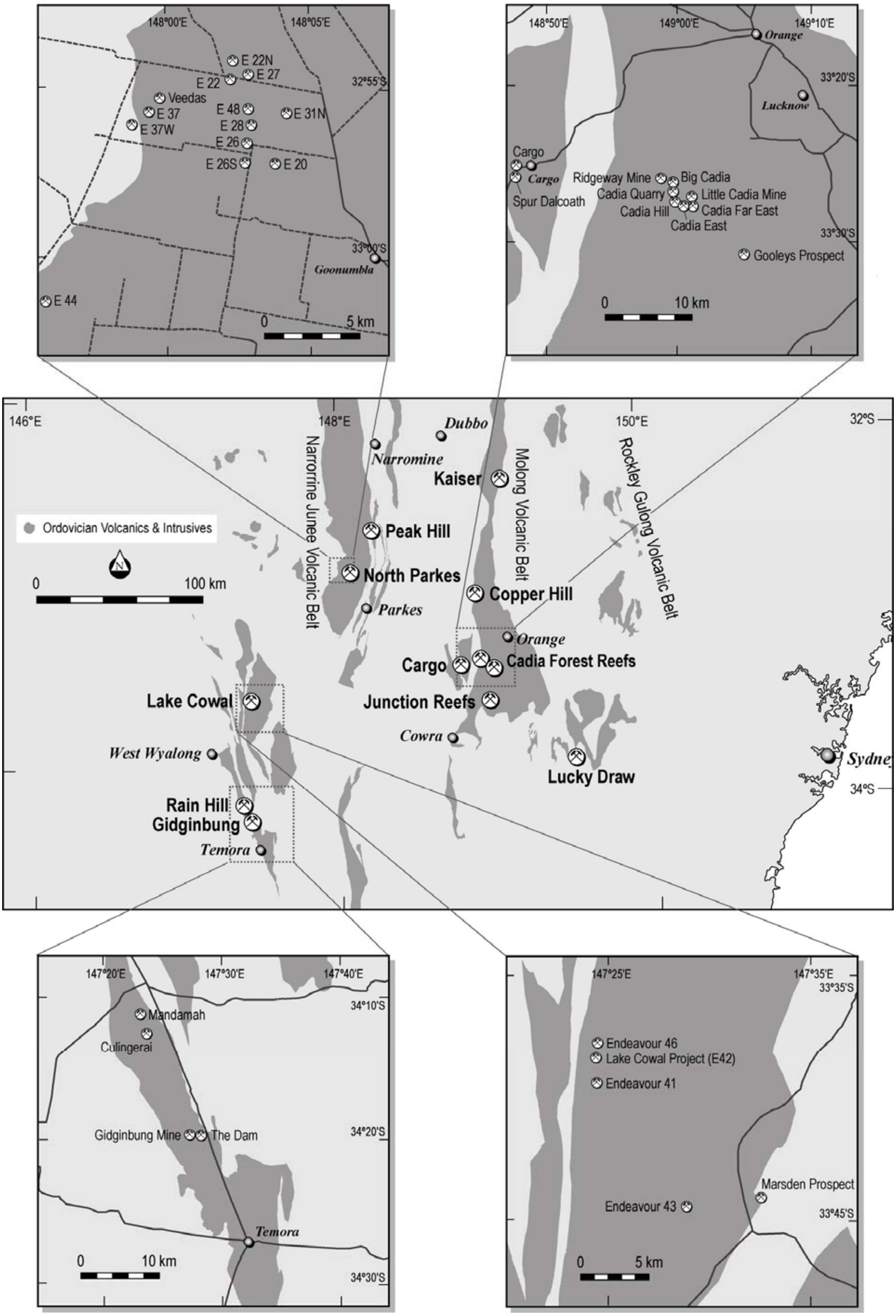


Figure1. Location of Macquarie arc porphyry and porphyry-related systems.

Table 1. Macquarie arc porphyry and porphyry-related systems

System	District	Style	Position of Magnetite	Status	Resources (Total Measured, Indicated and Inferred Resources and Reserves) or Intersections		
					Mt	Au (g/t)	Cu (%)
E26	Northparkes	Porphyry Cu-Au	Peripheral magnetite-bearing zone, overprinted	Mine	65.3	0.39	1.37
E22	Northparkes	Porphyry Cu-Au	Peripheral magnetite-bearing zone, overprinted	Mine	18.6	0.61	0.71
E27	Northparkes	Porphyry Cu-Au	Peripheral magnetite-bearing zone, overprinted	Mine	14.4	0.73	0.71
E48	Northparkes	Porphyry Cu-Au	Peripheral magnetite-bearing zone, overprinted	Mine	33.4	0.59	1.04
E37	Northparkes	Porphyry Cu-Au	Unknown	Inactive Prospect	6.8	0.02	0.66
E37W	Northparkes	Porphyry Cu-Au	Unknown	Inactive Prospect			
Veedas	Northparkes	Porphyry Cu-Au	Unknown	Inactive Prospect	102 m @ 0.47% Cu , Au <0.1 g/t		
E22North	Northparkes	Porphyry Cu-Au	Unknown	Inactive Prospect			
E20	Northparkes	Porphyry Cu-Au	Unknown	Inactive Prospect			
E31North	Northparkes	Porphyry Cu-Au	Unknown	Inactive Prospect	6.6	0.39	0.35
E26S	Northparkes	Porphyry Cu-Au	Unknown	Inactive Prospect			
E28	Northparkes	Porphyry Cu-Au	Unknown	Inactive Prospect			
E44	Northparkes	Magnetite Skarn	Unknown	Inactive Prospect			
Cadia Hill	Cadia-Forest Reefs	Porphyry Cu-Au	Widespread and unrelated to ore forming stage	Mine	352	0.63	0.16
Cadia Ridgeway	Cadia-Forest Reefs	Porphyry Cu-Au	Central and widespread peripheral	Mine	54	2.5	0.77
Cadia East	Cadia-Forest Reefs	Porphyry Cu-Au		Inactive Prospect	220	0.43	0.37
Cadia Far East	Cadia-Forest Reefs	Porphyry Cu-Au	Related to early weakly mineralised veins	Feasibility	63	1.7	0.48
Cadia Quarry	Cadia-Forest Reefs	Porphyry Cu-Au	Widespread and unrelated to ore forming stage	Active Prospect	40	0.4	0.21
Gooleys	Cadia-Forest Reefs	Porphyry Cu-Au		Active Prospect	44 m @ 1.3 g/t Au, 0.55% Cu		

Big Cadia	Cadia-Forest Reefs	Magnetite Skarn	Central	Former mine			
Little Cadia	Cadia-Forest Reefs	Magnetite Skarn	Central	Inactive Prospect			
Junction Reefs	Cadia-Forest Reefs	Pyrrhotite Skarn		Former Mine	247,500 ounces produced		
E43	Lake Cowal	Porphyry Cu-Au	Central and peripheral magnetite-bearing zone	Inactive Prospect	490 m @ 0.19% Cu		
Marsden	Lake Cowal	Porphyry Cu-Au		Inactive Prospect	123 m @ 0.63 g/t Au, 0.7% Cu		
E42	Lake Cowal	Carbonate -BM Au			69.9	1.5	
E41	Lake Cowal	Carbonate -BM Au					
E46	Lake Cowal	Carbonate -BM Au					
Mandamah	Rain Hill	Porphyry Cu-Au	Central magnetite-bearing zone	Inactive Prospect	206 m @ 0.51 g/t Au, 0.37% Cu		
Cullingarai	Rain Hill	Porphyry Cu-Au	Central magnetite-bearing zone	Inactive Prospect	50 m @ 0.76 g/t Au, 0.53% Cu		
The Dam	Rain Hill	Porphyry Cu-Au	Completely overprinted	Inactive Prospect	167 m @ 1.0 g/t Au, 0.7% Cu		
Gidginbung	Rain Hill	High-S epithermal		Former Mine	8.7	2.4	
Copper Hill		Porphyry Cu-Au		Active Prospect	6.6	0.8	0.8
Cargo	Cargo	Porphyry Cu-Au	Peripheral magnetite-bearing zone	Active Prospect	108 m @ 0.22 g/t Au, 0.52% Cu		
Cargo Area Au Systems (eg Spur Dalcoath)	Cargo	Quartz-sulphide Au		Inactive Prospect	3.7	1.24	
Peak Hill		High-S epithermal		Former Mine			

References

Blevin P.L., 2002. The petrographic and compositional character of variably K-enriched magmatic suites associated with Ordovician porphyry Cu-Au mineralisation in the Lachlan Fold Belt, Australia. Mineralium Deposita, Vol 37, 87-99.

Clarke, D.A. & Schmidt, P.W., 2001. Petrophysical properties of the Northparkes Volcanic Complex, NSW: Implications for magnetic and gravity signatures of porphyry Cu-Au Mineralisation. ASEG 15th Geophysical Conference and Exhibition. Australian Society of Exploration Geophysicists. Brisbane.

Close, D. I. 2000. A geophysical study of the Ridgeway gold-copper deposit NSW. Unpubl. BSc. Hons Thesis, University of Tasmania.

Cooke D. R., Wilson, A.J., Lickfold, V. and Crawford A.J. 2002. The alkalic Au-Cu porphyry province of NSW. In AusIMM Conference 2002, Proceedings Volume, The Australasian Institute of Mining and Metallurgy, p. 197 – 202.

Glen R.A. & Walshe J.L., 1999. Cross-structures in the Lachlan Orogen: the Lachlan Transverse Zone example. Australian Journal of Earth Sciences. Vol 46, 641-658.

Glen R.A. & Wyborn D., 1997. Inferred thrust imbrication, deformation gradients and the Lachlan Transverse Zone in the Eastern Belt of the Lachlan Orogen, New South Wales. Australian Journal of Earth Sciences. Vol 44, 49-68.

Glen R.A., Walshe, J.L., Barron, L.M. & Watkins, J.J., 1998. Ordovician convergent margin volcanism and tectonism in the Lachlan sector of east Gondwana. Geology. Vol 26, 751-754.

Harper B.J. 200. Hydrothermal alteration at the Ridgeway porphyry gold-copper deposit, NSW. Unpublished BSc Honours thesis, Hobart, Tasmania, University of Tasmania, 130 p

Harris, A.C. 1997. Vein emplacement, E26 porphyry copper gold deposit, Goonumbla, New South Wales. Unpubl, BSc Hons Thesis, University of Queensland.

Harris, A.C. & Golding S.D., 2002: New evidence of magmatic-fluid–related phyllic alteration: Implications for the genesis of porphyry Cu deposits. Geology:v.30, p. 335–338.

Heithersay P.S. 1991. The Shoshonite-associated, Endeavour 26 North porphyry copper-gold deposit, Northparkes, New South Wales. Unpubl, PhD Thesis, Australian National University.

Heithersay P.S. & Walshe J.L., 1995. Endeavour 26 North: a porphyry copper-gold deposit in the late Ordovician shoshonitic Northparkes Volcanic Complex, NSW, Australia. Economic Geology, Vol 90, 1506-1532.

Heithersay P.S., O'Neill W.J., van der Helder P., Moore C.R., and Harbon P. 1990. Northparkes Porphyry Copper District – Endeavour 26 North, Endeavour 22 and Endeavour 27 copper-gold deposits. in Geology of the Mineral Deposits of Australia and Papua New Guinea (ed F. E. Hughes) The Australasian Institute of Mining and Metallurgy, Melbourne. p. 1385-1398.

Holliday J.R., Wilson, A.J., Blevin, P.L., Tedder, I.J., Dunham, P.D. & Pfitzner, M., 2002. Porphyry gold-copper mineralisation in the Cadia District, NSW, and its relationship to shoshonitic magmatism. Mineralium Deposita, Vol 37, 100-116.

Hooper B., Heithersay, P.S., Mills M.B., Lindhorst, J.W. & Freyburg, J. 1996. Shoshonite-hosted Endeavour 48 porphyry copper-gold deposit, Northparkes, central New South Wales. Australian Journal of Earth Science. v. 43, p. 279-288.

House, M., 1994. Gold distribution at the E26 porphyry copper gold deposit, Goonumbla, New South Wales. Unpubl, M Econ. Geol Thesis, University of Tasmania.

Kolkert, R., 1998, Carbonate-base metal veins peripheral to the Northparkes Cu-Au deposits - vectors to mineralised centres?: Unpublished BSc Honours thesis, Hobart, Tasmania, University of Tasmania, 144 p

Lickfold, V., 2002, Intrusive history and volatile evolution of the Endeavour porphyry Cu-Au deposits, Northparkes district, NSW, Australia: Unpublished PhD thesis, Hobart, Tasmania, University of Tasmania, 230 p

Lickfold V., Cooke D.R., Smith S.G., and Ulrich T. 2003. Endeavour Cu-Au porphyry deposits, Northparkes, NSW – Intrusive history and fluid evolution. Economic Geology, v 98, p. 1607-1636.

Lowell, J.D., and Guilbert, J.M., 1970, Lateral and vertical alteration-mineralisation zoning in porphyry ore deposits. Economic Geology, v. 65, p. 373-408.

Lyons P. & Wallace D. (eds), 1999. Forbes 1:250 000 Geological Sheet Field Conference Guide. AGSO Record 1999/20. Australian Geological Survey Organisation, Canberra.

Muller D., Heithersay P.S. & Groves, D.I., 1994. The shoshonite porphyry Cu-Au association in the Goonumbla District, NSW, Australia. Mineralogy and Petrology. Vol 51, 299-321.

Radclyffe D., 1995. Regional scale propylitic alteration in the Northparkes mineral filed, Parkes New South Wales. Unpublished BSc Hons thesis, Hobart, Tasmania, University of Tasmania.

Smith S.G., Mowat B.A., & Sharry M.J., 2003. Distribution of porphyry Au-Cu systems in the Ordovician Macquarie Arc of NSW, Australia. 7th SGA Conference Athens, August 2003.

Torrey C.E. & White P.D., 1998. Porphyry copper and gold mineralisation at Cargo, NSW. 14th Australian Geological Conference, Townsville. Geological Society of Australia. 442.

Wilson A.J.. 2002. Diverse styles of porphyry gold-copper mineralisation, Cadia district, NSW, Australia. Giant Ore Deposits Workshop, Centre for Ore Deposit Research, University of Tasmania, Hobart, June 17-19, 2002

Wilson A.J., Holliday J. R. & Tedder, I.J. 2002. The Cadia gold-copper district, NSW, Australia: geology and discovery. Vancouver Mining Exploration Group Meeting October 2002.

Wilson A.J., Cooke, D.C. & Harper, B.L. 2003. The Ridgeway gold-copper deposit: A high-grade alkalic porphyry deposit in the Lachlan Fold Belt, New South Wales, Australia. Economic Geology, Vol. 98, pp. 1637-1666.

Wolfe, R.C. 1994. The geology, paragenesis and alteration geochemistry of the Endeavour 48 Cu-Au porphyry, Northparkes NSW. Unpubl, BSc Hons Thesis, University of Tasmania.

Wolfe R.C. Cooke D.R. Hooper B. & Heithersay P.S. 1996. A magmatic origin for late-stage sericite-alunite alteration at the Endeavour 48 Cu-Au porphyry deposit, Northparkes, NSW', 13th Australian Geological Convention, Canberra, Australia, p. 480

Wyborn D., 1992. The tectonic significance of Ordovician magmatism in the eastern Lachlan Fold belt. Tectonophysics. Vol 214, 177-192.

Wyborn D., 1997. Synthesis of Ordovician volcanogenic units of the LFB. (Unpublished) AMIRA P425 Report to Sponsors. AMIRA Melbourne.

GEOLOGY AND MINERALISATION OF THE COPPER HILL AREA

Chris Torrey[1] and Paul Burrell[2]

[1] Apex Silver Mines Limited, Suite 1A, Level 2, 802 Pacific Highway, Gordon NSW 2072 chris.torrey@optusnet.com.au

[2] Burrell Exploration Services Pty Ltd, P O Box 31, Cowra NSW 2794 burrell@westserv.net.au

The Copper Hill prospect is located approximately 40 km north of the city of Orange, within the Molong High, a magmatic arc of Ordovician age. Copper Hill was mined intermittently for copper from 1845 to 1931, with production figures of 3.3kt at 1.4% copper from the supergene zone. The Copper Hill area has been explored in modern times by Anaconda and Amax, in the 1960s, Homestake and Cyprus in the 1980s, and Cyprus, MIM and Newcrest in various joint ventures in the 1990s and early 2000s. More recently Golden Cross Resources Ltd (GCR) has commenced an intensive exploration program which includes over 17 000m of RC and diamond drilling and has recently published a resource, which contains inferred and indicated material, for a total of 105 million tonnes at 0.33% copper and 0.33g/t gold.

Copper Hill is hosted by an igneous complex of diorite-quartz diorite-tonalite. These rocks occur in a distinctive northwest striking magnetic low corridor and intrude the Fairbridge Volcanics of Late Ordovician age, comprising predominantly basaltic andesite. A similar, less explored northwest striking magnetic corridor is evident at Larras Lee located four kilometres to the north. The intrusive igneous complex consists of early and locally well mineralised porphyry bodies that were intruded, and partially assimilated by later less mineralised (intra-mineral) intrusions. GCR has recognised at least four different phases of intrusion. Dominantly northerly striking, narrow, post-mineral dykes cross-cut all mineralised porphyries and generally contain less than 100ppm copper.

A broadly concentric alteration zonation has been identified at Copper Hill from drill core and RC chips. From the periphery to the centre of the Copper Hill hydrothermal system, the following alteration zones are recognised:

1. Porphyry bodies and andesitic volcanic rocks, on the margins of the system exhibit an epidote-chlorite-calcite±haematite assemblage (ECC). At the contact between the volcanic and intrusive rocks, a biotite-magnetite hornfels (BMT) is well developed and epidote-andradite skarn is locally described at the Little Copper Hill prospect, where intrusions are in contact with limestone. The dominant sulphide mineral is pyrite, which occurs as disseminations and veinlets comprising 1-5% of the rock.

2. Closer to the centre of the system, a pervasive sericite-chlorite-calcite assemblage (SCC) occurs within early- and intra-mineral porphyry bodies. Disseminated and veinlet pyrite, with minor chalcopyrite, is intimately associated with this alteration style. Veins comprising quartz-carbonate-pyrite, with strong sericitic haloes, overprint all but the central alteration type (SSC) and locally contain abundant sphalerite, galena and high grade gold up to 30g/t. These tend to occur in well developed structural zones or faults. Copper grades commonly range from 0.1-0.3% and gold grades are 0.1 to 0.2g/t.

3. Immediately surrounding the core of the hydrothermal system is a zone of pervasive sericite-chlorite-magnetite alteration (SCM), which hosts several areas of intense sheeted and stockwork quartz veins, developed in early mineral porphyry bodies. These mostly comprise smoky quartz-magnetite veins that contain centreline chalcopyrite and locally bornite mineralisation. K-feldspar and a distinctive green chlorite, possible after secondary biotite are also locally present. Carbonate-dominant veins are observed to cross-cut smoky quartz-magnetite veins and also host chalcopyrite and minor bornite mineralisation. This alteration type hosts the highest grades of copper and gold at Copper Hill. Grades generally average over 0.5g/t gold and 0.5% copper. GCR

published results from GCHR064, which returned 36m at 1.6% copper and 4.43g/t gold from the Saddle Zone.

4. The centre of the hydrothermal system is characterised by a pervasive sericite-silica-clay assemblage (SSC or phyllic), which hosts open, vughy quartz-chalcocite-pyrite veinlets and chalcocite, minor bornite and possible digenite disseminations. The chalcocite in this alteration zone is separate and distinctive from a poorly developed supergene blanket, beneath a leached cap. This assemblage is hosted by intra-mineral porphyry bodies. Grades locally exceed 1% copper but gold grades vary from 0.1 to 1g/t.

Mineralisation at Copper Hill first formed during early intrusive stages, probably in the upper carapace and specific structures, as sheeted quartz-magnetite veins, hosting copper and gold. The early mineralisation was subsequently disrupted and assimilated into later, less mineralised intra-mineral porphyries. Remnant fragments of early mineralisation occur as xenoliths in the marginal zones of the intra-mineral porphyry complex. They range in size from centimetre-sized vein quartz xenoliths to “cognate xenoliths”, which may contain several million tonnes of mineralised rock. In the core of the complex, coincident with the strong SSC alteration and chalcocite-pyrite mineralisation, no fragments of early mineralisation are recognised.

In conclusion, Copper Hill is a large, multiphase porphyry system, in which well-mineralised, early porphyry phases have been intruded and disrupted by a series of weakly mineralised, intra-mineral porphyry bodies. This has resulted in high grade material being diluted, leading to the formation of a large, but relatively low grade porphyry deposit. Potential remains for the discovery and/or expansion of high grade remnants of the early mineralisation.

THE DISCOVERY HISTORY OF THE NORTHPARKES DEPOSITS

Andrew Lye, Graham Crook and Lennard Kolff van Oosterwijk

Northparkes Mines, PO Box 995, Parkes, NSW, 2870

Key Words: copper, gold, porphyry, Goonumbla, discovery

Abstract

Porphyry copper-gold mineralisation was discovered in the Northparkes area in 1976 when one kilometre spaced roadside traverse drilling by Geopeko intersected the E22 deposit. Grid based RAB drilling discovered the E27 and E26 deposits in 1978 and 1980 respectively. Testing of a discrete magnetic target with co-incident copper geochemistry in 1992 led to the discovery of the E48 deposit. Sub-vertical quartz monzonite porphyries intrude the host volcanic sequence, with mineralisation and alteration zoned around these porphyries. Production at Northparkes commenced in 1993 and the operation has produced 490,000 tonnes of copper and 691,000 ounces of gold to the end of 2005. Exploration continues today with the aim of extending the current mine life.

Introduction

Northparkes Mines is a copper-gold mine located at Goonumbla, approximately 27 kilometres north / north-west of the town of Parkes in Central West New South Wales, Australia. The mine is a joint venture between Rio Tinto (80%) and the Sumitomo Group (20%).

Porphyry copper mineralisation at Northparkes was discovered in 1977 and open cut mining at Endeavour 22 (E22) and Endeavour 27 (E27) commenced in 1993. Production from the Endeavour 26 (E26) underground mine commenced in 1996, employing the block cave mining method.

In 2005 the operation processed 5.5 Mt of ore from the E26 underground block cave mine, the E27 open cut and oxide ore stockpiles. Since July 2005, the E26 underground block cave mine has been the sole supplier of ore to the mill. The Endeavour 48 (E48) orebody is currently subject to a Feasibility Study, and an Exploration Drive is being developed to further assess the characteristics of the deposit. A decision to proceed with development is anticipated in October 2006.

At 31 December 2005, the operation had produced 490,000 tonnes of copper and 691,000 ounces of gold, and had ore reserves of 52.2 Mt grading 1.1% Cu and 0.5g/t Au for underground block cave mining and 3.75 Mt grading 0.67% Cu and 0.58 g/t Au of stockpiled open cut ore, sufficient for a further 11 years of production.

Northparkes produces a high grade copper-gold concentrate. This product is shipped to smelters in Japan, China and India under long term supply contracts.

Geology

The Northparkes deposits occur within the Ordovician Goonumbla Volcanics of the Goonumbla Volcanic Complex (Simpson et al, 2000). The Goonumbla Volcanics form part of the Junee-Narromine Volcanic Belt of the Lachlan Orogen (Glen et al. 1998). At Northparkes, the Goonumbla Volcanics are a folded sequence of trachyandesitic to trachytic volcanics and volcaniclastic sediments that are interpreted to have been deposited in a submarine environment.

In the Northparkes region the Goonumbla Volcanics have been intruded by equigranular monzonite stocks. Quartz monzonite porphyry pipes and dykes, some of which are associated with mineralisation, have intruded both the Goonumbla Volcanics and the equigranular monzonite stocks.

The Northparkes deposits are typical porphyry copper systems in that the mineralisation and alteration are zoned around quartz monzonite porphyries. The porphyries form narrow (typically less than 50 metres in diameter) but vertically extensive (greater than 900 metres) pipes. Mineralisation extends from the porphyries into their host lithology. The E26 and E48 deposits range from 60 to 400m in diameter (>0.4% copper) and extend vertically for more than 900m.

Sulphide mineralisation occurs in quartz stockwork veins, as disseminations and fracture coatings. Highest grades are generally associated with the most intense stockwork veining. Sulphide species in the systems are zoned from bornite-dominant cores, centred on the quartz monzonite porphyries, outwards through a chalcopyrite-dominant zone to distal pyrite. As the copper grade increases (approximately >1.2% Cu), the content of covellite, digenite and chalcocite associated with the bornite mineralisation also increases. Gold normally occurs as fine inclusions within the bornite.

The alteration zonation is complex but tends to be zoned around the quartz monzonite porphyries with a central K-feldspar altered zone surrounded by biotite magnetite alteration. The K-feldspar alteration zone at E26 is well developed and extends up to 100 metres outboard from the porphyry. This is in contrast to E22, E27 and E48 where K-feldspar alteration is generally less than 10 metres outboard from the porphyries. The biotite magnetite zone is strongly developed at the E22, E27 and E48 deposits, and forms a zone up to 200 metres from the porphyry. It is this biotite-magnetite zone that forms the distinctive annular magnetic features at E22 and E27.

A central white sericite-quartz +/- alunite alteration zone occurs at E26, and to a lesser extent at E48, and is generally associated with the high grade zones within the deposits (Wolfe, 1994, Wolfe et al, 1996; Harris & Golding, 2002). At E48, an alteration assemblage of hematite-sericite+/- carbonate occurs both within and proximal to the mineralisation.

All of the Northparkes deposits are cross cut by late faults/veins filled with quartz-carbonate+/- gypsum, anhydrite, pyrite, chalcopyrite, sphalerite and galena. The associated sericite alteration extends up to 10 metres from the fault.

Oxide mineralisation blankets were well developed over the E22 and E27 deposits. The upper blanket was gold rich and copper poor. The lower blanket was enriched in copper by supergene processes. The dominant copper oxide minerals at E22 and E27 were copper carbonates (malachite and azurite) and phosphates (pseudomalachite and libethenite) with lesser chalcocite, native copper, cuprite and chrysocolla. A gold poor, less well developed, supergene copper blanket was also developed over the E26 deposit. At E26 the oxide copper minerals included atacamite, clinoatacamite and sampleite, in addition to those copper minerals observed in E22 and E27.

The Goonumbla Volcanics at Northparkes have undergone little deformation, with gentle to moderate bedding dips as a result of regional folding. The dominant structure observed to date in the Northparkes area is the Altona Fault, an east dipping thrust fault, which truncates the top of E48, and is known to extend from east of E26 to east of E27.

Discovery History to 1998

Geopeko commenced exploration in the Northparkes district in 1972 assessing the potential for VHMS hosted Pb–Zn deposits in the submarine volcanics of the Goonumbla Volcanic Complex. Regional mapping and rock geochemical sampling discovered outcropping lead-zinc skarn mineralisation in 1973 at the Endeavour 7 prospect. Several more prospects were identified before 1975 when mapping and sampling of outcropping areas was complete. An aeromagnetic survey was flown in 1974 to extend coverage in areas of cover to the north.

Exploration efforts remained focussed on VHMS style deposits, however the identification of skarns had demonstrated the importance of intrusive related mineralisation. In 1975 a programme of regional scale auger-core drilling was commenced along public roads perpendicular to the regional strike. This technique had been successfully used in the Ranger Uranium field in the Northern Territory to obtain a sample of core from beneath thick soil cover for geological and geochemical analysis.

In the summer of 1976 a traverse of auger-core holes, at 1 kilometre centres, was conducted along Adavale Lane. Drill hole ACH697-21, located in the eastern side of what is now the E22 open pit, intersected pink K-feldspar alteration and minor chalcopyrite-bornite mineralisation in the 2 metres of drill core, assaying 0.25 % Cu. Follow-up RAB drilling defined a large Cu-Au anomaly and in 1977 a diamond hole was drilled beneath the peak of the anomaly, returning 229 metres at 0.61 % Cu and 0.67 g/t Au from 65 metres. Follow-up drilling of weak copper anomalism (0.15 % Cu) in the auger-core hole 1 kilometre to the east of E22 was undertaken and resulted in the E27 discovery in 1978.

Regional mapping and rock chip sampling continued in 1978. Quartz-malachite veined monzonite was mapped at the E28 prospect, 2 km south east of E22. Quartz-sericite altered outcrops were sampled in the vicinity of what is now E26, however these returned low geochemical values. Southerly extensions of the E28 RAB drilling grid identified a bedrock copper anomaly over the E26 deposit (originally the E26N prospect) in 1980. The first diamond drill hole to test the anomaly, DDH26, returned 441 metres at 0.67 % Cu from 63 metres depth.

In 1992, based on recently acquired 120 metre line spaced aeromagnetic data, a magnetic targeting programme was completed by Stolz (1992) using the signatures of the known deposits. Magnetic target MT9, located midway between E26 and E27, in part had a coincident copper geochemistry anomaly and was selected for drill testing (Hooper et al, 1996). The first reverse circulation drill hole, MT9RP1, returned an intersection of 83 metres at 0.95 % Cu and 0.15 g/t Au from 49 metres to end of hole.

Exploration between 1978 and 1998 led to the discovery of additional porphyry systems at E20, E22 North, E28 North, E31 North, E37, and E37 West. All these systems were discovered by RAB drilling with the exception of E37 West which was a discrete magnetic high target located immediately west of E37.

Mine Development History

North Limited approved development of Northparkes Mines in November 1992, 15 years after the first discovery was made, based on open cut mining of E22 and E27 and underground mining of E26. The aggregate ‘Mining Reserve’ was 64.1 Mt grading 1.31% Cu and 0.60 g/t Au of sulphide ore, 1.68 Mt grading 1.95 g/t Au of oxide gold ore and 1.66 Mt grading 1.10 % Cu and 1.34 g/t Au of oxide copper-gold ore.

Development was staged with initial production in November 1993 from the E22 and E27 open pits and later from the E26 underground block cave mine in 1996. The ore processing plant comprised two modules and began treating oxide ore from E22 and E27 in April 1994. Module 1 processed oxide gold ore at a rate of 1.5 Mtpa using CIP recovery from April 1994 until September 1995, producing 74,000 oz of gold. The flotation circuit was commissioned in September 1995 when Module 1 switched to sulphide ore at an increased rate of 2 Mtpa and Module 2 began processing oxide copper-gold ore at a rate of 2.6 Mtpa. In January 1996 both circuits processed sulphide ore, reaching the combined design capacity of 5 Mtpa in 1997 and record production of 5.5 Mt in 2005.

Construction of the E26 underground block cave mine, Australia’s first, commenced in October 1993. The initial mine, Lift 1, was designed to extract ore to 480 metres below the surface, based on a reserve of 28.7 Mt @ 1.45% Cu and 0.39 g/t. In 1997 Lift 1 reached its design production rate of 3.9 Mtpa and become the world’s most productive underground hard rock mine, producing 42,600 tonnes of ore per underground employee year (including contractors). Productivity peaked in 2000, reaching over 50,000 tonnes per employee.

Construction of the second block cave mine to extract ore between 480 and 830 metres below surface, E26 Lift 2, was approved by the Joint Venture partners in 2001 and development was completed in 2004. Full production ramp up to an annualised production rate of 5.5 Mtpa was achieved in 2005.

As production from Lift 1 declined, stockpiled ore from the earlier open cut mining campaigns was processed. Open cut mining resumed in both E22 and E27 in July 2000 to maintain the mill at full capacity during the transition to Lift 2, with mining completed in June 2002. The most recent opencut mining campaign in E27 commenced February 2003 and ceased in August 2005.

Production from Lift 2 is expected to wind down from early 2009, coinciding with the initial production from E48. E48 is currently subject to a Feasibility Study and, subject to approval, is scheduled to commence production in 2009, extending the mine life to 2016.

Northparkes Mines Exploration

All exploration activities in the Northparkes area were conducted by the corporate exploration groups of Geopeko and North Limited until 1998. In December 1998 the North Limited Exploration Group withdrew from the Northparkes area as they considered the potential for discovery of deposits consistent with corporate objectives low (Lew, 2003).

Northparkes Mines considered exploration could add value to the business unit and committed to fund exploration internally from 1999. The primary objective of exploration was the delivery of another 'E26', however the value of modest discoveries and incremental ore from the existing deposits was also recognised. The value of continuing near mine exploration was also recognised by Rio Tinto following the acquisition of North Limited in September 2000 (Lew, 2003).

The Northparkes Mines exploration programme initially involved extensive compilation of all existing geological, geochemical and geophysical datasets (Lew, 2003). Exploration efforts were subsequently focused on understanding the deposit characteristics, in particular their mineralisation and alteration halos (Lew, 2003).

The exploration efforts since 1999 have led to the discovery of four new porphyry systems within 6 kilometres of the existing infrastructure (Veedas, Hopetoun Gold, Brazen and GRP314).

A discrete magnetic high target, 1 kilometre north-east of the E37 prospect, was identified following the acquisition of 25 metre line spaced aeromagnetic data in 2000. Drill testing led to the discovery of the Veedas porphyry system.

Hopetoun Gold was discovered in 2002 by drill testing a multi-element bedrock geochemical target, following a review of historical bedrock geochemical data.

Construction of the Lift 2 infrastructure provided the opportunity to explore beneath the Altona Fault north of E26 towards E48. The Brazen system, located blind beneath the Altona Fault, was found following lateral underground drilling in 2002, and application of the improved understanding of the mineralisation and alteration halos.

The identification of the Brazen system further highlighted the prospectivity of the untested ground beneath the Altona Fault. A programme of reverse circulation drilling was conducted to explore beneath the Altona Fault south of E48 to E26. This programme led to the discovery of the GRP314 system, located only 1km from E26, in 2004. Exploration programmes continue to assess GRP314.

Recent exploration efforts have also added incremental tonnage to the E26 and E48 resources. The potential for additional mineralisation at E22 is currently being re-evaluated.

As the Northparkes area matures new and innovative technologies are being developed to better locate mineralised systems. These technologies will be applied to test new targets and also to re-assess old prospects. Recent exploration activities have provided extensive deep drill coverage in the mine corridor. Updating and refining the three dimensional geology model within the mine corridor, in conjunction with an improved understanding of known systems, will help direct future exploration.

Acknowledgements

This paper has been compiled from published and unpublished Northparkes, Rio Tinto, North Limited and Geopeko reports. The contribution of all geologists, geophysicists, geochemists (and associated support staff) and other mining professionals who have worked on the exploration, evaluation and development of Northparkes Mines is gratefully acknowledged. Special thanks are extended to both Northparkes and Rio Tinto Management for their permission to compile and publish this paper.

References

Glen R.A., Walshe, J.L., Barron, L.M. and Watkins, J.J., 1998, Ordovician convergent margin volcanism and tectonism in the Lachlan sector of east Gondwana: Geology, v. 26, pp. 751-754.

Harris, A.C., Golding S.D., 2002: New evidence of magmatic-fluid–related phyllic alteration: Implications for the genesis of porphyry Cu deposits. Geology: Vol. 30, No. 4, pp. 335–338.

Hooper, B., Heithersay, P.S., Mills, M.B., Lindhorst, J.W., and Freyberg, J., 1996, Shoshonite-hosted Endeavour 48 porphyry copper-gold deposit, Northparkes, central New South Wales: Australian Journal of Earth Sciences, v. 43, pp. 179-288.

Lew, J.H., 2003, Northparkes Mines Exploration and Development Potential, Presented at 2003 NSW Mineral Exploration and Investment Conference.

Simpson, C., Cas, R.A.F., and Arundell, M.C., 2000, The Goonumbla Caldera, Parkes, NSW: fact or fiction?: in Skilbeck, C.G., and Hubble, T.C.T., eds., Understanding planet earth: Searching for a sustainable future: Abstracts for the 15th Australian Geological Convention, University of Technology, Sydney, Australia, 2000, p. 452.

Stolz, N., 1992, An aeromagnetic interpretation of the Goonumbla area. Unpublished confidential report to Geopeko, Report No; PK92/75/1.

Wolfe, R.C., 1994, The geology, paragenesis and alteration geochemistry of the Endeavour 48 Cu-Au porphyry, Goonumbla NSW: Unpublished BSc Honours thesis, Hobart, Tasmania, University of Tasmania, 102 p.

Wolfe, R.C., Cooke, D.R., Hooper, B & Heithersay, P.S., 1996, A magmatic origin for late-stage sericite-alunite alteration at the Endeavour 48 Cu-Au porphyry deposit, Northparkes, NSW, 13th Australian Geological Convention, Canberra, Australia, p. 480.

TOMINGLEY GOLD PROJECT – GEOLOGICAL SETTING AND MINERALISATION

D Ian Chalmers[1], Terry W Ransted[1], Rimas A Kairaitis[2] and David G Meates[1]

[1] Alkane Exploration Ltd, PO Box 8178, Perth Business Centre, Western Australia 6849
[2]Alkane Exploration Ltd, PO Box 1110, Orange, New South Wales 2800

Key Words: gold, Tomingley, Wyoming deposits, lode style, Lachlan Orogen

Abstract

The Tomingley Gold Project includes a large north-south oriented tenement package covering Ordo-Silurian volcanics and sedimentary rocks with minor intrusives. Significant mineralisation in and about the Project Area includes the Wyoming Gold Deposits, the Peak Hill Gold Mine and the historic Myalls United Gold Mine.

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

Outcrop in the Wyoming area is limited with the Ordovician sequence obscured by clay-rich cover of probable Quaternary to Cretaceous age with depths up to 60 metres. Regional aeromagnetic data define a north-south trending linear belt interpreted to represent the Ordovician andesitic volcanic sequence within probable Ordo-Silurian pelitic sediments.

Extensive drilling has identified substantial mineralisation associated with sericite–carbonate (ankerite)–albite–quartz-(± chlorite ± pyrite ± arsenopyrite) alteration of an andesitic feldspar porphyry intrusion and adjacent volcaniclastic sediments. The Wyoming deposits appear to have formed as the result of a rheological contrast between the porphyry host and the surrounding volcaniclastic sediments, with the porphyry showing brittle fracture and the sediments ductile deformation, and many similarities to well documented lode-style gold deposits. The age of the alteration and mineralisation remain problematic but a relationship with possible early to mid-Devonian deformation is considered likely.

The mineralisation at Wyoming is in stark contrast with that at Peak Hill, located just 12 kilometres to the south, where mineralisation displays all of the characteristics of a high sulphidation style epithermal deposit.

Regional Geological Setting

The Wyoming deposits are located near the eastern margin of the Junee-Narromine volcanic belt, just east of the interpreted Parkes Thrust. This structure separates the flat lying 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 Tomingley Gold Project 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).

The Goonumbla volcanics are overlain by sediments thought to be equivalents of the Cotton formation. Although Sherwin (1996) suggest that the Cotton formation may have been contemporaneous with deposition of the Goonumbla volcanics, Squire et al (in press) suggest that differences in detrital composition and biostratigraphy means the units are distinctly separate, and are perhaps part of the Silurian Forbes group. At this stage there is no data to support either argument at Wyoming although where mapped, the sediments consist of well-bedded fine quartzose sandstone and laminated siltstone with a diagnostic basal quartz rich conglomerate.

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

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

Wyoming Geology

The immediate Wyoming area is almost entirely covered by alluvial sequences of clays, sand and gravel of Quaternary to Cretaceous age up to 50 m thick.

The gold deposits at Wyoming are hosted within volcaniclastic sediments, rare lavas and shallow intrusive porphyritic rocks. The volcanic units are of trachy-andesite to basaltic trachy-andesite in composition with very rare detrital quartz in the volcaniclastic rocks which are dominated by well bedded sandstones and siltstones with minor breccias, lithic conglomerates and black mudstones. The dominant sandstones and siltstones have a primary composition of plagioclase and augite but are now largely altered to sericite, carbonate, chlorite, albite with the rare primary quartz.

The volcaniclastic units are intruded by numerous coarse feldspar ± augite porphyritic bodies of trachy-andesitic to mafic trachy-andesite affinity. These bodies are weakly concordant to the bounding sediments and are interpreted as sills. The identification of rare peperitic textures suggest that the intrusions were emplaced at a relatively shallow level. A narrow, marginally discordant, chlorite-talc schist has also been located by drilling just to the east of the porphyry sills at Wyoming One. This may have a mafic-ultramafic precursor, similar to olivine rich lavas (picrites) which are known from the Molong Belt (A Crawford, pers. comm. 2004).

To the west, the andesitic volcaniclastic sequence is in sharp contact with well foliated fine grained sediments that are interpreted to correlate with rocks of either the Ordo-Silurian Cotton formation or the Forbes Group. The contact does not appear to be faulted. The eastern margin of the volcaniclastic sequence is uncertain.

A detailed deformational history of the Wyoming deposits cannot be determined at this stage, however a number of empirical observations have been recorded from orientated drill core. The andesitic volcaniclastic sequence strikes north-northwest and dips steeply east. Current interpretation suggests that the Wyoming One feldspar porphyry is located near the axis a tight, easterly vergent, antiform.

Within the massive feldspar porphyry, brittle fracture is dominant and a number of vein directions are evident. Major structures are orientated west-northwest, exemplified by the near vertical faults that appear to dislocate the porphyry and several sub-parallel vein sets within the porphyry. A pervasive set of shallow north dipping veinlets also have a west-northwest to east-northeast strike.

Recent structural analysis and modelling indicates a complex structural history involving a sinistral transpressional event with a rotation of the stress field to develop the mineralised vein array seen at Wyoming One, the structures at Wyoming Three and the regional foliation.

Mineralisation

Mineralisation has been identified at a number of locations within the volcanic belt but to date evaluation of deposits has focussed on the Wyoming and Peak Hill areas.

Wyoming

Gold mineralisation at Wyoming One is distributed both around and within a sub-vertical, south plunging, feldspar ± augite phyric sill. The deposit has been separated into distinct mineralised zones: the porphyry zone; contact zone; hangingwall zone; the ‘376’ zone and the ‘831’ zone.

Gold mineralisation is characterised by strong quartz ± carbonate (ankerite) ± albite ± pyrite ± arsenopyrite veins within intense sericite–carbonate (ankerite)–albite–quartz-(± chlorite ± pyrite ± arsenopyrite) alteration of the feldspar ± augite-phyric intrusion and the volcaniclastic sediments. The hangingwall zone appears stratigraphically controlled by a fine-grained carbonaceous mudstone and the ‘376’ and ‘831’ are high grade east west zones truncating and transecting the porphyry.

Gold mineralisation at Wyoming Three also shows a strong spatial relationship with feldspar porphyritic rocks however pervasive alteration is limited or absent with mineralisation hosted

within structurally controlled quartz ± carbonate ± chlorite ± pyrite ± arsenopyrite veining striking about 105°.
Resources at Wyoming One and Wyoming Three total 7.1 million tonnes grading 2.70g/t gold.

Peak Hill

The Peak Hill Gold Mine is located 12 kilometres south of Wyoming and the mine was operated by Alkane between 1996 and 2003 with the production of 150,000 ounces of gold from the oxide zone. Treatment was by heap and dump leach.
The alteration and mineralisation at Peak Hill display all of the characteristics of a high sulphidation style epithermal deposit. The Peak Hill deposit has a distinct sub-vertical zoning with a pyrophyllite and vuggy-quartz core, that today extends about 350 metres east-west and at least 550 metres north-south, which grades out through paragonite+muscovite, kaolinite to a chlorite+epidote alteration zone at the margin (Squire et al, in press). Gold-copper mineralisation is associated with late quartz-pyrite-barite veins and the highest gold grades occur mainly in microcrystalline-quartz–altered rocks in the paragonite+muscovite alteration zone, generally within 50 metres outward from the boundary of the pyrophyllite and vuggy-quartz core (Squire et al, in press).
Total sulphide resources at Peak Hill are currently 11.27 million tonnes grading 1.29g/t Au and 0.11% Cu. Mining of oxide deposits totalled 5.25 million tonnes grading 1.56 g/t gold.

Myalls United

Little is known about the geology of the Myalls United mine which is situated 1.5 kilometres south of the Wyoming One deposit. The two parallel quartz reefs hosted in ‘andesitic volcanics’ were mined to a depth of 200 metres between 1883 and 1912 with 70,000 ounces of gold produced (Clarke, 1986). Little recent exploration has been conducted as the mine was used as a disposal site for obsolete munitions and a mining reserve was constituted in 1976 to exclude future mining and exploration.

Other Prospects/Occurrences

Some 45 other prospects or mineral occurrences occur throughout the volcanic belt. Many of these have not seen any significant recent exploration and little recent drilling by Alkane.
Tomingley Prospects – drilling by Alkane along a structural trend north from Tomingley has identified a number of mineralised zones associated with alteration and veining within massive siltstone. The zones are situated below up to 70 metres of transported cover and appear to be structurally controlled orogenic styled vein networks. Better intercepts in the drilling included 3 m @ 4.93g/t Au and 24m @ 1.29 g/t Au at the Tomingley Two prospect. The Tomingley Prospects are aligned north-south for over 3 kilometres of strike and are interpreted as a fault controlled, regional fluid corridor which may well form the ‘plumbing’ to the Wyoming deposits and the Myalls United Gold Mine.
Black Snake / Trewilga – lode style sheeted vein system in volcaniclastic sediments. Limited drilling returning best intercept of 8m @ 1.6g/t Au and 0.37% As from 23m.
Smiths – quartz-carbonate veining within sericite-carbonate-albite altered feldspar porphyry having visual similarities to Wyoming One. Limited previous drilling returned 8m @ 0.49g/t Au.
Monte Carlo – veining and alteration associated with carbonaceous mudstones in a very similar stratigraphic setting to the hanging wall zone at Wyoming One.

Conclusions

The mineralisation at Wyoming has few documented affinities with the typical Ordovician aged magmatically derived deposits identified elsewhere in the Lachlan Orogen in New South Wales.

The style of mineralisation and associated sericite-carbonate-albite-quartz alteration assemblage is more typical of orogenic lode style gold deposits.

Within the Wyoming One deposit, the mineralised fluids are interpreted to have been focused by differential strain in and around the feldspar porphyry sills due to the rheological competency contrast between the sills and the bounding volcanic sediments. Higher grades (+5g/t Au) appear to be concentrated where the competency contrast is the greatest (ie Contact Zone) and by internal cross structures, sub-parallel to the 376 zone, within the feldspar porphyry body. The Wyoming Three quartz lodes appear to have similarities with shear hosted sheeted vein deposits, but also formed as a competency contrast between porphyry and volcaniclastic rocks.

The mineralisation at Wyoming is in stark contrast with that at Peak Hill where alteration and mineralisation displays all of the characteristics of a high sulphidation style epithermal deposit.

Acknowledgements

The petrology of Tony Crawford and the late John Borner have provided valuable insight into the mineralogy and alteration that are an important part of the understanding of the Wyoming deposits. Julian Vearncombe has provided input into the recognition of many of the structural trends within the deposits. Core logging and numerical modelling by Peter Schaubs (pmd*CRC) has added significantly to the understanding of the structural setting of the Wyoming deposits.

GRANITE-ASSOCIATED MINERALISATION IN NEW SOUTH WALES: DATA, MODELS AND OPPORTUNITIES FOR THE FUTURE

Phillip Blevin

Department of Primary Industry (Geological Survey of New South Wales), PO Box 344, Hunter Regional Mail Centre, NSW 2310.

Key Words: granite, intrusion-related gold deposits, tin, tungsten, molybdenum, metallogeny.

Granites (*sensu lato*) and related rocks are important mineralisers for a wide range of elements including Sn, W, Mo, Au, Cu, Ag, Pb, Zn, Bi, As U, Th, F, Li, Nb, Ta and the REE. They are also the vehicles by which substantial vertical redistributions of fluids and heat occur within the crust. Granites are also important in the supply of dimension stone, aggregate, silica, feldspar, mica and even artificial sand.

Granite-related mineral deposits are important ongoing contributors to mineral production and potential in New South Wales. Tin is associated with both I-types in the New England Orogen (NEO) and with S-types in the Lachlan Orogen (LO). Substantial Sn resources are also associated with the I-type Midway Granite near Bourke, which is one of the most evolved granites in NSW. Molybdenum is well represented by deposits associated with various combinations with W, Bi and Au in the NEO and LO. Tungsten occurs as wolframite and scheelite in both Sn-W and W-Mo combinations determined by granite compositions and oxidation state.

“Intrusion Related Gold Deposits” (IRGDs) have been recently added to the granite menagerie. These were initially defined in the Alaska-Yukon region (the Tintina Gold Province) for a range of deposit types with a general Au±As,Bi,Te,Sb metal chemistry. An important difference is that Australian IRGDs are essentially polymetallic in character and show intimate hydrothermal and magmatic associations with their associated granitic igneous suites.

Gold-rich, Cu-poor systems associated with felsic I-types in eastern Australia are associated with W-Mo mineralised suites with Au occurring within a predictable metallogenic zonation. Gold mineralised I-types comprise weakly to moderately oxidised, high-K granitoid suites that, at least in the east Australian context, have low K/Rb ratios and show strong fractionation trends. Compositionally, they are not oxidised enough and are too evolved and/or felsic to be associated with Cu. They are too oxidised to be associated with significant Sn production. They occur in the redox-fractionation compositional range normally associated with minor W-Mo±Sn occurrences and W-scheelite mineralisation. The Tintina Gold Province granites are more reduced and less compositionally evolved than their Australian equivalents.

Given then polymetallic nature of IRGD mineralisation in eastern Australia and the compositional diversity of granite compositions with which they are associated, the definition of Au-rich granite-related deposits needs to be broadened or redefined. Deposits at Burraga and Browns Creek (in addition to Dargues Reef) fit such an expanded classification.

Gold is readily removed from granitic magmas through the early precipitation of sulfides, or to a lesser extent by magnetite. Crystallisation of Fe-poor, silica-rich granitic magmas in a relatively narrow oxidation window between the FMQ and NNO buffers may provide conditions where retention of Au in magmas in felsic granitic magmas is optimised.

New Studies

The granites of New South Wales will be the subject of a major synthesis and strategic assessment in order to recognise prospective tracts within the state for the full range of granite related deposit types and metal associations. Preliminary work in this regard has already recognised the need for a major reclassification of the mineralised granites of the NEO. In addition, in the south east of the LO, reinterpretation of the granite petrology and geochemistry on the Goulburn 250k sheet has lead to the recognition of a prominent eastwards change in granite compositions from low Na intermediate S-types in the west to high Na, felsic and weakly peraluminous granites of intermediate I-S character in the east. Some of these latter granites have (Mn-) garnet and allanite. The most extensive example is the problematic Wologorong Batholith. The Davies Creek granite on the Bathurst 250k sheet is now also included as an equivalent of the Wologorong Batholith. Further south, granites of similar intermediate character are also present down through the Canberra 250k sheet and includes the Sutton, Tinderry, Watchbox and Shannons Flat Granites, through to the magnetic, weakly peraluminous Dalgety Granite, Murrumbucka Tonalite and the (Mn-) garnet-bearing 500 Acre Granite. This belt may represent a broad zone of variably contaminated or transitional I-S granites located immediately to the west of the “I-S Line” and as such, represents the first recognition of systematic E-W changes in the composition of LO granites as the I-S Line is approached from the west. Westwards changes have previously recognised in the Bega Batholith located to the east of this line.

These east west compositional gradients also mirror a general shift from Sn in the west (Koetong/Bullenbalong Supersuites), through W (associated with the Wyangala Supersuite), to Mo in the east. Gold is associated with the Braidwood Granodiorite in the Bega Batholith but IRGD type systems may be also associated with the W dominant portion of this overall zonation. Interestingly, the Carboniferous Rossdhu and Au-mineralised Burraga Granites in the Oberon region of the Bathurst 250k sheet (immediately to the north of the Wologorong Batholith) are also garnet bearing I-types or weakly peraluminous character.

THE MT CARRINGTON EPITHERMAL GOLD-SILVER-ZINC SYSTEM AND THE HOST DRAKE VOLCANICS

Bob Beeson and David Borton

Drake Resources Ltd, 6/34 York Street, North Perth, WA 6006

Key Words: silver, lead, zinc, copper, epithermal, volcanic rocks, Permian

Introduction

The Mt Carrington epithermal deposits have been mined for gold and silver since the nineteenth century. They were the subject of intense exploration and research over at least three decades, and the gold deposits were mined by Mt Carrington Mines in the period 1988-90. Surprisingly, in 1994, all exploration activity came to a complete halt, and has only been reactivated by the Drake Resources programme in the past year.

Mt Carrington is a low sulphidation epithermal system within a package of late Permian intermediate to felsic volcanic rocks. The mineralisation occurs in very extensive alteration systems; Mt Carrington is one of several such alteration systems throughout the Drake Volcanics.

This abstract relies heavily on past explorers and researchers. In particular the Geological Survey of New South Wakes' excellent metallogenic report for the Warwick-Tweed Heads 250,000 sheet which brings together the work of explorers and researchers, addressing geology, alteration and mineralisation (Brown et al., 2001). Major contributions have also been made by CRA and Aberfoyle geologists, particularly Matt Houston and Lindsay Bottomer respectively.

Mt Carrington is located just north of the township of Drake, which is on the Bruxner Highway between Tenterfield and Casino, in North Eastern NSW.

Geology

The Mt Carrington epithermal deposits are hosted by the Drake Volcanics, a local subdivision of the Wandsworth Volcanic Group (Brown et al., 2001). The group represents part of a major Late Permian to Early Triassic episode of igneous activity throughout this part of New England. At many locations the volcanic sequences were intruded by high-level plutons.

INTERPRETED RELATIONSHIPS BETWEEN THE STRATIGRAPHIC SUCCESSION IN THE DRAKE AREA (After Brown et al 2001)

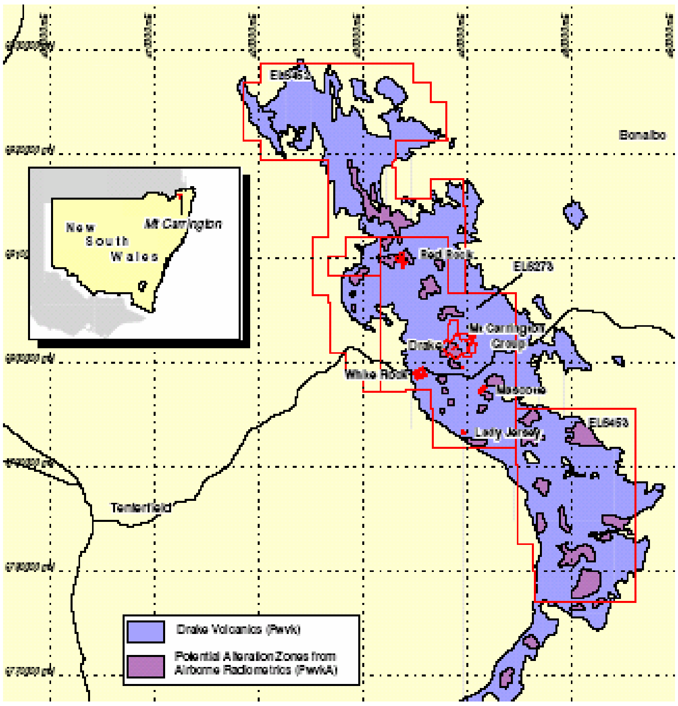
AGE	GROUP	STRATIGRAPHIC UNIT	LITHOLOGIES
Tertiary	?	Unnamed	Basalt flows, dolerite sills or dykes
Late Permian-Early Triassic	Leuco-monzogranites	Stanthorpe Monzogranite	Coarse grained equigranular to weakly porphyritic biotite poor leucogranite.
		Morgans Creek Monzogranite	Equigranular, coarse grained monzogranite
	Clarence River Plutonic Suite	Bruxner Monzogranite	Leucocratic altered monzogranite and light grey granodiorite
Late Permian	Wandsworth Volcanics Group	Gilgurry Mudstone	Dark grey to green siltstone
		Drake Volcanics	Complexly interbedded rhyodacitic to andesitic volcanics
Carboniferous		Emu Creek Formation	Interbedded sandstone, siltstone, and conglomerate

The Drake Volcanics cover an area of approximately 700 km2. The Volcanics comprise about 400 metre thickness of interbedded acid to intermediate volcanic flows and volcaniclastic sedimentary rocks. Pyroclastic and flow rocks, agglomerate, breccia, crystal-lithic tuff and sub-volcanic intrusions are common. The compositional types vary from rhyolite to trachyandesite, to andesitic and to dacitic. The rocks of andesitic to trachytic composition are green, grey, blue-green, purple or brown coloured.

The volcanic flow rocks are normally porphyritic. Intrusives include flow banded rhyolites, quartz andesite and andesite, microdiorite, quartz-feldspar porphyry, and “banded felsite”. Flow laminae within the intrusives are typically steep to sub-vertical. The volcanics are characterised by rapid vertical and lateral facies variations and by pervasive alteration related to numerous subvolcanic intrusives.

The Drake Volcanics unconformably overlie the Razorback Creek Mudstone and are themselves conformably overlain by the Gilgurry Mudstone. The volcanics are intruded by numerous Late Permian-Early Triassic granitoids and basic intrusions.

The majority of the Drake Volcanics are interpreted to have been deposited in a shallow marine environment, although there is local evidence of sub-aerial volcanism (Perkins, 1988a, b). The Drake Volcanics are overlain by the marine Gilgurry Mudstone, again of late Permian age.



Local geology

The Mt Carrington deposits occur within an area 20 kilometres in diameter of subdued magnetic response, termed the “Drake Quiet Zone”, by previous explorers. This is interpreted to be a sub-horizontal laccolith of felsic rock, from which many of the felsic bodies with which mineralisation is associated may have originated.

The immediate Mt Carrington area contains andesitic volcaniclastic rocks of largely epiclastic origin, intruded by both andesitic and rhyolitic dykes and other rhyolitic bodies. The main hosts to mineralisation in the district are andesite bodies and coarser fragmental rocks. Debate continues as to whether some of the andesitic bodies are intrusive or extrusive.

Alteration

The Mt Carrington mineralised area contains large areas of pervasive alteration. Silica-sericite-pyrite alteration hosts all of the known main zones of mineralisation in varying degrees of intensity. The intensity of this alteration type has led to many andesites being mapped and logged as felsic rocks, which has caused historical problems in establishing a comprehensive geological map.

Other major alteration types are argillic, propylitic, sericite-illite and ankerite. Smith (1989) suggested a model zonal alteration pattern around mineralisation of proximal sericite-pyrite-dominant to distal, chlorite-dominant propylitic alteration.

Particularly intense silica - sericite - pyrite alteration exists in the central Strauss and North Kylo gold deposit areas.

Mineralisation

Epithermal mineral occurrences are developed throughout the 40 kilometres of strike of the Drake volcanic belt. Although the occurrences are scattered generally throughout the outcrop area of the volcanics there is a concentration of major mineralisation within the Drake Quiet Zone. The centre of the zone lies between Mt Carrington and Red Rock, two of the larger mineralised alteration systems in the field.

A three-fold classification of the mineralisation has been generally used by explorers and researchers in the area:

- discordant fissure veins
- stratabound stockworks
- stratabound disseminations

Most mineral occurrences contain combinations of some or all of the three styles listed above. For example, most fissure veins are accompanied to some degree by stockworks or disseminations along their margins.

Veins are commonly 1metre or less in thickness and comprise massive to often classic epithermal colloform and crustiform laminar banding, with alternating layers of quartz to chalcedonic or jasperoidal silica and sulphides, with sericite, chloritic aggregates, and sideritic to ankeritic carbonates. Veins may have brecciated vein fill in their cores.

Veins typically have dominant pyrite and lesser sphalerite in the gold rich systems such as Strauss and Kylo, Carrington and Guy Bell. Gold occurs as discrete grains up to 150 microns, but is commonly 10 to 30 microns on the boundaries of sulphide grains, and occurs in electrum of between 400 and 800 fineness. Sphalerite may be replaced by fine chalcopyrite. Accessory minerals in the gold deposits are galena, tetrahedrite – tennantite.

In the silver dominant systems such as Lady Hampden, Silver King and White Rock pyrite is the dominant sulphide, with lesser sphalerite and galena, tetrahedrite and tennantite. A variety of sulphosalts such as pearcite, polybasite, pyrargyrite, proustite occur in trace amounts, as do chalcopyrite, gold and electrum. While mineralisation is often vein breccia hosted as at White Rock, there is significantly more disseminated mineralisation at Lady Hampden

Depth of oxidation varies from 60 metres on top of Mt Carrington to less than a few metres in some prospects.

Supergene processes see the development of chalcocite blankets of up to 20m thickness after primary stringer quartz-chalcopyrite veined host rocks in the Gladstone area.

Mt Carrington

The current inferred resources (Kanowna Lights) at Mt Carrington are as follows:

	Mt	**Grade Au**	**Grade Ag**	
Gold resources (Strauss, Kylo)	1.0	3.77	7.00	126,000 oz Au, 0.6 Moz Ag
Silver resources (White Rock, Lady Hampden)	0.78	0.93	176	4.4 Moz Ag, 20,000 oz Au

These resources were calculated when the gold price was US$350/oz Au and when the silver price was US$4.79/oz Ag.

The mineralisation in the Mt Carrington-White Rock area displays local and broad scale zoning. The central Mt Carrington deposits are gold-rich, with Ag: Au ratios of 2: 1. This ratio increases to 100-500: 1 in the silver-dominated systems of Lady Hampden and Silver King, 1200 metres to the southeast. Furthermore primary, and supergene, copper mineralisation is concentrated in the western part of the Mt Carrington mine leases.

The gold rich deposits at Mt Carrington, for example Strauss, North Kylo, West Kylo, Carrington and Guy Bell, concentrate near the centre of the Mt Carrington system. The mineralisation is structurally complex, although steeply dipping vein sets generally dominate. Locally there are stratabound controls on the overall distribution of mineralisation, as in the Strauss pit. The deposits are characterised by unusually high zinc contents, and much of the mineralisation at Strauss and North Kylo averages 1-2% Zn.

There are two main areas of silver mineralisation at Mt Carrington, the Cheviot Hills Fault Trend, containing the Lady Hampden and Silver King deposits, and the Mozart Prospect, and the White Rock area. The former area of mineralisation is hosted by volcaniclastics and lapilli tuffs of the Hampden Member; coarser volcanic rocks appear to be particularly favourable hosts. The majority of the mineralisation occurs as disseminations, although there are high grade sulphide-rich segregations or veins along NE-trending vertical fractures. At White Rock silver-zinc mineralisation occurs in hydrothermal breccias and stockworks in flow-banded rhyolites.

Primary copper mineralisation occurs in the central and western parts of the Mt Carrington field, primarily associated with felsic porphyry bodies. There has been limited exploration for copper mineralisation in general, but one early Newmont drill hole intersected copper veining over most of its length of 279 metres. The grades, although modest, include an aggregate of 164 metres at 0.26% Cu.

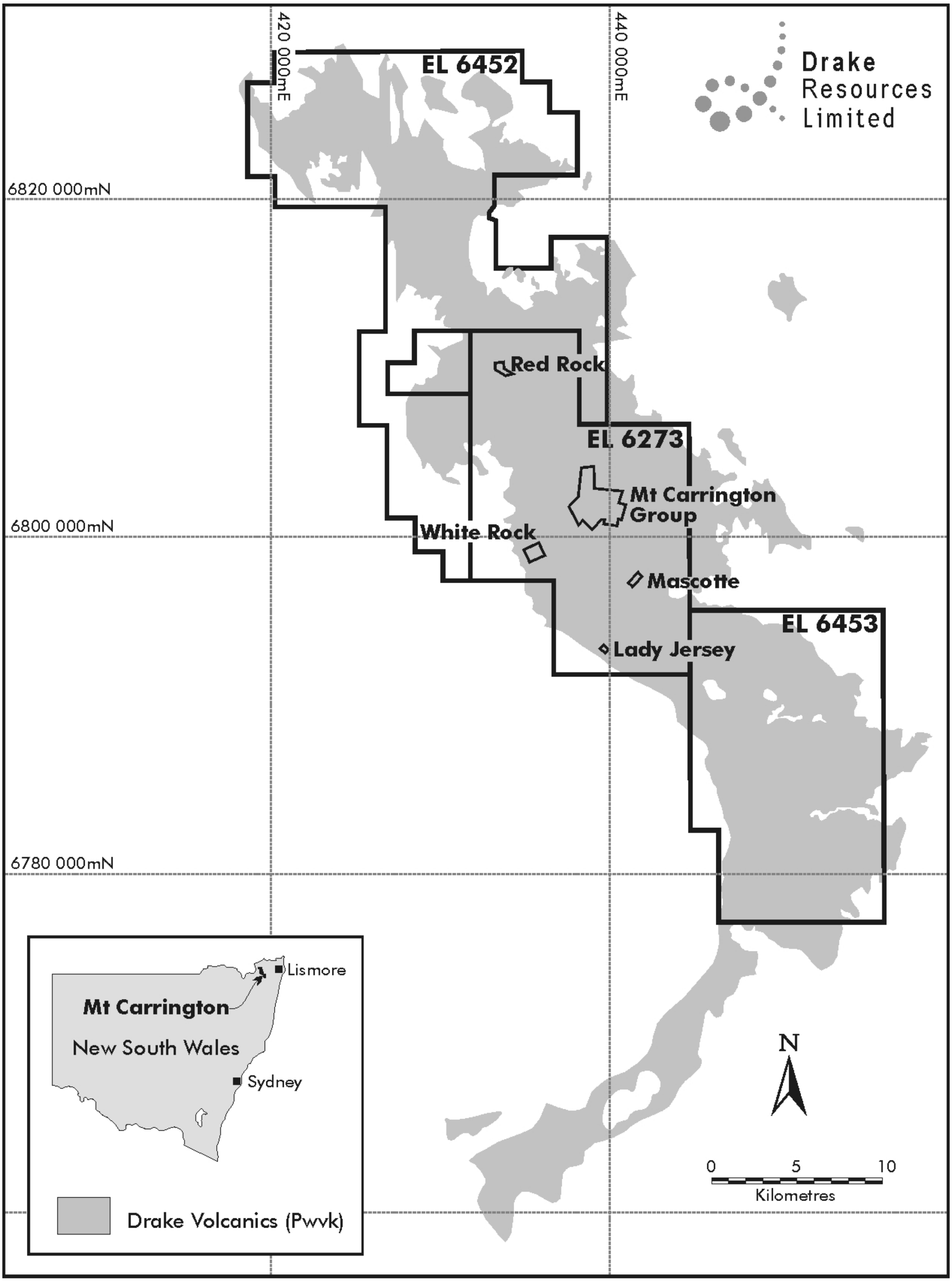
Supergene copper mineralisation has been identified at three locations at Mt Carrington. The main area, Gladstone, displays the transition from chalcopyrite, chalcopyrite rimmed with chalcocite, to chalcocite-only mineralisation. There has been very limited exploration for this style of mineralisation in the district.

Summary

The Mt Carrington gold-silver-zinc deposits occur in an extensive area of alteration within the intermediate to felsic Drake Volcanics. The deposits are considered to have formed during the evolution of this late Permian volcanic belt, at relatively shallow depth in a submarine to emergent environment.

Mt Carrington occurs in the south-western portion of a subtle but well-defined circular structure, nested within a broader magnetic “quiet zone” that is interpreted to correspond directly to a regional-scale but poorly developed caldera-like feature. The flow-banded nature of the intrusives, their commonly fault-like contacts, and the locally faulted margins of the bodies suggest that, despite proximity to surface, the magma was too cool and stiff for significant volumes to be vented to surface.

There are strong spatial and probably genetic relationships between the distribution of certain rhyolitic and andesitic intrusions and the epithermal mineralisation. In particular much of the copper, zinc, gold and silver mineralisation is associated with rhyolitic intrusive bodies which are commonly highly silicified and flow laminated.



Drake Volcanics with Tenements

Main References

Bottomer L.R. 1986. Epithermal silver-gold mineralization in the Drake area, north-eastern New South Wales. Australian Journal of Earth Sciences 33, 457-473.

Brown R.E., HENLEY, H.F., and Stroud W.J.2001. Warwick-Tweed Heads 1:250,000 sheet Exploration Data Package. Geological Survey of New South Wales, GS2001/087.

Houston M.J. 1993. The geology and mineralisation of the Drake mine area, northern NSW, Australia, pp. 337-348. In Flood P.G. & Aitchison J.C. eds. New England Orogen, Eastern Australia.

Perkins C. 1988a. Origin and provenance of submarine volcaniclastic rocks in the Late Permian Drake Volcanics, New South Wales. Australian Journal of Earth Sciences. 35, 325-337.

Perkins C. 1988b. The Red Rock deposit: Late Permian submarine epithermal precious metal system in north-eastern New South Wales. pp. 895-898 In Pacific Rim Congress 87. Australasian Institute of Mining and Metallurgy, Conference Proceedings.

Smith S.G. 1989. Geology and geochemistry of Permian epithermal mineral deposits at Drake: a study of a precious metal-base metal hydrothermal system. BSc Hons thesis, University of New England, Armidale (unpublished).

COBAR SUPERBASIN SYSTEM METALLOGENESIS

Vladimir David

Golden Cross Operation Ltd, 22 Edgeworth David Ave., Hornsby NSW 2077

Key Words: Cobar Superbasin, Basin architecture, growth faults, turbidites, limestone, mineralisation.

Abstract

The term Cobar Superbasin System refers to a regional, complex tectono-stratigraphic terrain in the Central Subprovince of the Lachlan Orogen marked by Late Silurian-Early Devonian sedimentation of the Cobar Supergroup.

The Cobar Superbasin System developed as four deep-water troughs surrounded by shallow-water flanking shelfs. The northern portion (Cobar Basin) is characterised by siliciclastic sediments locally intruded with felsic volcanics. The southern portion (Mt Hope and Rast Troughs) is dominated with volcanics of bimodal character and volcaniclastic rocks intercalated with sediments. During the Early Devonian, an array of scattered carbonate reefs (or probably a carbonate ramp) existed along the eastern margin of the Cobar Superbasin System. As rifting persisted, carbonate reefs (ramp) broke-down and collapsed in the deep-water parts of the superbasin system.

The Cobar Superbasin System developed during Silurian-Devonian time (Glen, 1995) and was (half-) inverted by combined thick and thin-skinned tectonic style (Glen, 1990). The region underwent deformations during Late Devonian Tabberaberran Orogeny and Middle Carboniferous Kanimblan Orogeny (Scheibner, 1989; Glen 1992). The Cobar Basin opened as a haft-graben, by transtensional NE-SW extension and closed by NW transpression. The overall structural style of the Cobar Basin is NW-SE folding overprinted by NE-SW folding and eastwards oblique left-lateral thrusting. In general, the basin development was influenced by placement of Silurian granite batholiths, which acted as structural weakness and/or tectonic butters.

The Cobar Superbasin System metallogenic work in conjunction with basin architecture, facies analysis and structural history attempted to find answers to the metal sources, mechanism of fluid-flow and mineral deposition in a dynamic environment of basin evolution. Metallogenesis is characterised with formation of initial mineral deposits (early mineralisation stage), their subsequent modification and formation of syn-tectonic deposits (late mineralisation stage). Early mineralisation stage is characterised with syn-rift phase of basin development accompanied with extensional tectonic environment, whilst later mineralisation formed in the inversion phase under compression.

In the early mineralisation stage, the intrusion related epithermal, the VMS and the Irish type deposits were formed. These deposits are hosted in the syn-rift sedimentary sequence, where intense lithofacies distribution and basement architecture controls their occurrences. They formed in the zones of growth faults, intersections of growth faults and transform/transfer faults and intersection of major transform/transfer faults. The later mineralisation stage formed Cobar style deposits, quartz vein hosted deposits and Mississippi Valley Type deposits. The reverse lateral inversion tectonic environment controls morphology of these deposits. Deposits are localised in the structurally favourable sites: at the deflected segments of strike slip faults (CSA); at the intersection of reactivated growth and transfer/transform faults (Elura); at the end of major strike-slip faults (as results of differential displacement – Peak and Perseverance); at the overlap zones of en-echelon strike-slip faults (Cobar Goldfields; Rayner, 1969); and at the junction of major faults (McKinnons Tank).

The Cobar Superbasin System represents a mineralisation continuum, where the deposits formed during the syn-rift phase underwent structural overprinting and green-schist grade metamorphism during the basin inversion phase.

Introduction

The Cobar Superbasin System forms the richest polymetallic ‘basin’ in the Lachlan Orogen. It contains a metal inventory of 198t Au; 4,597t Ag; 2.2Mt Cu; 4.8Mt Zn and 2.9Mt Pb. About 70% of these resources have been mined since initial discovery in 1870. In the district, three polymetallic underground mines are operating.

After the discovery of the Elura deposit in 1974, a modern approach was introduced to metallogenic studies. Such modern approach generated controversial interpretations of ore genesis.

Syngenetic, sediment-hosted, genetic models were introduced by Brooke (1975); Gilligan and Suppel (1978); Sangster (1979), Schmidt (1980) and Marshall et al., (1981). These models also involved the possibility of mechanical remobilisation close to the original place of deposition. Syn-deformational, structurally controlled models were advocated based on the study of fault relationships between the major deposits and quartz vein microstructures (Glen, 1978; Schmidt 1980, 1990). DeRoo (1989); Lawrie (1990); and Glen (1987, 1995) interpreted a syn-deformational, structurally controlled model for the Elura zinc-lead deposit. Similar, syn-deformational models were proposed to the CSA copper-zinc-lead deposit by Brill (1989) and to the Peak gold deposit by Hinman and Scott (1990), and Perkins et al., (1994). However, some authors proposed a polymodal genesis for the Cobar deposits (Marshall and Gilligan, 1987; 1993), based on overlapping concepts of remobilisation and syn-tectonic formation. Secombe and Brill (1989); Seccombe (1990); Jiang (1996), Foster (1997) and Jiang et al., (2000) provided detailed studies on fluid inclusion, stable isotopes, lead isotopes of the individual deposits in the Cobar Basin. During the 1990’s, Marshall and Gilligan (1987; 1993), Glen (1987, 1995) and Stegman (2001) made the most significant contributions in a complex approach to the understanding of metallogenesis.

In the metallogenic studies, the high quality 1:100 000 NSW Geological Survey geology maps of the Cobar region (Pogson, 1982; MacRae, 1987; Glen, 1988; Glen 1994) played a crucial role. In addition, under the NSW government project Discovery 2000 the Geological Survey of New South Wales in collaboration with numerous of mineral exploration companies acquired high-quality geophysical coverage: airborne magnetic on 400m spaced lines, radiometrics and ground gravity with 1x2km grid. These data helped to create a structural-geological framework on which this metallogenetic work is based.

In this paper, author undertook a complex approach to the metallogenesis involving basin evolution processes and tectonostratigraphic placement of mineral deposits. In addition, the paper correlates basement architecture, lithofacies distribution and deformation styles which controls deposit occurrences

Structural History

Structural history of the Cobar Superbasin System is associated with processes of basin evolution: basin formation (extensional tectonic) and basin inversion (compressional tectonic).

The Cobar Basin formed by subsidence along NNW-trending normal listric faults (e.g. Jackermaroo Fault, Woorara Fault, Coonara Fault and Rookery Fault), which developed perpendicular to the main extensional direction. The pre-existing weaknesses and heterogeneities in the basement rocks, such as granite batholiths governed the occurrences and orientations of the listric faults. The variations in the spacing, orientation, geometry and the detachment depth of the listric faults were accommodated by NW- and NE-trending strike-slip and/or dip-slip sub-vertical transform/transfer faults. The Buckwaroon Fault, Plug Tank Fault, Amphitheatre Fault and Wagga - Nymagee Structure developed as a conjugate set of

NW- and NE-trending extensional faults (Figure 1). Cobar Basin formed as a haft graben with greater block down-throw on the eastern margins.

The basin inversion phase commenced with development of N-S cleavage associated with open folding and low-angle thrusting (Glen, 1990), and the selective reactivation of normal gently dipping listric faults along the eastern trough margins. The reactivated faults penetrated into basin sediments and formed blind reverse fault systems and leading imbricate fan structures. The irregular reactivation of listric (syn-sedimentary) faults caused the development of tear faults and rotation of structural blocks. The tear faults formed NE- and SW-trending en–echelon array of left-lateral, with and south block-down movement in the northern part and vice versa in the southern part. Tight folds and decollement faults advanced eastwards with deformation culminating in reverse lock-up thrust faults at the eastern margins. Tectonic barriers such as basement horsts of Silurian granites caused clockwise rotation of local stress axes (σ1' rotated from E-W to WNW-trend) and left-lateral movement along basin bounding faults. This short description of structural history supports Glen's (1990) interpteratation implying that Cobar Basin was (half-) inverted by combined thick and thin-skinned tectonic style.

Cobar Superbasin System Lithofacies

Facies analysis includes study and interpretation of textures, sedimentary structures, fossils and lithological associations of sedimentary rocks on the scale of an outcrop, drillhole or small segment of a basin (Miall, 1990). The Cobar Superbasin System comprises deep-water troughs, flanking and intra-basinal shelves delineated by major structures and abrupt lithofacies changes (Figure 1). The major tectono-stratigraphic units characterised with sedimentary environments and constrained by distinct lithofacies are:

- Flanking shelfs on the deep-water troughs margins (Kopyje Shelf and Winduck Shelf);
- Intrabasinal shelves (Wiltagoona Shelf and Walters Range Shelf); and
- Deep-water troughs (siliciclastic Cobar Basin, volcanic-volcaniclastic-siliciclastic Mt Hope and Rast Troughs).

Basin evolution commenced in latest Silurian to Early Devonian, with formation of the shallow-water shelf to the east (Kopyje Shelf with late Silurian fossils) and deeper water Rast and Mt Hope troughs to the west. Basin subsidence progressed northwards, followed by transgressive facies. Sedimentation started with upward finning outwash-fan facies of conglomerates, arkoses and greywacke (Glen, 1990, 1994; MacRae, 1987; Trigg, 1987). A high-rate of basement subsidence in the Rast and Mt Hope Trough was followed by a high-thermal gradient that produced bimodal volcanism (Scheibner, 1987). Volcanism ranges from rhyolite, rhyo-dacite, dacite to basaltic composition and occurs as submarine intrusions. The initial volcanism of the Mt Kennan Group volcanism was I-type, followed later S-type volcanism of the Mt Halfway Volcanics. Tectonically, the Mt Hope and Rast Troughs were separated by Walter Ranges Shelf, which was characterised as an area of stable shallow-water sedimentation.

Clastic sediments

In the syn-rift phase of basin-formation, sedimentation commenced with shallow-water sequences (lower sequence of the Nurri Group, Mouramba Group) that pass rapidly up section into turbidites such as the Chesney Formation) and turbidites of the lower Amphitheatre (e.g. lower sequence of the CSA Siltstone). In the Cobar Basin, deep-water turbidites comprise the Nurri Group, lower Amphitheatre Group and upper Amphitheatre Group. The relationship between different lithofacies suggests that fans from the east were progressively abandoned by a marine transgression. In general, the thin-bedded, fine-grained turbidite sequences of mudstone, siltstone and fine-grained sandstone intervals (marked by C and D Bouma sequences) with distinct sedimentary structures and fossiliferous assemblages indicate a basin plain with distal submarine fans at the variable depth (Glen, 1994).

The progressive rifting and extension is exemplified by facies relations around the Elura Mine, where carbonate facies of the Kopyje Shelf are overlain by turbidites of the CSA siltstone. At Elura the following facies can be identified from bottom to top:

- Mud mouth shallow-water carbonates reef;
- Proximal back-reef facies with domination of carbonate components;
- Distal back/fore reef facies with domination of siliciclastic components;
- Open outer shelf bellow storm base; and
- Fine-grained turbidites.

These relations are interpreted to reflect drowning of the carbonate shelf during renewed extension along part of the northern margin of the Cobar Basin.

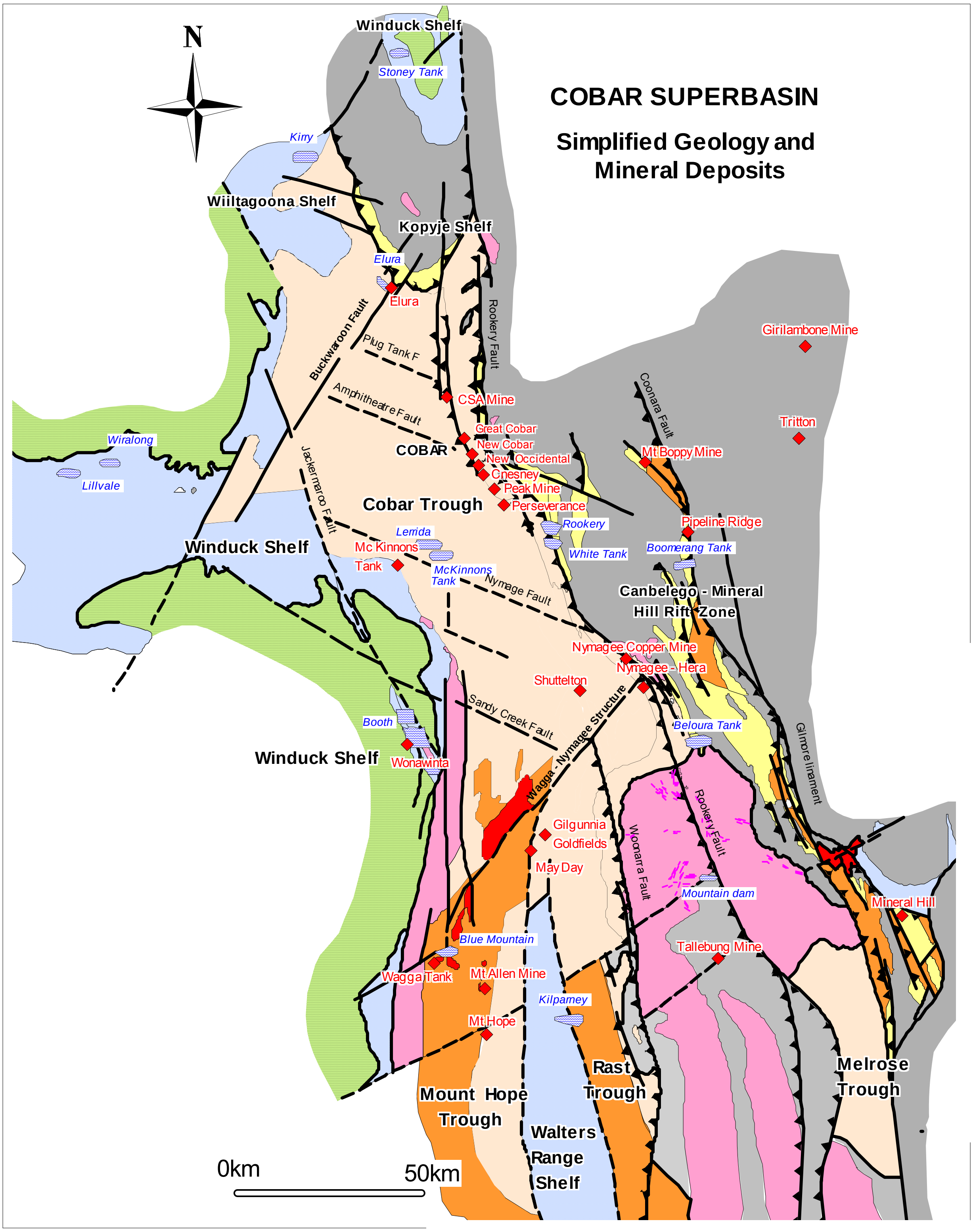


Figure 1. Simplified geology map of the Cobar Superbasin System. Map shows locations of the Early Devonian limestone and major mineral deposits. In addition, the major tectonostratigraphic units are marked.

LEGEND

🟩	Mulga Downs Group
■	Shallow-water sediments
□	Deep-water siliciclastic sediments
🟧	Volcanic and volcanoclastics
🟨	Kopyje Shelf and Canbelego - Mineral Hill Rift Zone
▦	Early Devonian limestone (outcrops and intersections in drillholes)
🟥	Devonian granite
🟪	Silurian granite
⬜	Ordovician metasediments
▲	Reverse Fault
═	Fault without character
◆	Major mineral deposit

Sag-phase deposition in the Cobar Superbasin System is reflected by reversion to thin-bedded turbidites in the Cobar Basin and silty turbidites of the Broken Range Formation in the Mt Hope Trough. Sag phase deposition extended over granite and Ordovician basement west of the basin where it is deposited as the Winduck Group and between the Mt Hope and Rast troughs where it is deposited as the Walters Range Group. A hiatus marked by disconformity and paraconformity separates the Winduck Group from coarse-grained sandstone, conglomerate and shale of the fluviatile Munga Downs Group which probability ranges in age from late Early to Mid Devonian up into Late Devonian, possible with an internal break.

Limestone

Until recently, rare and small limestone outcrops did not attract the interest of geologists who worked in the Cobar region. Following the discovery of the mineralised limestone reef beneath Elura the importance of limestone was recognised in basin evolution and basin metallogenesis deposit (Carolan, 1999; Coller, 1999; David, 2000; David et al., 2001).

Limestone was deposited in the places with insufficiency of terrestrial material and along the growth faults. It occurs in a discontinuous N-S trend along the deep-water trough margins (eastern and northern) and on the Winduck Shelf (Figure 1). Limestone was deposited in the areas of a steady basin subsidence and insufficiency of terrestrial material. The sedimentation vanished with increased subsidence rate and increased input of terrestrial material. The shallow-water fossil assemblages (conodonts, brachiopods, molluscs, bryozoans, crinoids, corals and ostracods) (Pickett, 1979; Felton, 1981; Sharp, 1992; Carolan, 1999; Talent et al., 2002) in limestone indicate the existence of uniform sedimentary environment in the Lockhovian. The uniform limestone lithofacies implies an existence of an array of patchy reefs or carbonate ramp along the growth faults, now preserved below the turbidites along the basin margin. Advanced rifting probably break-up carbonate reefs/ramp and caused collapse of large limestone blocks - olistolithe in the deep-water troughs such as Lerida Limestone (Glen, 1987).

The limestone marks the position of major growth faults and the top of basement-tilted blocks. During basin extension and inversion, limestone reefs acted as rigid buttresses (tectonic barriers) creating dilatation sites. In terms of basin metallogenesis, limestone played an important role as a fluid conduit for fluid focussing as a chemical reactant and as a host rock for mineralisation (Elura and Wonawinta).

Early Devonian Porphyritic Intrusions and Volcanics

An advanced basin extension and subsequent decrease in crustal thickness produced regions of abnormally high heat flow, which may have led to igneous activity (c.f. McKeinzie, 1974). These regions occupy zones of listric faults with a high heat-flow rate at the eastern trough margins and deflected deep-seated strike-slip transform faults. In addition, there is a close spatial relationship between occurrences of volcanic rocks and mineralisation in the Cobar Superbasin System.

In the northern siliciclastic–rich Cobar Basin, Early Devonian volcanic rocks occur sporadically as small porphyritic dyke-like bodies (Arrowa, Ferricartup), whilst in the south they are a significant constituent of the basin sequence. The occurrences of bi-modal (I- and S-type) rhyolite/dacite volcanic rocks in the Mt Hope Trough are associated with Early Devonian S-type (Gilgunnia Granite and Boolabone Granite) and I-type (Mt Allen and Coan Granite) granitoids (Scheibner, 1987). These rocks are highly anomalous in Cu, Pb and Zn and were probably one of the sources for metals accumulated in the mineral deposits in the basin. In the Rast Trough, I-type the Shepherd Hill Volcanics interfinger with and overlie the Crossleys Tank Formation turbidites of Cobar Supergroup.

Early Devonian volcanic rocks are rare in the siliciclastic portion of the basin and are associated with major structures: growth faults and transform/transfer faults high terrain subsidence rate and high sedimentation rate. They occur at the following locations:

- Arrowa and Ferricartup, - quartz-feldspar porphyritic dykes in the northern trough
- Elura Tuff, (Schmidt, 1980; Maetz, 1985 and this study) - several tuff beds up to 0.5m thick with mafic composition;
- Mopone Tuff, (Maetz, 1985) - several tuff beds up to 0.3m thick with felsic composition;
- Peak - CSA Tuff (Robertson, 1974) – sub-aerial felsic tuff unit up to 35m thick occurs between Peak and CSA;
- Peak Rhyolite (Stegman, 1998) - flow banded rhyolite extrusion is emplaced coeval with basin sediments at the Peak Gold Mine;
- Queen Bee Porphyry (Kelso, 1982) – feldspar porphyry at Queen Bee deposit ; and
- Other small occurrences are: McKinnons Porphyry (Glen, 1987a; at McKinnons Mine), Shuttelton Rhyolite (MacRae, 1987), Nymagee-Hera Rhyolite (David, 2001), and Nymagee Porphyry (Pogson, 1983).

The whole rock composition of the Early Devonian volcanics infers a magma derived from partial melting of a pre-existing volcanic arc or sediments derived from a volcanic arc provenance. The porphyry intrusions belong to the high-K calc-alkaline series. High Cu and Zn are due to presence of sulphide, which may have been introduced later by hydrothermal alteration. These volcanic rocks may also be one of the sources of metals for Cobar-style mineralisation deposits, but there is not enough evidence to support this hypothesis.

Basement Architecture

The Cobar Superbasin System basement architecture illustrates the final output of results derived from geophysical modelling, lithofacies analysis and structural analysis. The basement architecture is interpreted as a half graben basin with greater block down-throw on the eastern margin then on the western margins. The deepest part of the basin is located in the central part, along the eastern margin, between two subparallel transform/transfer structures: the Buckwaroon Fault and the Nymagee-Wagga Structure (Figure 1).

In relation to the basement architecture, the mineral deposits are located in the:

- In proximity to major marginal faults (growth faults; hangingwall) with the maximum block down-throw (the intermediate size Au-rich (Cu) deposits: Cobar Goldfields, Peak, Queen Bee);
- In proximity to the intersection of growth faults with transform/transfer faults (the largest base metal deposits (+Au); CSA, Elura in the siliciclastics and small

polymetallic deposits; Nymagee-Hera and Wagga Tank in the volcaniclastic and volcanic rocks) and
- In proximity of major transform/transfer faults (small size polymetallic deposits: McKinnons Tank, Mt Hope and May Day).

The metal bearing fluids were focused by growth faults and associated transform/transfer faults into tectonic (blind faults, overlapping and deflected strike-slip faults) and stratigraphic traps (carbonates and sediments enriched in carbonaceous component) forming mineral deposits. The reactivation of the basement structures during basin formation created current morphology of mineralisation in the basin.

Cobar Superbasin System Mineral Deposits

A spectrum of mineralisation styles occurs in the Cobar Superbasin System. These mineralisation styles are characterised by differed tectonostratigraphic settings, volcanic activity, host lithology and amount of deformations (Figure 2). The mineralisation styles are shortly described bellow in the order of abundance.

1) Cobar-Style mineralisation includes syn-tectonic, remobilised structurally controlled deposits dominated by Cu-Au mineralisation (Glen, 1987; Lawrie and Hinman, 1998; Stegman, 2001). The mineralisation is controlled by right-stepping deflections within the Rookery Imbricate fan accompanied by reverse oblique left-lateral movement. This group contains major mineral deposit (e.g. CSA deposit, New Cobar, Peak, Great Cobar, New Occidental and Chesney, Nymagee –Hera).

2) Carbonate and sediment hosted base metal mineralisation occurs in the reef limestone open-platform and silciclastics turbidites at the margin of the deep-water troughs (Elura) and shelf limestone (Wonawinta). This mineralisation is characterised with dominant Zn-Pb-Ag metal associations and replacement/cavity fill mineralisation textures. The most important deposits are Irish Type (Elura) and MVT (Wonawinta).

3) Metamorphosed VMS mineralisation (Sangster, 1979) is characterised by recrystallised and mechanically remobilised, discontinuous transposed en-echelon sulphide lenses. The mineralisation is localised in high-strain zones in proximity to the Early Devonian volcanics and porphyritic intrusive. Base metal associations, locally with high-grade gold, dominate the mineralisation. In this group, belong following deposits and occurrences: Pipeline Ridge, Shuttleton, Queen Bee and May Day.

4) The epithermal gold mineralisation is hosted by quartz and sulphide stockwork veins, e.g. McKinnons Tank deposit (Brywater, 1996: Foster, 1997) and Mt Boppy (Corbett, personal communication).

5) Intrusion-related mineralisation (Tenant Creek Style) occurs at Mt Allen (Au, Fe) and Double Peak (Au, Cu) in the Mt Hope Trough. Mineralisation is characterised with gold-bearing haematite-magnetite lenses and haematite-magnetite-quartz-pyrite stockwork veins in chloritic siltstone. In addition, mineralisation and alteration are strongly associated with anomalous Ag, Bi and W (Suppel, 1979) and the I-type Mt Allen Granite.

6) The gold-bearing quartz-vein mineralisation is hosted by Early Devonian turbidites (Gilligan and Suppel, 1978; Suppel and Gilligan, 1993). The vein geometry is controlled by their position in relation to fold axial plane and deflection along the fault jogs.

7) Porphyry-style mineralisation occurs in the central basin adjacent to Sandy Creek Fault - 20km north of Gilgunnia (Skirka, 2002). Mineralisation is hosted by coarse-grained quartz-feldspar-chlorite-sericite granite.

8) Skarn mineralisation occurs on the eastern margins of the Walter Range Shelf. A magnetite skarn occurs at the contact between limestone and dacite porphyry (Aberfoyle Exploration, 1980).

Genetic Model of Cobar Superbasin System Mineral Deposits

The deposits in Cobar Superbasin System display some of the common features such as tectonostratigraphic settings, host rocks, strain domains and mineralogical paragenesis. In addition, they have similar fluid chemistry, and metal and sulphur sources (Secombe, 1994; Jiang 1996; Foster, 1997; Jiang et al., 2000; Gilles and Marshall, 2003).

The major mineral deposits are located on the unstable eastern basin margins in the zone of growth faults. Exception is the MWT deposit Wonawinta, which is located on the stable Winduck Shelf. The lithostratigraphic settings of mineral deposits in the Cobar Basin show that all the major deposits (Peak, Chesney, New Occidental, Great Cobar, New Cobar, CSA, Elura, Nymagee-Hera, ect.) are hosted in the syn-rift sedimentary sequences associated with high rates of sedimentation and local volcanic activity. The sag sequence hosts only small quartz veins hosted Au-deposits (Gilgunnia Goldfields) and mineral occurrences. The high strain domain at the eastern basin margins host major Cobar Style deposits; the medium strain domain hosts VMS and epithermal deposit and low strain domain hosts MVT Wonawinta deposit (Figure 2). Mineralogical paragenesis is characterised with an early Cu-Au mineralisation, which is overprinted by later Pb-Zn mineralisation (Robertson, 1974; Gilligan and Suppel, 1978; 1986; Brill, 1991; Scott and Philips, 1990; Hinman, 1991; Perkins et al., 1994; Lawrie and Hinman, 1998; Jiang, 1996; Stegman, 2001).

Genesis of mineral deposits comprises initial deposit formation and their subsequent modification. Ones the sulphides are deposited, they are subject to diagenesis, regional metamorphism, deformation and supergene alteration. The genetic model for mineral deposits in the Cobar Superbasin System is an integral part of the basin evolution. The metallogenic event is a mineralisation continuum, which progressed northwards subsequently with lithofacies migration. This event can be divided in two phases:

1. The early mineralisation Basin syn-rift metallogenic phase (including sag phase) characterised by:
    a) VMS deposits;
    b) Intrusion related deposits;
    c) Epithermal gold deposits (porphyry style);
    d) Sediment and carbonate hosted Pb-Zn (Irish Type); and
    e) Skarn deposits.
2. The late mineralisation the Basin inversion metallogenic phase characterised by:
    a) Cobar Style deposits (syn-deformational or remobilised from the early mineralisation);
    b) Quartz-vein hosted Au deposits; and
    c) MVT deposits.

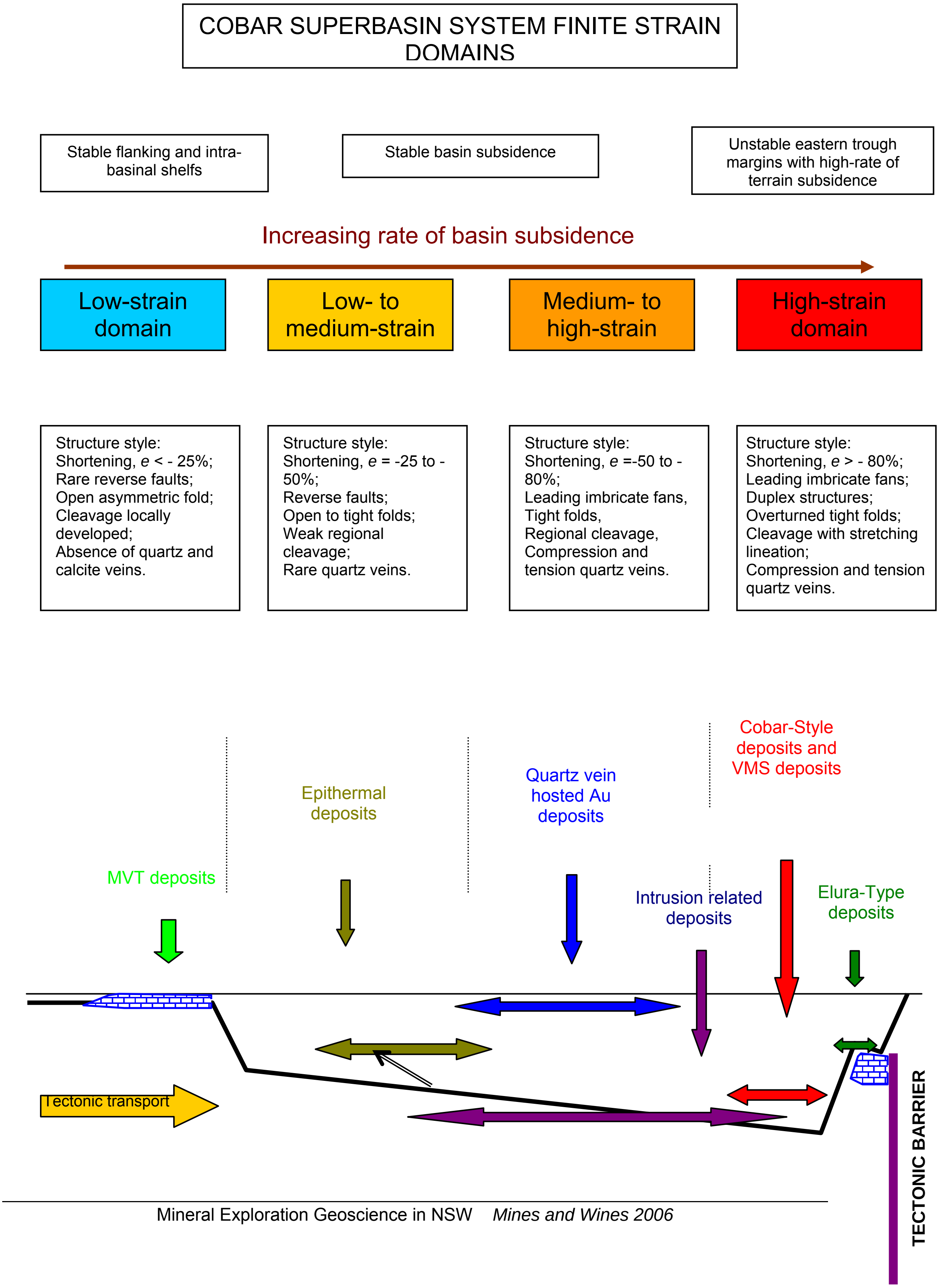
In the Superbasin System, syn-rift metallogenic phase early mineralisation formed deposits on the eastern margins characterised by growth-faults, rapid subsidence, elevated geothermal gradient and felsic to intermediate volcanism. The deposits formed proximal to intersections between transfer/transform faults and basin marginal growth-faults. The deposits formed in this phase were similar to epithermal intrusion related, sediment hosted VMS and Irish-Type.

The late mineralisation Basin inversion metallogenic phase is characterised by modification of an early syn-rift mineralisation, formation of the Cobar Style mineralisation (CSA, New Cobar, New Occidental and Peak), quartz-vein hosted Au deposits (Gilgunnia Goldfield) and MVT deposits (Wonawinta). The quartz vein hosted Au-mineralisation is controlled by the inversion tectonic, whilst MVT mineralisation is controlled with the lithofacies of the host rock lithology (Booth Limestone).

The Cobar Style mineralisation is characterised with a subsequent modification including metamorphism and remobilisation and syn-deformational ore formation processes. The formation of new deposits and remobilisation of pre-deformational deposits are overlapping concepts (Marshall and Gilligan, 1993). In addition, these processes can produce similar types of geometric relationship, ore textures, fluid chemistry, and metal and sulphur sources.

This make hard to distinct genetic nature of the Cobar Style mineralisation. In the absence of the clear distinguishable genetic characteristics between syn-deformational and remobilisation model, they are probably polygenetic.

The late mineralisation is characterised with subsequent modification and metamorphism of pre-deformational deposits associated with formation of new deposits (syn-tectonic ore emplacement).



COBAR SUPERBASIN SYSTEM FINITE STRAIN DOMAINS

Stable flanking and intra-basinal shelves

Stable basin subsidence

Unstable eastern trough margins with high-rate of terrain subsidence

Increasing rate of basin subsidence

Low-strain domain	Low- to medium-strain	Medium- to high-strain	High-strain domain
Structure style: Shortening, *e* < - 25%; Rare reverse faults; Open asymmetric fold; Cleavage locally developed; Absence of quartz and calcite veins.	Structure style: Shortening, *e* = -25 to -50%; Reverse faults; Open to tight folds; Weak regional cleavage; Rare quartz veins.	Structure style: Shortening, *e* =-50 to -80%; Leading imbricate fans, Tight folds, Regional cleavage, Compression and tension quartz veins.	Structure style: Shortening, *e* > - 80%; Leading imbricate fans; Duplex structures; Overturned tight folds; Cleavage with stretching lineation; Compression and tension quartz veins.

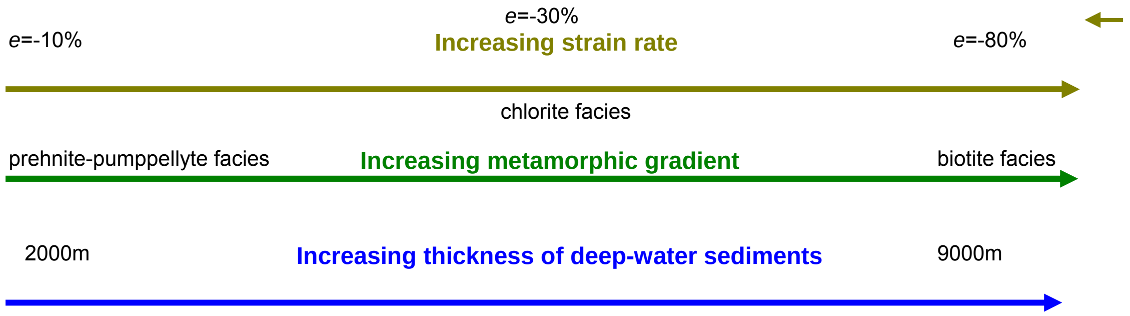


Figure 2. Distribution of major mineral deposits in relation to strain domains and tectonostratigraphic settings.

Conclusion

The Cobar Superbasin System represents a complex metallogenic system containing mineral deposits formed in a mineralisation continuum from the rift phase through the sag phase to the inversion phase of the basin evolution. The initially formed deposits subsequently underwent deformation tectonic transposition and metamorphism, as well as mechanical and chemical remobilisation.

Acknowledgements

Author would like to thank Golden Cross Resources Ltd for supporting research beyond day-to-day exploration work and for permission to present this paper.

References

ABERFOYLE EXPLORATION Pty Ltd., 1980/82. Prospecting reports, PLs 519 and 631, Kilparney area. GS 1980/426.

BRILL, B. A. 1989. Deformation and recrystallisation microstructures in deformed ores from the CSA mine, Cobar, N.S.W., Australia. Journal of Structural Geology, Vol 11. No. 5 pp 591-601.

BYWATER, A., JOHNSTON C., HALL C. R., WALLECE P. and ELLIOT S. M., 1996. Geology of McKinnons Gold Mine Cobar, New South Wales, In the Cobar Mineral Field - A 1996 Perspective. (Ed Cook et al.) pp 279–271 (Australian Institute of Mining and Metallurgy: Melbourne.

CAROLAN, P. M., 1999. Geology of Shelf Strata and Carbonate Hosted Mineralisation at the Elura Mine, Cobar, NSW. BSc thesis. School of Geoscience. University of Wollongong.

DAVID, V., 2000. Structural Setting of the Elura Zn-Pb-Ag Deposit, Cobar, NSW, Australia. Central West Symposium Cobar 2000: Geology, Landscapees and Mineral Exploration.. In Extended Abstracts, Edited by K. G. Mc Queen and C. L. Stegman, 15-20.

DAVID, V., LEEVERS, P. and LORRIGAN, A., 2001. A new look at the Elura deposit, Cobar, NSW. Abstract AGS Conference.

DeROO, J. A., 1989. The Elura Ag-Pb-Zn mine in Australia - ore genesis in a slate belt by syndeformational metasomatism along hydrothermal fluid conducts. Economic Geology, 12, 577–589.

FELTON, E. A., 1981. Geology of the Canbelego 1:100 000 Sheet 8134, 171p. New South Wales Geological Survey, Sydney.

FOSTER, D. B., 1997. The Geology and Origin of the McKinnons Gold Deposit, Cobar. Unpublished Honours Thesis – The University of Newcastle.

GILLIGAN, L. B., and SUPPEL, D. W. 1978. Mineral deposits in the Cobar Supergroup and their structural setting: New South Wales Geological Survey v. 33, 15–22.

GLEN, R. A., 1987. Copper and gold rich deposits in deformed turbidites at Cobar, Australia: their structural Control and hydrothermal origin. Economic Geology 82, 124-140.

GLEN, R. A., 1990. Formation of inversion of transtensional basins in the western part of the Lachlan Fold Belt, Australia, with emphasis on the Cobar basin. In A.E. Grady, P.R. James, A.J. Parker and J.P. Platt (Editors), Australian Tectonics. J. Structural Geol., 12: 601-620.

GLEN, R. A., 1994. Cobar 1:100,000 geological sheet 8035, 2nd edition. Sydney. New South Wales Geological Survey, map and notes.

GLEN, R. A., 1995. Thrusts and thrust-associated mineralisation in the Lachlan Orogen. Economic Geology, 90, 1402-1429.

HINMAN, M. C. and SSOTT A. T., 1990. The Peak gold deposit, Cobar in Geology of the Mineral deposits of Australia and Papua New Guinea (Ed. F.E. Hughes), pp. 1345 -1351 (The Australian Institute of Mining and Metallurgy: Melbourne).

JIANG, Z., 1996. Geochemical studies of the Peak and Chesney Gold Deposits, Cobar, NSW, Australia, Unpublished PhD Thesis. University of Newcastle.

JIANG, Z., Sun Y. and Seccombe P. K., 2000. Significance of Fluid Inclusions Within sulphide minerals – an Example from the Peak and Elura Deposits, Cobar, NSW. Abstract AGS Conference.

MARSHALL, B. and GILLIGAN, L.B., 1993. Remobilisation, syn-tectonic processes and massive sulphide deposits: Ore Geology reviews, 8, 39-64.

MIALL, A., D., 1990. Principles of Sedimentary Basin Analysis. Springer Verlag., 668 p.

PERKINS, C., HINMAN M. C. and WALSHE J. L., 1994. Timing of mineralisation and deformation, Peak Au mine, Cobar, New South Wales. Australian Journal of Earth Sciences 41, 59–522.

PICKETT, J. W., 1979. Conodont assemblage from the Amphitheatre, Baledmund and Meryula Formations, and Great Cobar Slate, Cobar district. New South Wales Geological survey – Palaeontological Repost 1979/17 (unpublished) (GS 1979/245).

SCHEIBNER, E., 1989. The tectonic of the New South Wales in the second decade of application of the plate tectonic paradigm. Journal of Proceedings of the Royal Society of New South Wales, 122, 35-74.

SANGSTER, D. F., 1979. Evidence of an exhalative origin for deposits of the Cobar district, New South Wales: BMR Journal of Australian Geology and Geophysics, v. 4, 15-24.

SCHMIDT, B. L., 1980. A geology of the Elura Ag-Pb-Zn deposit, Cobar district, N.S.W. MSc thesis, Australian National University, Canberra (unpublished).

SCHMIDT, B. L., 1990. Elura zinc-lead-silver deposit, Cobar. In Hughes F. E. ed. Geology of the Mineral deposits of the Australia and Papua New Guinea. Australian Institute of Mining and Metallurgy, Monograph Series 14 (2), 1329-1336.

SCCOMBE, P., 1990. Fluid inclusion and sulphur isotopes evidence for syntectonic mineralisation at the Elura Mine, southeastern Australia. Mineralium Deposita, 25, 304-313.

SECCOMBE, P. K. and BRILL, B. A., 1989. Fluid inclusions and S, O, H and C isotopic evidence for metamorphic Cu, Zn, Pb and Au ore formation at Cobar, New South Wales, Australia. 28th Int. Geol. Congr. Abstracts 3, 66-

SHARP, R. T., 1992. Mapping of the Devonian sequence at Mount Gunderbooka north of Cobar, with emphasis on stratigraphy and sedimentology. Unpublished BSc thesis. University of Technology, Sydney.

SKIRKA, M. and Mc INNES D., 2002. Combined Annual Report for the period ending 28th of August 2002 on the Shuttleton EL 5769 and Sandy Crick EL 5975. Pasminco Exploration, Cobar. CB 148.

STEGMAN, C. L., 2001. Cobar deposits: Still defining Classification. SEG Newsletter. No 44.pp 15-25.

SUPPEL, D. W., 1979. Mineral deposits and potential of the Cobar Region. New South Wales Geological Survey – Report GS 1979/106 (unpublished).

SUPPEL, D. W. and GILLIGAN L. B., 1993. Nymagee 1:250,000 Metallogenic Map SI/55-2: Metallogenic Study and Mineral Deposit Data Sheets. Geological Survey of New South Wales, Sydney.

TALENT, J., MAWSON, R., WINCHESTER-SEETO, T., MATHIESON, D., MOLLY, P., STROLZ, L. and ENGELBRESTON, M., 2002. Progress report on Micro-palaeontological studies from Blantyre#1, Berangabah#1, Mt Emu#1, Pondie Range#1, Poopelloe lake#1. Geological Survey of New South Wales. Unpublished report.

CSA – 40 years Old and Enjoying a Mid Life Renaissance!!! No Crisis here folks! Aspects of Mine and Surface Geology and Recent MIMDAS Surveys at the CSA Mine, Cobar NSW SUPERBASIN METALLOGENESIS

Ian Stockton[1] District Exploration Geologist, Derek Webb[2] Senior Geophysicist, Jason Hosken [3] Geology Superintendent

[1, 2, 3] Cobar Management Pty Ltd, PO box 31 Cobar NSW, 2835

Key Words: CSA, mining, copper, structure, MIMDAS, regional geology

Background

The CSA deposit was discovered in 1871 by Tom O'Brian and subsequently sold to a syndicate consisting of a Cornishman, a Scotsman and a Australian, from whose nationalities the mine was subsequently named (CSA).

The mine operated intermittently until 1964, when the current infrastructure was built. Modern mining commenced from this time at approximately 700 000 tonnes per annum from the Eastern System (Cu+/-Zn) and the Western System (Pb+Zn+Ag) lenses. The copper rich QTS System was discovered in the mid 1970's and is currently the main source of ore.

Mineralisation consists of steeply dipping sulphide and quartz sulphide lenses. These are hosted in the CSA siltstone and may be structurally related to the Cobar fault.

Historical mine production from 1964 to 2005 is estimated 21mt @ 2.76% Cu for 592,000t of Cu. Total reserves and resources on the QTS North System as of March 2006 were 9.5mt at 6.7% Cu and 29 g/t Ag for 641,500t Cu. Current throughput is 810,000t per annum. Current development is at 1.42km below surface and the resource is open at depth, 1.8km from surface.

The CSA mine is operated by Cobar Management Pty Ltd (CMPL), a wholly owned subsidiary of Glencore International.

Regional Geology

The CSA mine is located on the eastern side of the Cobar Basin (Figure 1). The basin was formed during the early Devonian, depositing the Cobar Supergroup, consisting of the Kopyje and Wiltagoona shelf sequences and the deeper water Nurri and Amphitheatre Group sediments (Glen, R.A. 1994). The Nurri group is an upward fining turbidite sequence passing up from the lower Drysdale Conglomerate through to the Chesney Formation consisting of massive sandstone, interbedded sandstone and siltstone and mudstone. The Amphitheatre Group overlies and interfingers the Nurri Group at the eastern margin, consisting of thin bedded turbidite sequences, including the CSA siltstone and a thick bedded turbidite sequence (Biddabirra Formation).

In the Late Devonian the Cobar basin underwent inversion and reactivation of Syn-depositional Faults. These faults are interpreted as steeply dipping at surface, developing into a single thrust fault at depth (Glen, R.A. 1994). These faults separate the major lithological units (Figure 1). A pervasive cleavage developed during inversion is interpreted as being related to the timing of mineralisation.

Local Geology

The local geology of the CSA mine is dominated by the CSA siltstone, a thinly bedded and occasional slaty sequence. Bedding is commonly 1-4 cm thick, consisting of silt sized to fine grained sandstone bedding. Occasional thicker and coarser sandstone units also occur. Numerous sedimentary structures occur within the bedding (graded bedding, cross stratification, scour structures etc), which is interpreted as being a distal turbidite sequence. Small scale folding and faulting is common through the CSA siltstone, increasing in intensity towards the top of the sequence to the west and the Biddabirra Formation.

The CSA siltstone borders with the Cobar slate to the east. Mapping within the interpreted Cobar fault contact area has yet to determine the nature boundary of the two units, however this is interpreted as being an inter-fingering and probably gradation boundary. No surface expression of the Cobar fault has been identified and it is quite possible that the Cobar Fault encompasses the CSA mine as a broad fault zone.

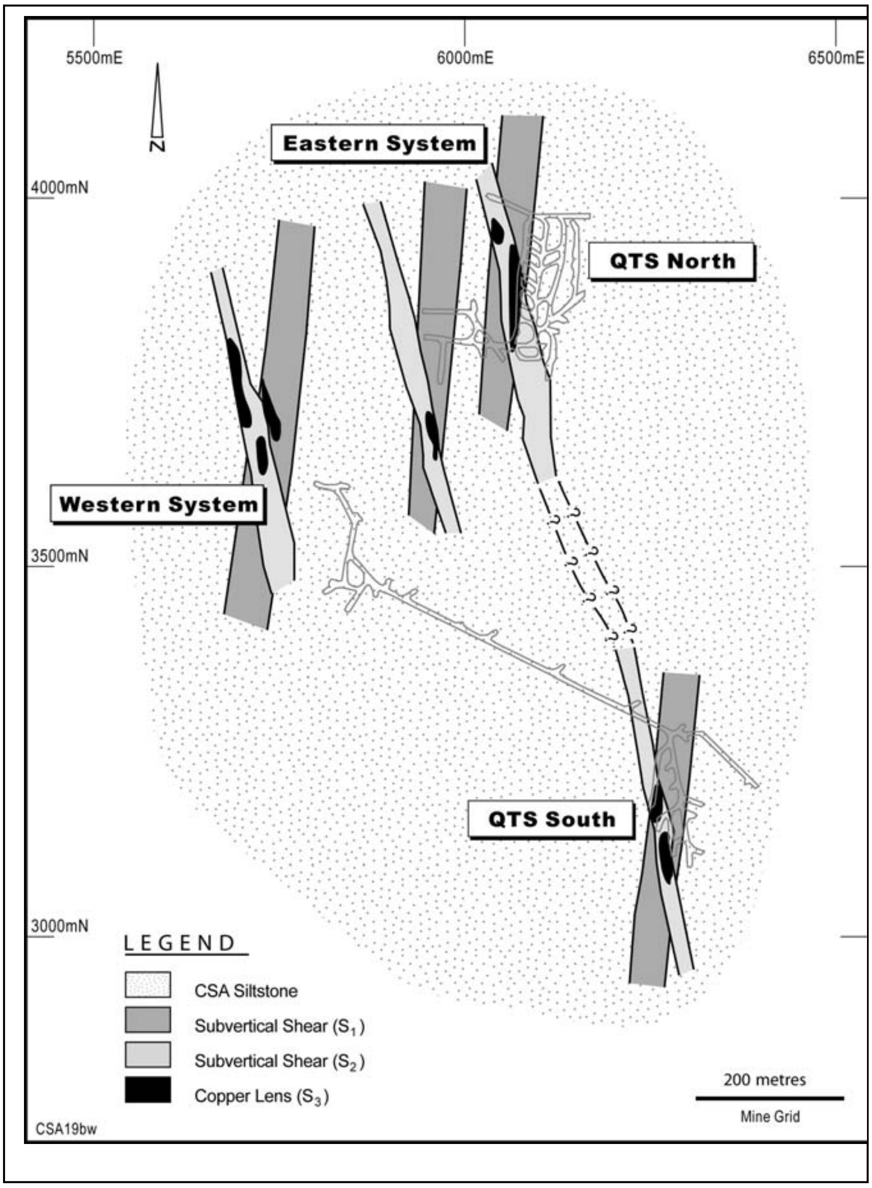


Figure 2- Plan view showing ore systems and structure, 11 level, CSA mine (1000 m below surface).

Mineralisation

The CSA mine is comprised of four mineralised systems, QTS North, Eastern System and QTS South (Figure 2). The principal sulfide phase in all the CSA ore systems is chalcopyrite. Other copper bearing phases include cubanite and trace amounts of bornite, chalcocite and covellite. A copper-silver correlation exists within the ore lenses indicating silver is in solid solution with chalcopyrite. A moderate amount of zinc and lead were extracted from the Western System.

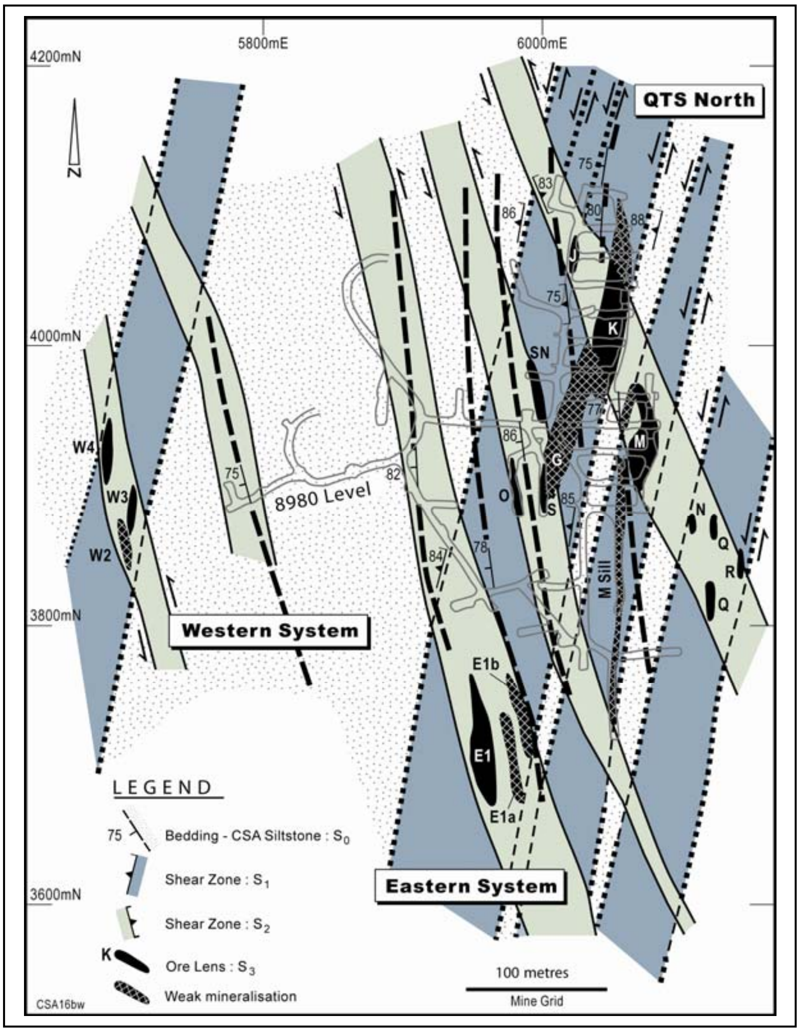


Figure 3 - North looking geological cross-section of 4065 N within the CSA mine illustrating typical QTS North style mineralisation and structural controls.

QTS North system

The QTS North System, currently mined is the largest ore system consisting of purely copper lenses. Mineralisation begins 600m below the surface. Thirteen lenses have been interpreted within the QTS North system and form the majority of the CSA resource and reserve.

QTS North Lenses trend north-south and are sub vertical to steeply west dipping with strike lengths between 15m and 130m as shown in Figure 3. Widths are between 5m and 16m. Down plunge lengths range between 400m to in excess of 1km. Lenses are clearly defined by semi massive to massive chalcopyrite hosted within S3 structures. The margins of the lenses are usually defined by chalcopyrite and quartz veining.

Eastern system
The Eastern system mineralisation begins 250m below the surface and consists of multiple lenses of moderate length between 50m to 80m and variable width averaging 10m. Mineralisation consists predominantly of chalcopyrite, pyrrhotite and numerous quartz and pyrite veins in an intensely cleaved chlorite siltstone. Less commonly, sulfides are massive and contain granular to nodular quartz with little or no quartz veining (Scott and Phillips, 1990).

Western system
The Western System is the only outcropping system at the CSA. Lenses average 45m long and 7m wide and extend down plunge in excess of 200m. Lenses consist of high grade pods of copper rich and lead-zinc rich ore. The copper lenses consist of vein type chalcopyrite, pyrrhotite, pyrite and quartz, and the lead-zinc rich lenses consist of galena, sphalerite, pyrrhotite, pyrite and chalcopyrite and are often banded.

QTS South system
The QTS South system is blind to the surface with mineralisation occurring 700m below surface and some 500m south of the other systems. The mined portion of QTS South consists of several north-south trending steeply east dipping lenses with a strike length of 200m and average widths of 8m to 10m. The system has a steep southerly down plunge component of 300m. Mineralisation occurs in a chlorite altered siltstone similar to the Eastern system. The system is principally copper rich, with minor pyrrhotite and isolated pods of galena and sphalerite at the extremities.

A south plunging extension named QR1 was discovered below and to the south of the old QTS South workings during 2005. The lens is north-northeast trending with a steep westerly dip. The lens extends down plunge for greater than 400m with a strike length of 90m and average width of 15m. The mineralogical zoning is unusual with a 10m wide zone of quartz-chalcopyrite-chlorite veining bounded to the east by a 5m wide zone of massive chalcopyrite. Cubanite inclusions are common within the chalcopyrite.

Structure

Recent efforts at interpreting the structure at the CSA have involved combining mine structure data, surface data and geophysical data. Local terminology has been used here to describe deformation (D) and Shear (S) events at the mine scale. These are not implied to reflect regional deformation events.

All four systems are defined by mineralisation at the intersection of two sub-vertical mine scale structures. The north-northeast trending structures are interpreted as D1 events and are referred to as S1 shears (figure 3 and 4). The north-northwest trending structures are interpreted as D2 events and are referred to as S2 shears. Subsequent reactivation of S1 and S2 by a D3 event generated a dilation zone at the S1/S2 intersection. The dilation zone and associated mineralisation are referred to as S3. S3 structures host the majority of the CSA resource.

S1 shears are defined by north-northeast trending quartz vein shear zones that transect bedding and dip steeply west (85°) (Figure 3). At QTS South they dip steeply east at 85°. The S1 shears are characteristic of all underground workings and may extend well beyond the mine and are likely to be associated with the regional Cobar Fault. Shear zone widths range from 1m to 100m with varying intensities of parallel quartz veining.

S2 shears are north-northwest trending quartz vein shear zones that dip 85° to the east as shown in Figure 3. The S2 shears at QTS South dip 85° towards the west. The structures are clearly visible throughout the underground workings and clearly post date the S1 shears proximal to mineralisation. It is unknown whether the S2 structures are hosted within the Cobar Fault or extend beyond its boundaries. The structures are defined by zones of closely spaced quartz stringers similar to S1 veining. Parallel sulfide veining is common within areas immediate to lode structures.

S3 structures are north-south trending sub-vertical dilation zones. They are best developed in zones of intense S1 and S2 quartz veining. The northern and southern margins of S3 are usually defined by north-south trending sub-vertical quartz-sulfide veins and randomly orientated quartz-sulfide stock-work veins. The intersection of the sub-vertical S1 and S2 shears ensures the S3 domains have an extensive steep northerly plunge. At QTS South S3 has a steep southerly plunge due to the opposite dip directions of S1 and S2. S3 is a product of sinistral strike slip movement along the S1 and S2 boundaries.

At QTS North, S3 structures are clearly defined as large dilations filled with semi massive to massive sulfide exhibiting sharp contacts with the early quartz rich S1 and S2 veins. S1 and S2 quartz veins sets are often seen with brittle terminations at the S3 margins (Figure 5). Brecciation on the S3 margins is common up to several metres wide.

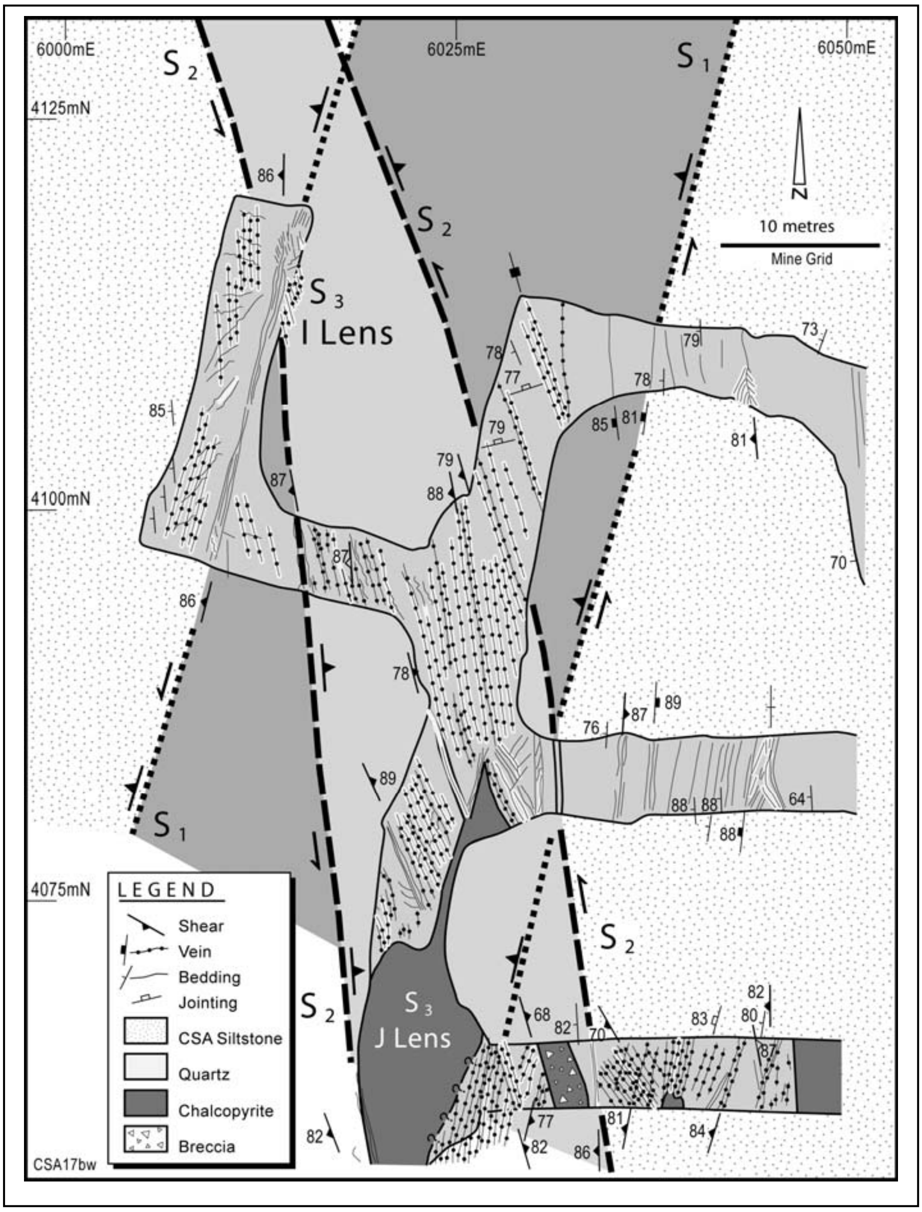


Figure 4 - Geological plan view of CSA geology, 8980 level (1290 m below surface), illustrating the relationship of mineralisation (S3) to earlier generated shear zones (S1 and S2).

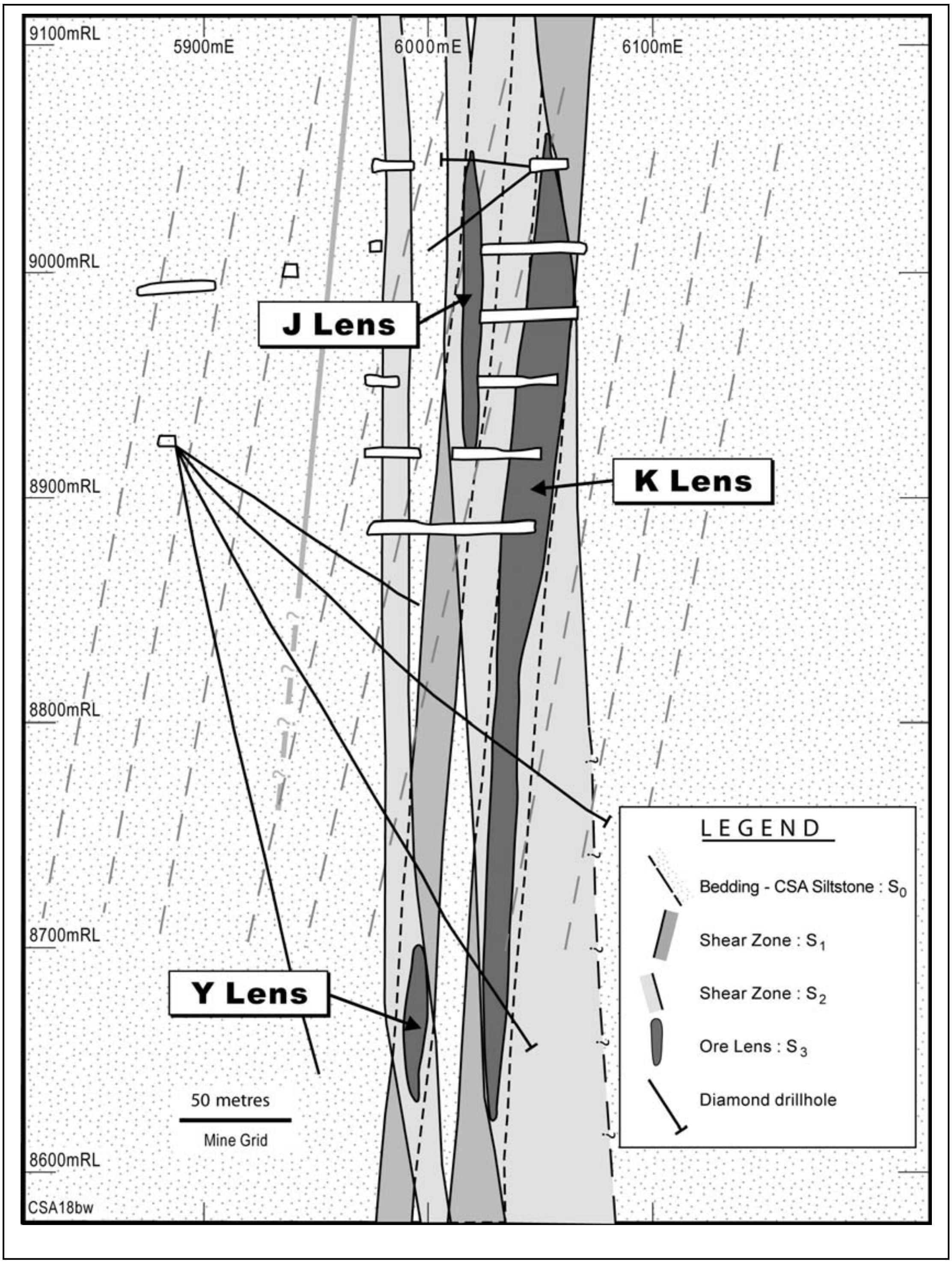


Figure 5 - Geological plan view of J lens, 8980 level (1290 m below surface), highlighting the brittle termination of S1 and S2 veins at the margin of J lens (S3).

Alteration

Alteration around the CSA mineralisation consists of two early generations of chlorite and (?) silica/quartz alteration events, relating to the deformation events described above. Early pre-mineralising alteration consists of broad zones of green chlorite +/- silica/quartz vein alteration associated with S1 and S2. This chlorite alteration extends out from the mineralised zone and completely encompasses mineralisation, without changing in intensity. This early alteration may have acted as ground preparation prior to the mineralising events. A third “black” chlorite and silica event occur as a limited halo to mineralisation, relating to S3 deformation.

MIMDAS Trial - 2006

A trial MIMDAS survey was conducted immediately to the north of the CSA mine infrastructure in February 2006 (Figure 6). Survey lines passed across QTS North, just to the north of the Eastern System. The trial had two overall objectives.

To determine whether MIMDAS could detect mineralisation and/or the structures that host mineralisation.
To assess the applicability of MIMDAS to exploration for CSA style systems.

The survey was conducted as two overlapping blocks of 3D pole-dipole IP, the first using 100m line spacing and the second 200m. A dipole length and station spacing of 100m was used for both blocks. Receiver lines for each block were 2000m long with transmit points along all receiver lines plus extensions (Figure 6). Standard MIMDAS field procedures and processing techniques were used to generate final data sets. UBC software was used for both 2D and 3D inversion modelling.

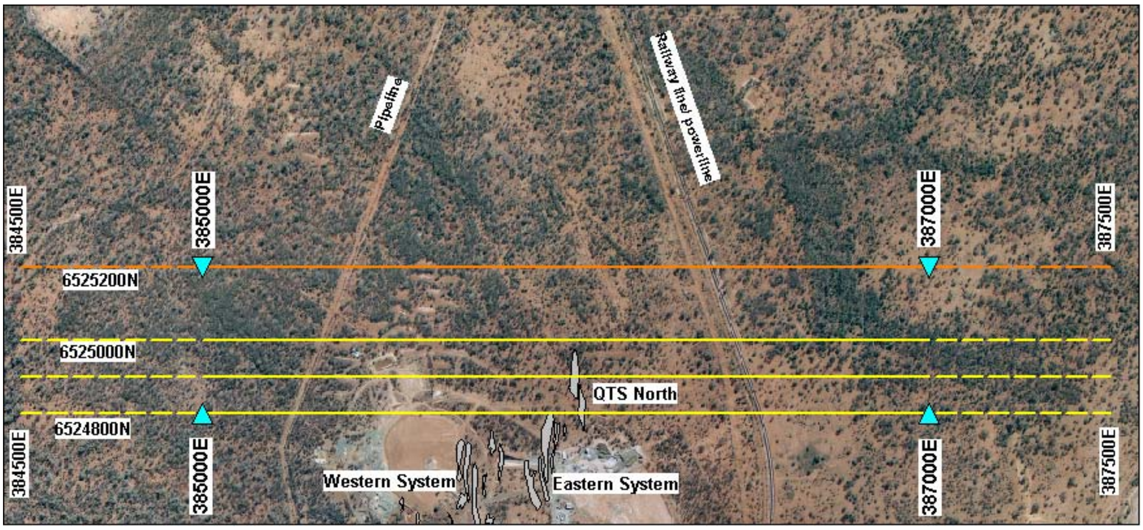


Figure 6 - Line locations, MIMDAS trial survey. Yellow lines indicate the Stage One 100m line spaced 3D array and the orange line the northernmost line for the Stage Two 200m line spaced 3D survey. Solid line sections are shown for receiver arrays, dashed sections indicate line extensions for signal injection only.

Results indicate that the overall CSA mineralised system is conductive to the point that, at this stage, the chargeability data is unusable due to strong negative responses (Figure 7). On the other hand, the resistivity data contains a wealth of information and is of a quality to allow model fits to the level where the average misfit for each observation is less than 1%.

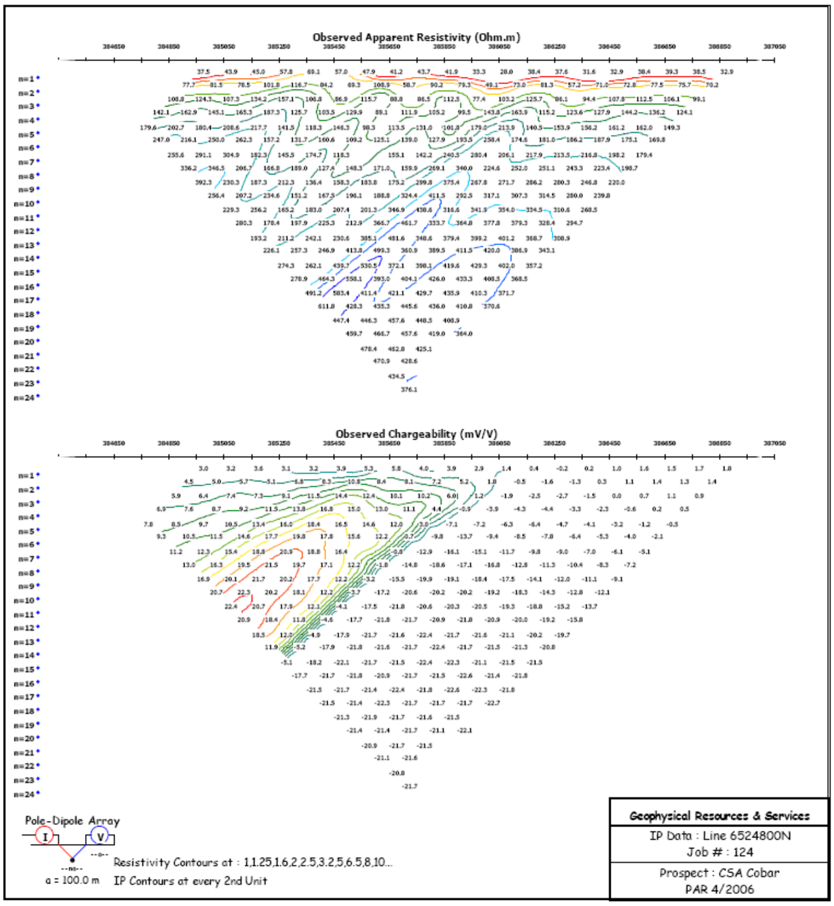


Figure 7 - Pole-dipole apparent resistivity and chargeability pseudosections for Line 6524900N. Note the strong negative chargeabilities for the eastern end of the line.

Resistivity modelling results are very encouraging with several significant structures being identified and traceable (variably) for several hundred metres vertically. These include structures hosting/ controlling the QTS North/ Eastern Systems (Figure 8). Structures outside the current known mineralised system have also been identified. Figure 7 shows a plan section at 480mbs through the resistivity model generated from all combined DC resistivity data. Structures labelled 1 and 2 in the figure are of interest to exploration. The apparent conductor toward the eastern end of the survey (marked ‘dubious’) does not appear in other models and is considered to be an artefact controlled by data from line 6524900N.

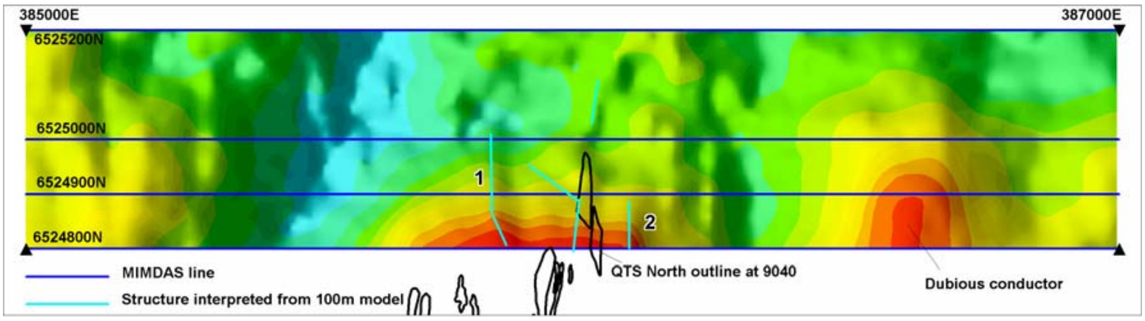


Figure 8 - Plan section through DC resistivity inversion model at 480mbs, shading is from the east. Note the interpreted controlling structure passing parallel to QTS North and the northern end of the Eastern System. Blue colours indicate higher resistivity, red higher conductivity with the range across the image from ~50ohm-m to ~1500ohm-m.

Two dimensional surveys are preferable from an exploration perspective. In the first instance, a potential ore system need only be detected, not defined and hence the detail of a 3D survey is not required. Field procedure for MIMDAS 3D surveys allows the extraction of 2D data from the 3D dataset and it is this data that was used to assess the applicability of MIMDAS to wider exploration.

Figure 9 shows 2D inversion results for Lines 6524800N, 6525000N and 6525200N. These lines show a diminishing 'offline' response to the CSA mineralised system, implying that a 'CSA system' would be detectable to between 200m and 400m offline. A line directly over such a system should see it to almost 500m.

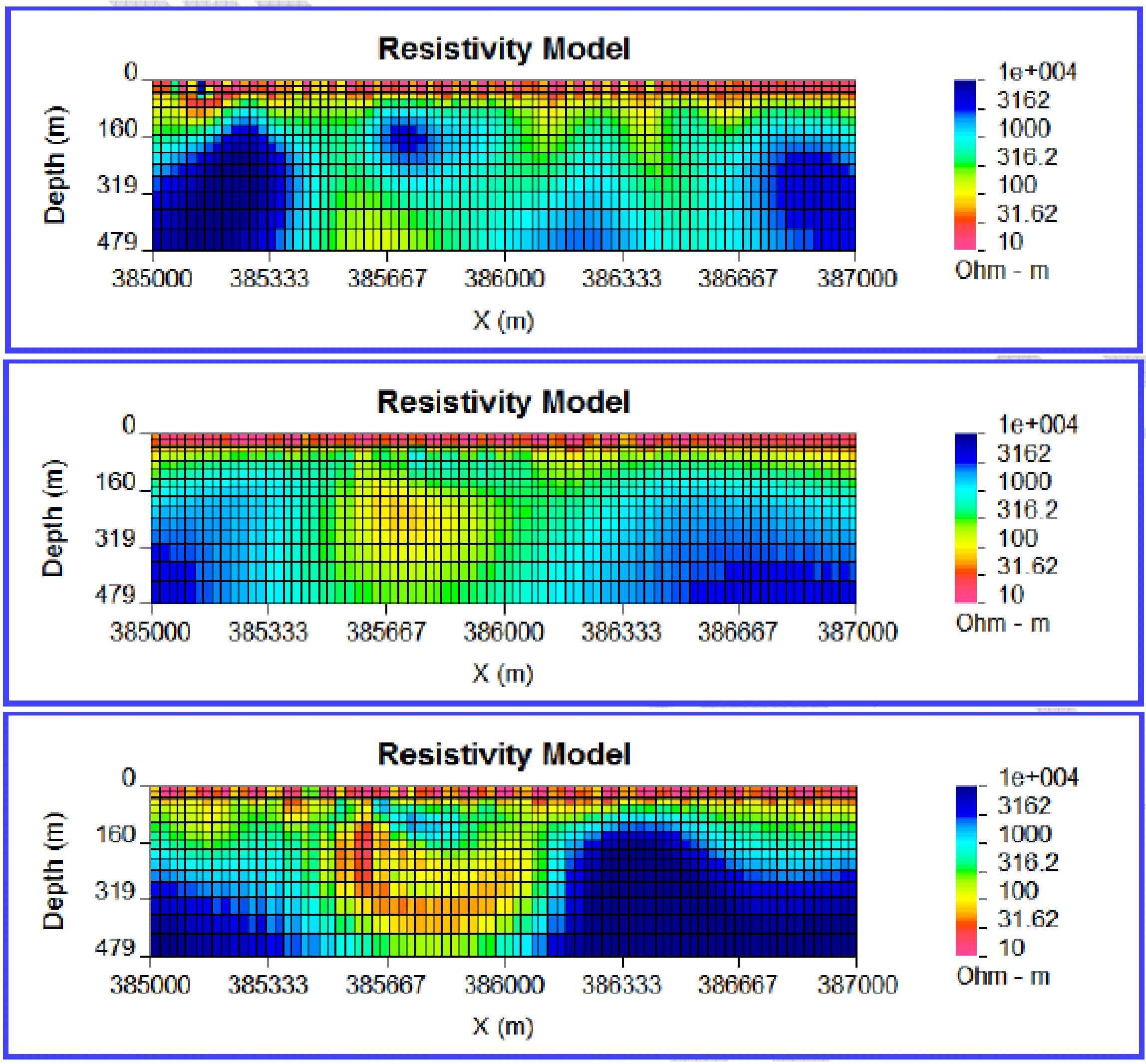


Figure 9 - 2D resistivity inversion models for 6524800N (bottom), 6525000N (middle) and 6525200N (top)

Overall, the MIMDAS trial has shown that MIMDAS can detect CSA style mineralisation and that it can define structures relating to mineralisation. The method is applicable to wider exploration for CSA style mineralisation.

Conclusions

Early structural deformation (S1 and S2) at the CSA mine created a brittle, fertile structure for S3 structures to develop, possibly in sync with a major mineralising event. The timing of structural development and mineralisation is an important consideration. Many of the major structures in the Cobar Basin are interpreted as listric in nature, reflecting basin development.

The vertical nature of the mineralised structures suggests a relationship with a different structural event, possibly the regional deformation event responsible for cleavage development. This is partly supported by the presence of minor mineralisation associated with cleavage.

The relationship between the CSA mineralised systems and the Cobar Fault have yet to be determined, though it could be part of or related to a later subsidiary or splay off the fault.

Efforts to incorporate surface information and underground mapping are currently in progress. MIMDAS trials have demonstrated success in detecting structures associated with mineralisation as well as the physical properties of the systems. Current exploration is developing 3D models incorporating structures mapped at surface, geochemical patterns and underground mapping to identify targets within 500m of the mine. This work will also increase the understanding of the nature of the broader system away from the mine.

References

Cook W.G., Ford A.J.H., McDermott J.J., Standish P.N., Stegman C.L. and Stegman T.M. (Editors). 1996. The Cobar Mineral Field – A 1996 perspective. Australian Institute of Mining and Metallurgy.

Glen, R.A. 1994 Geology of the Cobar 1:100,000 Sheet 8035. Geological Survey of NSW, Dept. of Mineral Resources

Scott, A K, Phillips K G, 1990. CSA Copper-Lead-Zinc deposit, Cobar, in The Geology and Mineral Deposits of Australia and Papua New Guinea – Volume 2. (Ed. F E Hughes) pp1337-1343 (The Australian Institute of Mining and Metallurgy: Melbourne).

Shi B L , Reed G C, 1998. CSA Copper-Lead-Zinc deposit, Cobar, in The Geology of Australian and Papua New Guinean Mineral Deposits. (Eds D A Berkman and D H Mackenzie) pp601-608 (The Australian Institute of Mining and Metallurgy, Melbourne)

Acknowledgements

CMPL are acknowledged for approving publication of this paper.

THE TRITTON COPPER MINE, NEW SOUTH WALES: NEW UNDERSTANDING OF THE DEPOSIT AND ITS POTENTIAL FROM MINING OF THIS BLIND DISCOVERY

Mike Erceg and Bruce Hooper

Tritton Resources, Yarrendale Road, Hermidale, NSW.

Key Words: copper, gold, silver, Girilambone, massive sulphide

Introduction

Tritton Resources Limited (Tritton) owns and operates the Tritton copper-gold-silver mine in central west New South Wales. The underground operation produces approximately 25,000 tonnes of copper, 7,000 ounces of gold and 100,000 ounces of silver per year.

Tritton was established in 2002 by its founding directors, Ian Culbert and Mick McMullen, specifically to acquire the Tritton mine assets from Straits Resources (Straits). In December 2003, Tritton successfully completed an initial public offering of its shares and was admitted to the Official List of the Australian Stock Exchange Limited. Straits retained a 27% interest in Tritton and in 2005 increased this to 58%. In May 2006 Straits made an offer to purchase the remaining shares in Tritton.

The Tritton assets comprise the central project, the Tritton Copper Mine and the surrounding exploration licenses which encompass most of the historical Girilambone mining district.

Construction of the plant and development of the mine commenced early in 2004 and the plant was commissioned in December 2004. The plant is a conventional jaw crusher, ball mill, SAG mill and flotation plant. It produces approximately 100,000 tonnes of concentrate per year at a grade of 25% Cu, 2g/t Au and 30g/t Ag.

The Tritton orebody was discovered in 1995 by the Straits/Nord Joint Venture. A SiroTEM survey over the historical Budgerygar and Bonnie Dundee copper-gold mines, 800m north of Tritton, indicated significant conductors beneath the shallow workings. The survey was extended to the south and a similar sized anomaly detected over the now known Tritton deposit.

The top of the Tritton deposit is approximately 180m below surface and early holes tested above this and failed to intersect significant mineralisation. Down hole EM was used routinely and off hole anomalies were recognized. Drilling of these anomalies intersected the Tritton orebody.

Geology

The Tritton ore body is hosted in Ordovician age metamorphosed quartz sandstones (quartzites) and metapelites (mica schists) of the Girilambone Group. The mineralisation consists of two zones, the upper (UOZ) and lower ore zone (LOZ), each approximately 400m long, which strike at 028°T, dip to the east at 20 to 70° and pitch towards 130°T.

The UOZ is not weathered and is hosted within quartzite and minor schist. The ore body varies from massive banded pyrite and chalcopyrite to bands of sulphide laminated with silicified schist. The UOZ contains the highest chalcopyrite:pyrite ratios, the highest gold and silver values, minor bornite and tennantite and more numerous lenses of hematite+magnetite+silica alteration.

The LOZ occurs as massive and banded pyrite+chalcopyrite lenses in chloritic semipelitic schist, immediately overlying carbonate+epidote+magnetite altered mafic schist(Fogarty, 1998). Narrow, sub-vertical mafic dykes cut the orebody.

The host rocks to the Tritton ore are metamorphosed to greenschist facies. At least four major deformation events are recognized (A. Ham and O. Holm, SRK Consulting, 2005, internal report). The first three deformation events were important in developing the pre-mineralisation architecture that was critical for controlling the internal geometry of the ore deposit. The last major deformation event was critical for controlling the overall geometry and the location of the ore deposit and initiating the faults that were synchronous with the mineralisation.

The Tritton ore body is controlled by both fault and fold structures. Deposit scale controls include domains defined by major (district scale) steeply dipping northwest trending faults. These faults are responsible for the overall NW-SE trend of the deposit. The overall south east plunge of the ore body is controlled by the east to east southeast dip of bedding and a bedding parallel fault which lies between the north west striking faults.

Recent surface mapping has indicated that the Tritton orebody is part of a much larger system with dimensions of several square kilometres. The Tritton ore body is hosted within a north east trending, south east dipping, bedding parallel structure - the Tritton lode which has no apparent surface expression. However two sub parallel structures have been mapped on surface - the Budgerygar and Bonnie Dundee lodes. These lodes have strike lengths in excess of 800m, and each has been the focus of intense silica-sericite alteration. Sulphide mineralisation is found along the entire length of these structures but is concentrated in high grade shoots.

The mineralisation is anomalous (maximum values within the ore zone as defined by the 2.5% Cu cutoff) in Cu (32%), Au (9.9g/t), Ag (470ppm), Zn (2.3%), Pb (1400ppm), Ni (110ppm), Co (1755ppm), Sb (3.2%), As (1700ppm) and Bi (27ppm). In addition analysis of the Tritton Assay Standard, composited from ore on the 5085 to 5010 levels returned elevated trace elements including Hg (6.5ppm), In (6.23ppm), Se (157ppm), Sn (35ppm), Cd (181ppm) and Tl (5ppm).

Mine Geology

The deposit was drilled by Straits/Nord during the nineties at a density of approximately 40m by 40m in the UOZ and out to at least 80m by 80m in the LOZ. A resource of 14Mt at 2.7% Cu, 0.3g/t Au and 12g/t Ag (at a 1% Cu cutoff) was outlined based on 80,000m of drilling in 241 drill holes. The resource was defined as a regular, tabular, easterly dipping sulphide zone separated into a distinct upper (UOZ) and lower ore zone (LOZ). A conventional mining approach was anticipated that utilized a footwall decline and long hole stoping methods.

Mining and grade control drilling ahead of advance has shown the ore body to be much more irregular with considerable variations in thickness, strike length, dip and grade distribution. Rather than a regular dipping zone, the ore body is strongly folded on a scale of tens of metres. The ore body can vary in dip from sub-vertical to flat lying with sections of west dipping ore on the western limbs of folds.

The result is a heavier than expected reliance on grade control drilling to define stopes accurately. Each level needs to be drilled out on a nominal 15m by 15m spacing. The added complexity of the ore body has also called for innovative engineering designs on each level. Often long hole, room and pillar and slot mining is required on a single level.

Alteration and Mineralisation

The host metasediments have under gone an initial stage of replacement style alteration that is zoned from proximal (to main fluid channels) laterally outward to more distal settings as quartz+magnetite+carbonate →stipnomelane+quartz+biotite±magnetite → Fe-chlorite+carbonate±biotite±quartz±sulphides. These zoned replacement assemblages are syn-deformation but are mainly post formation of metamorphic quartz±albite veins. The quartz+magnetite+carbonate assemblage may be restricted to shallow levels in the UOZ.

A subsequent series of open space or depositional events in dilatant fractures and local breccias exhibit the following sequence of events (T. Leach, 2005, internal report).

(a) Hematite+Fe-chlorite at very shallow levels.

(b) Fe-sulphide+quartz+Mg-chlorite. The Fe-sulphide minerals are zoned pyrrhotite+pyrite → pyrite → pyrite+arsenopyrite/arsenean pyrite at progressively shallow levels. The quartz grades from strained to ribbon clear and unstrained in progressively later events indicating a change from compressional to extensional regimes during the mineralisation events. Pyrite at very shallow levels exhibits botryoidal colloform banded texture indicative of very rapid cooling conditions.

(c) Base metal sulphides+carbonates. The copper sulphides are zoned chalcopyrite → chalcopyrite+bornite → tennantite+chalcopyrite at progressively shallow levels. Sphalerite and galena are associated with copper mineralisation in the late stages of the base metal event and in settings distal from major structures. The sphalerite is zoned Fe-rich from deeper to shallower levels. Galena abundance increases at progressively shallow levels.

Gold mineralisation took place during the late stages of the base metal event. Native gold occurs as minute (2-15μm) inclusions in tennantite, whereas silver rich electrum inclusions occur in late stage galena+sphalerite+chalcopyrite+pyrite veins.

The carbonates grade from ankerite to Fe/Mn rich carbonates (siderite, Mn-siderite and rhodocroisite) at progressively shallower and later stages of the base metal event.

(d) Siderite±pyrite/chalcopyrite veinlets cross cut all other assemblages and extent for tens of metres into the wallrock schist and quartzite units.

Genesis

Spatial and temporal zonations in alteration and mineralisation indicate that hot (>250-300°C) mineralized fluids were channeled into significantly cooler conditions (especially at very shallow levels in the orebody) during a change from compressional to extensional regimes. The cooling of the mineralized fluid resulted in base and precious metal mineralisation. The overall change from quartz+oxide (magnetite → hematite), to sulphide minerals (pyrite/pyrrhotite → copper sulphides → lead+zinc sulphides), to late stage carbonate deposition is closely comparable to that documented in intrusion related copper-gold systems throughout the south west Pacific (e.g. Corbett and Leach 1998).

The sequence of events in the Tritton deposit is closely comparable to that described from a number of deposits in the Cobar area (Stegman, 2001). A magmatic component to the mineralisation has been previously precluded for the Cobar deposits based on differences in age dates between intrusions in the region versus deformation and mineralisation events, and on isotopic evidence. However, the many similarities in alteration and mineralisation between intrusion related deposits and the Tritton deposit, the high selenium and Se:Te ratios and the close proximity to syn-deformation granite intrusions make a felsic-intrusion source to the mineralisation at Tritton compelling.

Acknowledgements

The management of both Tritton Resources and Straits Resources are acknowledged for permission to publish this abstract. Both Terry Leach of Terry Leach and Co., and Andrew Ham and Oliver Holm of SRK Consulting are acknowledged for their work conducted in house on petrological and structural aspects of the deposit respectively. Also acknowledged is the invaluable input from the site geologists Scott Middleton, Ben Thompson, Bruce Gardiner and Brad Underwood.

References

Corbett G.J. and Leach, T.M., 1998. Southwest Pacific gold-copper systems: structure, alteration and mineralisation. SEG special publication #6, 236pp.

Fogarty, J.M., 1998. Girilambone district copper deposits. In Geology of Australian and Papua New Guinean Mineral Deposits. (Eds D.A. Berkman and D.H. Mackenzie) pp593-600. AusIMM Monograph 22.

Stegman, C.L., 2001. Cobar Deposits: Still defying classification. SEG Newsletter Jan. 2001, no44, pp1, 15-26.

HERA GOLD BASE METAL DEPOSIT – THOUGHTS FROM THE PORCH

Angus Collins, Ian Mackenzie, Jeff Randell, Stuart Jeffrey

Triako Resources Limited, Level 2, 80 Mount Street, North Sydney NSW 2060

Key Words: gold, base metals, Cobar style, mineral resources, feasibility study

Introduction

The Hera gold base metal deposit is located 100 km southeast of Cobar in western NSW (Figure 1). The deposit was discovered after over thirty years of exploration activity in the area. It is a Cobar style polymetallic structurally controlled deposit in strongly altered and deformed shelf and turbiditic sediments located close to the eastern margin of the Cobar Trough.

Exploration History

Hera is a blind deposit commencing 150 metres below the surface. Early exploration concentrated heavily on electrical geophysics, magnetics and geochemistry with drilling to only shallow depths. It appears that Induced Polarisation surveys in 1975 following an airborne Input survey identified the mineralised system containing the deposit. It was not until 2000 however that the discovery drillhole intersected high grade gold, copper, lead and zinc mineralisation 300 metres below the surface and 180 metres below earlier drillholes.

The discovery was made by Pasminco Exploration, the ninth mineral explorer in the area. This company applied their detailed knowledge of the Cobar style of mineralisation to an extensive body of exploration information and, in particular, recognised that Cobar style deposits typically have much longer dimensions in the vertical dimension than along strike thus encouraging deep drilling.

Triako's Exploration

Triako Resources acquired the area in 2003 and is currently proceeding with a feasibility study for the development of an underground gold base metal mine. The deposit includes zones with significant amounts of visible gold contained in massive, brecciated and veined quartz, veined sphalerite, galena and pyrrhotite. The most recent published Indicated and Inferred Mineral Resource estimate in three lenses is 1.94 million tonnes at 6.7g/t gold (uncut), 2.8% zinc, 2.5% lead, 0.2% copper, 8g/t silver (kriged estimate, 2.5g/t gold equivalent cut-off) The deposit has a high nugget effect for gold and moderate nugget effect for zinc. Subsequently a global grade for the resource of 8.1g/t gold (uncut) was estimated, more than 20% higher than the block model grade. The deposit is open downdip and along strike to the north and south. As well, there are mineralised zones with potential to develop into ore grade lenses as exploration progresses. These include wide zinc, lead zones to the west and gold copper bearing structures to the east in the south.

Once Triako completed the acquisition of the Hera exploration licence and neighbouring tenements, a strategic decision was made to proceed with exploration having two objectives:

to attempt to discover sufficient resources in the vicinity of the three ore grade and width Pasminco drillholes to complete a feasibility study and develop a gold and base metal mine and,
to explore the balance of the tenements such that drilling targets were defined and tested.

From September 2003 surface drilling results at Hera have been combined with geological mapping, downhole EM surveys, baseline geochemical surveys, reassaying of previous drillcore by the screen fire method. Metallurgical testwork, geotechnical studies, hydrological studies, environmental baseline data collection and reviews of environmental factors, infrastructure studies including water, power and site layouts. Capital and operating cost estimates, consent processes and economic evaluations have been carried out. A scoping study in March 2005 indicated that the project had sufficient potential to justify the completion of a prefeasibility study that was completed in the December quarter 2005 and gave a positive result.

Feasibility Studies

Approval was given to commence a feasibility study. This study is considering two development plans and three processing options. The first development plan is a conventional programme with infill drilling from surface and completion of a feasibility study, leading to the decision to develop the mine. The second plan is to develop an exploration decline on the exploration licence ahead of completing the feasibility study. This plan reflects the difficulty of achieving accurate infill drilling from surface and the consequences of the high nugget effect, which makes representative sampling very challenging Three processing options being considered in the study a) construct a process plant at Hera, b) trucking ore to Mineral Hill plant where the plant would be modified to include gravity separation of gold and increase flotation capacity to produce both a lead and zinc concentrate and c) truck ore to a process plant in the Cobar region for toll treatment.

Metallurgical testwork has included flotation and gold gravity recovery tests. A 350 kg sample is currently being tested. From the testwork the following metallurgical performance has been developed:

- recover a gold gravity concentrate containing at least 50% of the contained gold.
- total gold recovery of 92% with about 42% of overall gold to copper and lead concentrates. The majority of this gold in concentrates can be recovered by leaching and combined with the gravity gold as dore bars.
- lead concentrate grade of about 63% Pb and 88% recovery.
- zinc concentrate grade of about 53% Zn at 80% recovery.
- copper concentrate to be produced if copper head grade is >0.2% Cu.
- copper concentrate grade of about 20% Cu with about 70% recovery.

For the project to proceed to production there are several further consents required including development consent, mining lease, environmental protection licence, access approvals, water licences, tailings storage facility approvals.

Future Exploration

As well as exploration for extensions to the Hera system, regional exploration of the exploration licences has progressed such that drilling targets for gold and base metals are being developed and tested within 25 km of the Hera project (Figure 1). These include targets in the Hera to Hebe corridor where there is extensive anomalous geochemistry, IP anomalism and gold mineralisation discovered by Pasminco (Figure 2).

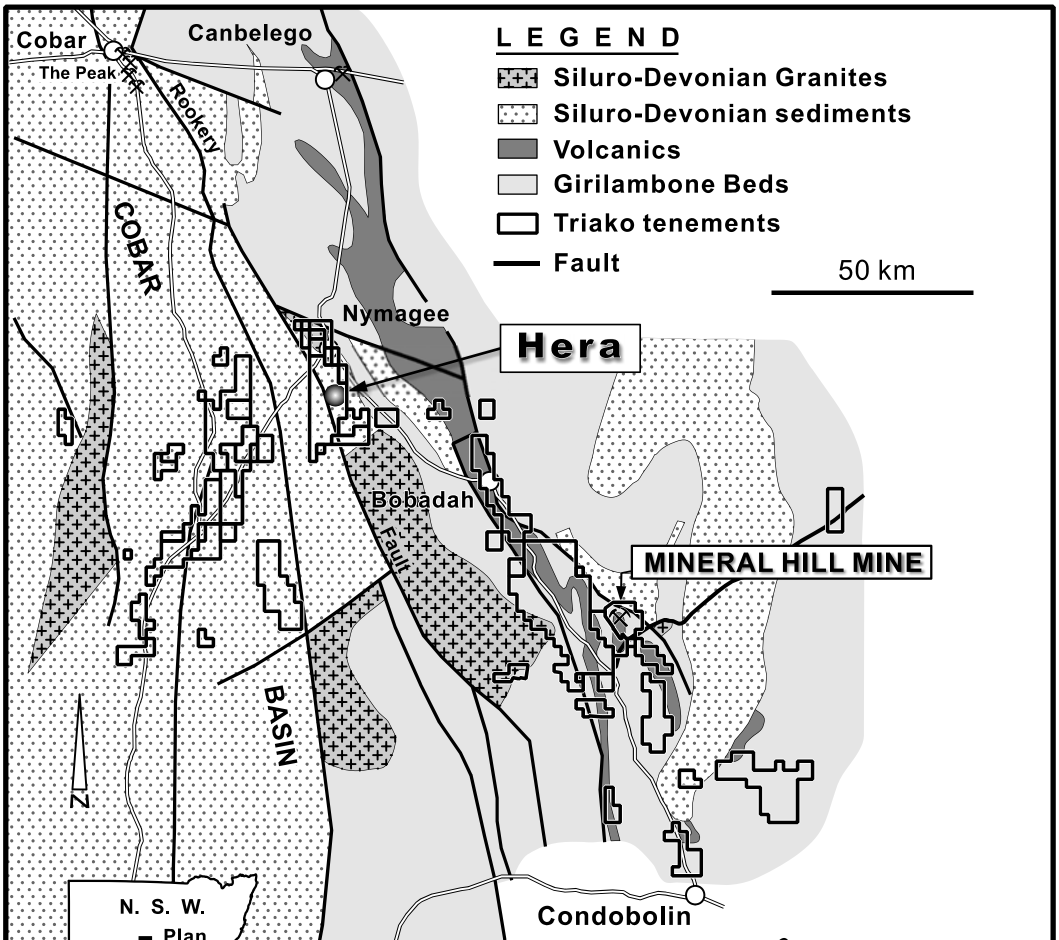


Figure 1.
EXPLORATION
HERA PROJECT AND REGION

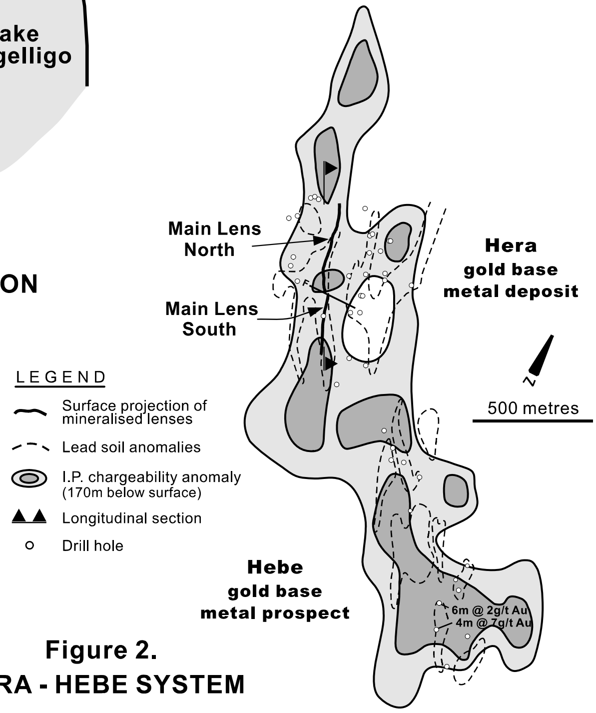


Figure 2.
HERA - HEBE SYSTEM

TR108HR

THE COBAR GOLDFIELD – A VARIATION OF A THEME

Rex Berthelsen

Peak Gold Mines Pty Ltd, Hillston Rd, Cobar

Key Words: gold, copper, bismuth, base metals, Cobar, shear hosted, sediment hosted

Introduction

The Cobar Goldfield is located immediately east and extends to approximately 8 km south east of the Cobar Township. It is host to four geographically separate mines currently owned and operated by Canadian company, Goldcorp Inc.'s, 100% Peak Gold Mines Pty Ltd. Refer to Figure 1.

The gold and copper deposits of the Cobar field each have their own unique mineralisation and alterations signatures, but can be characterised based on these features. The deposits have characteristically short strike lengths, narrow widths and generally are most continuous down a steep northerly plunge (Stegman and Pocock, 1996). The shear zones which host the mineralisation include the Peak – Perseverance Shear, Blue Shear, Lady Greves Shear and the Great Chesney Fault. These northwest trending structures are clearly visible in magnetic data as distinct linear magnetic ridges. The southern extensions to these faults, particularly the Great Chesney Fault and the Peak Shear, together with unnamed structures to the west have stronger and broader magnetic responses than those which host the Central Area deposits to the north. This is related to more intense pyrrhotite alteration along the cleavage from Peak and to the south. While the presence of magnetite at deposits in the central and northern areas including New Occidental, Chesney, New Cobar and Great Cobar gives rise to shorter wavelength and discrete magnetic anomalies.

Two stages of deformation have been recognised within the field (Hinman, 1992). An early D1 event, although poorly preserved, is a remnant axial plane cleavage parallel to folds in the Peak area. The later event, D2, is responsible for the most pervasive cleavage is more regional in nature, but most strongly evident proximal to the shear zones in the field.

The proposed deposit groupings are as follows. Firstly, Group1 is comprised of Peak and Perseverance, Group 2 – New Occidental, Chesney and New Cobar and Group 3 – Gladstone and Great Cobar. The parameters for grouping are based on metal ratios and content, host stratigraphy, mineralisation and alteration styles and curiously also northing with Group 1, southernmost and Group 3, northernmost. (Refer to 2)

Group 1

Peak and Perseverance, the southernmost group, are hosted by a variety of lithologies from Great Cobar Slate (DNG) to Chesney Formation sandstones and siltstones (DNC1 to DNC3) and rhyolite. The latter rock type is most characteristic of these deposits as it produces bonanza gold grades where it intersects mineralised shear zones. The rhyolite bodies are interpreted to have been intruded into wet sediments (Cook et.al., 1998).

The shear zones and subsequently, the orebodies within this group, have a steep, grossly west dipping attitude, but locally also dip east. At the top of Perseverance, from the 9405m level to about 9200m level the orebodies dip steeply west, however below 9200m level the ore bodies are vertical to steeply east dipping.

At Peak, the apparent displacement of the Great Cobar Slate and Chesney Formation contact across the Peak-Perseverance Shear is west block up by 250m (Cook et.al. 1998). This implies reverse movement. At Perseverance the apparent dip-slip displacement of stratigraphy is difficult to quantify. Intuitively it should be a similar amount, but there is still some debate as to the stratigraphy east of the Perseverance structure.

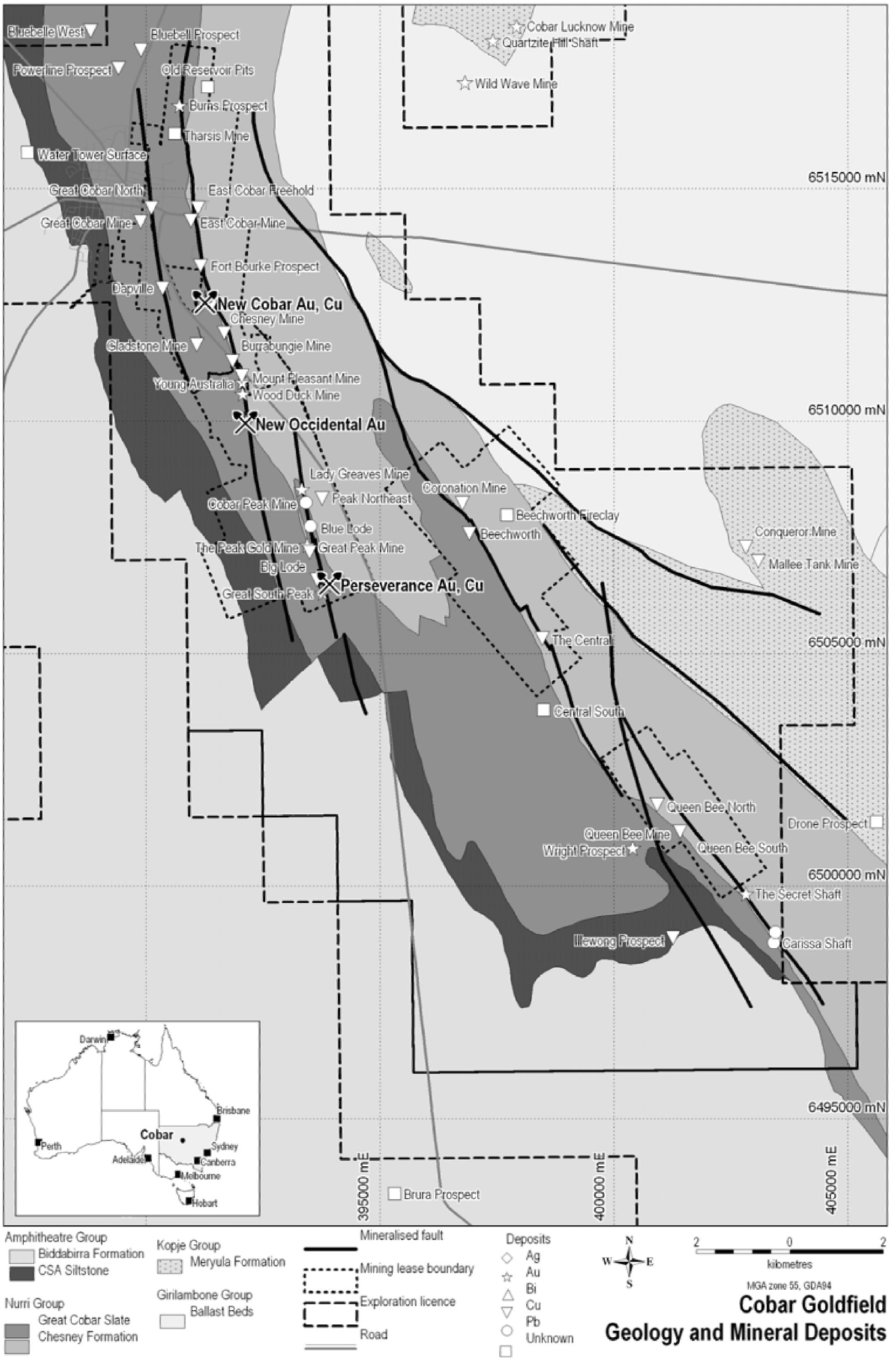


Figure 1 - Cobar Goldfield Geology and Perseverance Location plan

At both Peak and Perseverance the rhyolite body exhibits hyaloclastite textures predominantly on the northern margin of the easternmost rhyolite bodies (Cook et.al, 1996). At Perseverance, only one rhyolite body has been identified, while at Peak the geometries are more complex.

With depth, the pervasive alteration of green chlorite gives way to an increase in biotite alteration, particularly in close proximity to the ore zones. This is seen particularly below 9000m level in the southern Perseverance orebody known as Zone D.

Stegman and Pocock (1996) describe four styles of gold and base metal mineralisation at Peak. These being sediment hosted, contact zone hosted (sediment and rhyolite), volcanic hosted and late stage shear hosted mineralisation. At Perseverance, similar styles of mineralisation are seen, but with considerably less lead and zinc than that observed at Peak. The majority of ores mined at Perseverance fall into the sediment and contact hosted styles and have average grades of 9.4g/t Au, 1.6 % Cu, 0.12% Pb, 0.05% Zn, 11g/t Ag and 65ppm Bi.

High grades are seen particularly where the shears juxtapose favourable lithologies. These situations occur as two types. Firstly, siltstones faulted against thickly bedded sandstones ie. Great Cobar Slate (DNG) against Chesney (DNG21 or DNG23) () or secondly, sediment (siltstone or sandstone) faulted against rhyolite. (Refer to Figures 3, and 4)

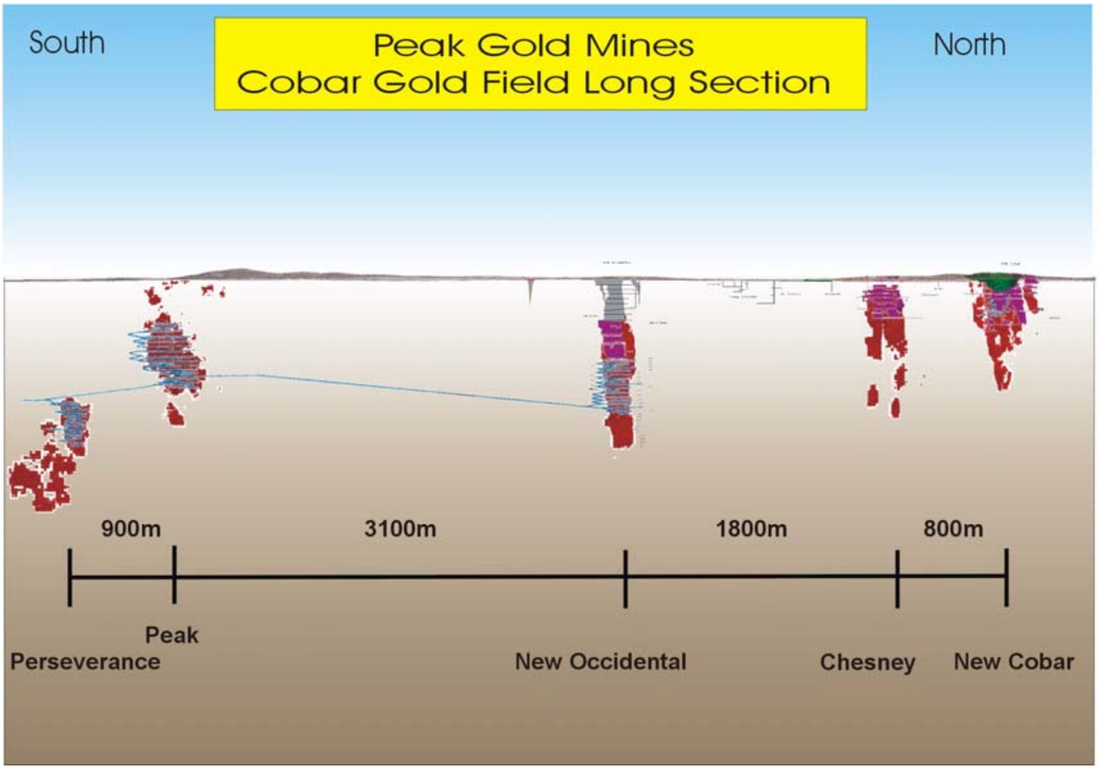


Figure 2 - Cobar Goldfield Longsection

Group 2

The second group consists of gold, gold – copper and copper – gold deposits hosted and controlled by the Great Chesney Fault and its related splays. These are from south to north, New Occidental, Chesney and New Cobar. All three mines have seen historic production, while New Occidental and New Cobar are currently in full production by the company.
These deposits have relatively simple geometries. The lenses have relatively short strike lengths less than 300m, are most continuous in the vertical direction and have widths of 5 to 30 metres (Stegman and Pocock, 1996) and have broad arcuate geometries. The Main lens of New Occidental bifurcates into an east and west lens. A weakly altered wedge of siltstone occurs within the deposit to the north (Refer to). New Cobar contains several recently identified, short strike length ore zones.
The most characteristic feature of these deposits is the early cryptocrystalline to chalcedonic silica veins which are closely associated with high-grade gold and bismuth mineralisation. New Occidental is the best example of the mineralisation style. Apart from a small but

vertically continuous lens, Gossan Lens, on the western side of the orebody, New Occidental does not have significant overprinting copper, lead or zinc mineralisation. A narrow quartz vein, often brecciated, occurs on the east side of the New Occidental deposit. It generally marks the hanging wall of orebody, although in some places this is not always the case with minor gold mineralisation occurring east of the vein. The western or footwall boundary is marked by a quartz breccia, locally known as the “Type four stockwork breccia” (Figure 6). Both Chesney and New Cobar have overprinting quartz veining, brecciation, pyrrhotite and chalcopyrite mineralisation. Much of the gold is remobilised by this later overprinting.

Early silicification and pervasive iron chlorite alteration is typical. Post cryptocrystalline to chalcedonic silica veins, is a coliform-banded, quartz – magnetite vein set which most commonly occur at New Cobar, but is recorded at Chesney and New Occidental. A different, splashy style of quartz magnetite intergrowths have been recorded at depth at New Cobar to the west of the main ore zones. Similar quartz magnetite veins have been observed at Great Cobar and are interpreted to be early (pre gold). This style of alteration is not associated with gold mineralisation.

An iron rich stilpnomelane occurs predominantly at New Occidental (Bell et.al. 2000) and to a lesser extent at New Cobar and Chesney. At New Occidental, the occurrence of this mineral increases with depth. In addition to the strong Au-Bi correlation is a Cu-Ag relationship. This is relationship is also seen within the Group 3 deposits discussed below. Fibrous and sometimes coxcomb textures are observed associated with stilpnomelane alteration.

The Great Chesney Fault (GCF) hosts the New Occidental deposit. It is the only one in the field. The main Chesney and New Cobar ore zones occur some 20 to 50m respectively west of the GCF and are hosted entirely within Great Cobar Slate (DNG). A relatively minor ore lens known as the Chesney Eastern Gold Lode is hosted by the GCF and exhibits similar characteristics to that of New Occidental.

Group 3

The northern most group is comprised of Gladstone and Great Cobar. These deposits occur some 400 to 900m respectively west of the GCF. They are hosted by siltstones and poorly bedded sandstones of the Great Cobar Slate (DNG). The sandstone units, while difficult to map, appear to play a controlling part in localising the mineralisation. The deposits are characterised by pervasive iron chlorite alteration and dark green magnesium chlorite alteration proximal to the mineralisation as in Group 2.

At Gladstone, the ore consists predominantly of chalcopyrite and minor pyrrhotite. The Gladstone mineralisation is characterised by quartz breccia veins and chalcopyrite. Great Cobar has more complex ore styles.

At Great Cobar, copper mineralisation occurs within a wide halo, up 100 metres. An historic, circa 1958 drill hole, CM1, intersected 45m @ 1.37% Cu, true width, from 1274m down hole and 36m @ 1.17% Cu true width from 1322.7m down hole. There have been at least 4 lenses identified at Great Cobar. These are lower grade eastern lens, the central lens (historically mined), a lead zinc lens occurring to the west and a lens to the north.

Early silicification, like the remainder of the Cobar field, is accompanied by iron chlorite alteration. Extensional textured quartz veins have intergrowths of stilpnomelane, biotite and chlorite. These textures are indicative of syntectonic metamorphic conditions (Ashley, 2004). Paragenetic relationships suggest that pyrite is early which has been partially replaced by magnetite, chalcopyrite, pyrrhotite and sphalerite (Ashley, 2004). The New Cobar style coliform-banded quartz-magnetite veins are not present at Great Cobar.

Great Cobar contains massive sulphide lenses. Porphyroblastic textures are commonly seen in the massive sulphides resulting from recrystallisation. Pyrrhotite, chalcopyrite and sphalerite are paragenetically later than pyrite and magnetite. The sulphides are partly intergrown in apparent equilibrium with chlorite, quartz, albite, stilpnomelane and biotite. The best recent intercept is 17.6m @ 0.63g/t Au, 4.45% Cu, 0.03% Pb, 0.12% Zn, 19.3 g/t Ag from 645m down hole, true width.

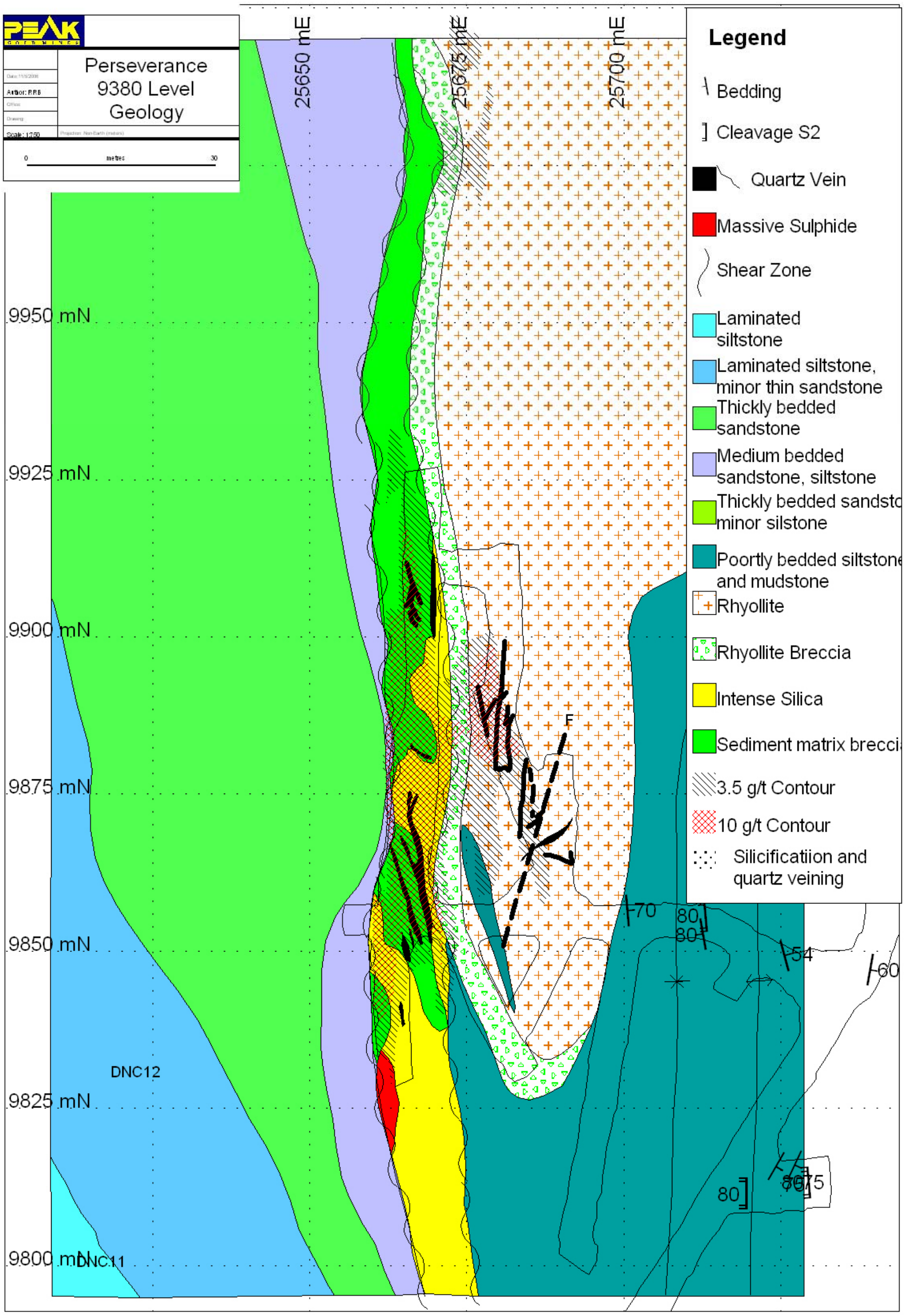


Figure 4 - Perseverance 9380 level Geology

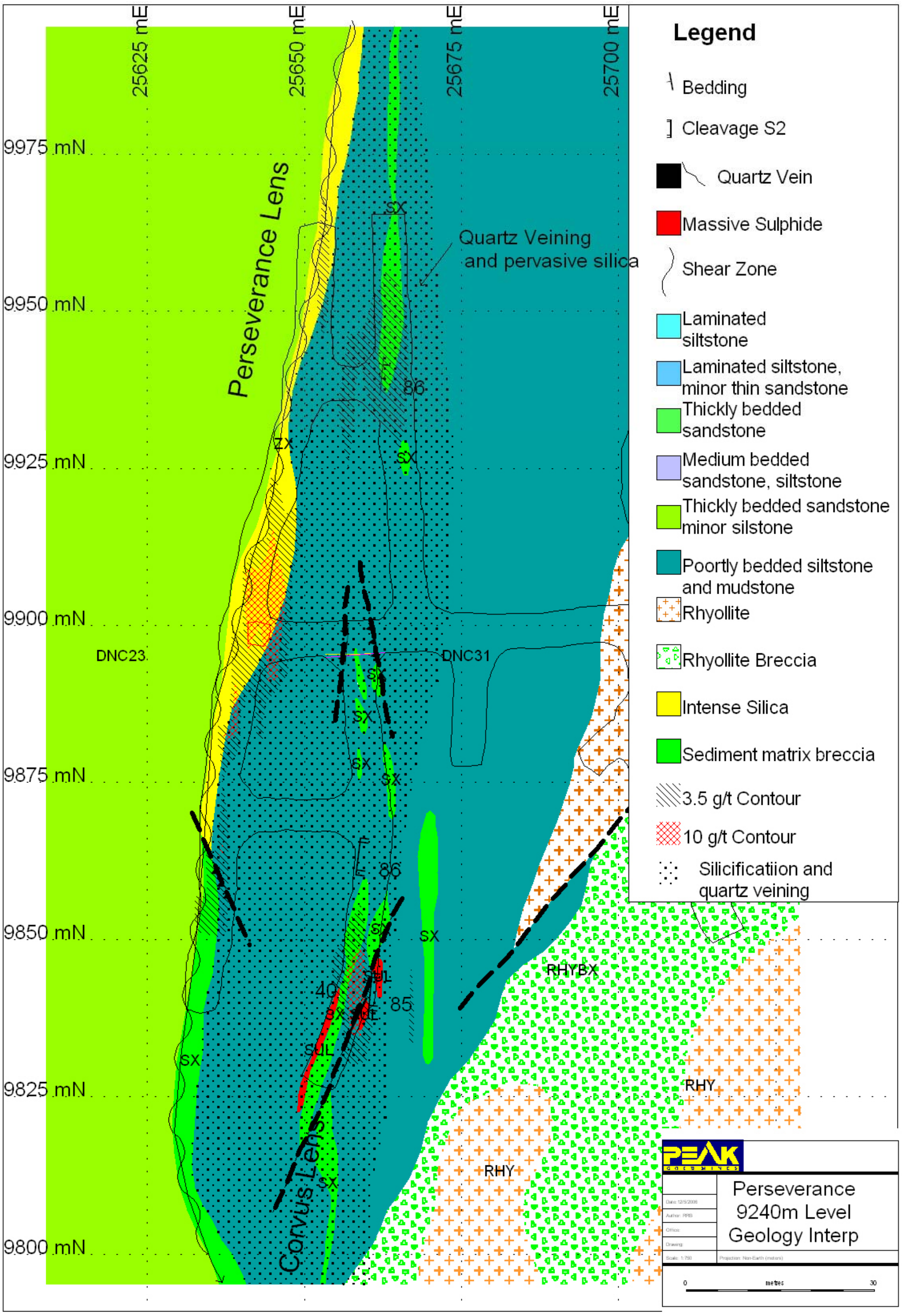


Figure 5 - Perseverance 9240 Level Geology

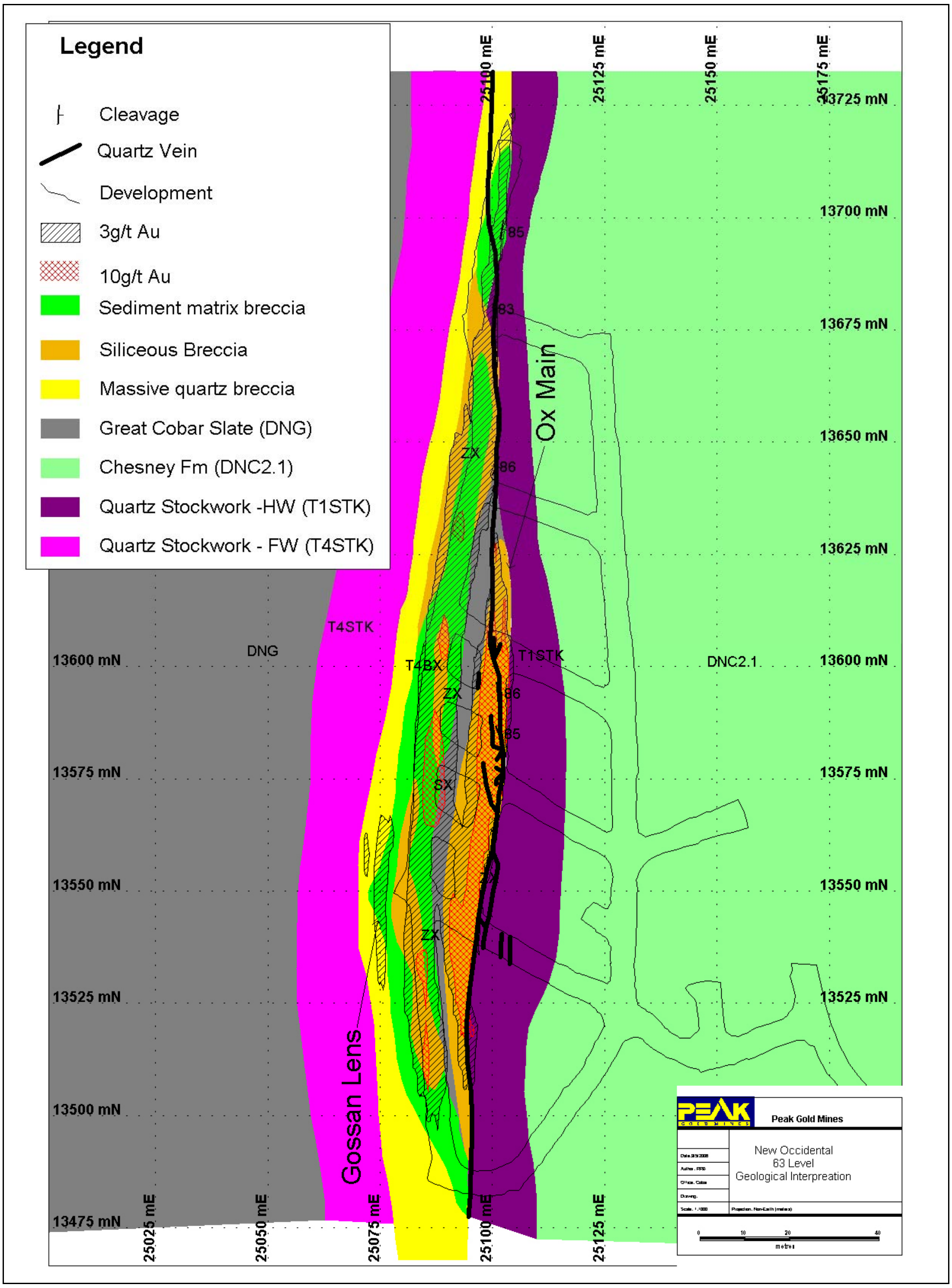


Figure 6 - New Occidental Plan at 63 Level (9690mRL)

Conclusions

There are three groups of ore deposits in the Cobar Gold field. They have characteristic ore styles, hosts rocks and mineral assemblages.

All deposits in the field have steep northerly plunges and are controlled by bends in faults and the juxtaposing of more competent rocks against less competent ones in faults and shears.

All of the deposits have grossly arcuate shapes to the ore lenses.

The Peak and Perseverance ore deposits, Group 1, are characterised by the presence of rhyolite as a host lithology. They have a complex history of ore deposition. They contain elevated levels of Cu (0.5-2%), Pb (0.1-1%), Zn (0.05 – 1%), Ag (10-12g/t) and Bi (50-

100ppm). Gold distribution tends to be more erratic with typical short strike length shoots within the broader mineralised envelopes.

The New Occidental, Chesney and New Cobar deposits are all hosted by or spatially related to the Great Chesney Fault and hosted by Great Cobar Slate. The early gold mineralisation is related to intense cryptocrystalline-chalcedonic silica veins. Bismuth mineralisation is regarded as coeval to this style of mineralisation. A later quartz breccia with associated copper mineralisation has strongly overprinted both Chesney and New Cobar, but to a lesser extent, New Occidental which contains a minor lens to the west known as Gossan Lens. Coliform-banded quartz – magnetite veins overprint the earlier gold mineralisation at New Cobar and to a minor extent, Chesney. These veins are also present at New Occidental in very restricted localities.

Stilpnomelane alteration has been observed with a later overprinting fibrous and sometimes coxcomb textured quartz veins. The textures indicate the quartz and stilpnomelane are syntectonic.

Copper rich and gold poor deposits of Group 3 include Gladstone and Great Cobar. Copper and silver have a strong correlation. The deposits are Great Cobar Slate hosted.

Acknowledgments

The author wishes to gratefully acknowledge the permission of Peak Gold Mines Pty Ltd to publish this paper. Many ideas and discussions with geologists both past and present have aided with the preparation of the paper.

References

Ashley, P.M., 2004. Petrographic Report on Four Drill Core Samples from the Great Cobar Project, Cobar, Western New South Wales. Unpublished Company Report PGM3191

Bell, I., Blunt, A., Christison, P., Stegman, C., Bourke, S., Hildebrand, M., 2000. New Occidental Feasibility Study, Peak Gold Mines Pty Ltd. Unpublished Company Report PGM1931

Cook, W.G., Pocock, J.A. and Stegman, C.L., 1998. Peak gold-copper-lead-zinc-silver deposit, in Geology of Australian and Papua New Guinean Mineral Deposits (Eds: D A Berkman and D H Mackenzie), pp 609-614 (The Australian Institute of Mining and Metallurgy: Melbourne)

Munro, S. and Berthelsen, R.R. 2004. The Perseverance Gold Deposit – The Next Step At Peak, (Eds A Spry and K Burt), pp 339-344 (The Australasian Institute of Mining and Metallurgy: Melbourne)

Stegman, C.L. and Pocock, J. A.1996. The Cobar Goldfield – A Geological Perspective, in the Cobar Mineral Field – A 1996 Perspective, (Ed Cook et al.),pp 229-264 (Australian Institute of Mining and Metallurgy: Melbourne)

THE GEOLOGY OF THE ENDEAVOR MINE: AN UPDATE

Peter Nicholson, Vanadis Mares and Don

Endeavor Operations Pty Ltd, via Louth Road, Cobar, NSW 2835.

Key Words: zinc, lead, silver, Cobar, geology

Introduction

The Endeavor zinc-lead-silver mine is located 43km NNW of Cobar. The mine contains two styles of mineralisation: above about 900m depth an irregular sub-vertical sheet is hosted by a turbidite sequence and broadly coincides with an anticline axial plane; at the bottom of this sheet mineralisation bifurcates into grossly concordant zones. These concordant zones are hosted by a shale-rich sequence and underlying limestone.

This paper updates the geology of the mine in light of recent compilations and newly collected data on deeper-seated mineralisation.

History

The Electrolytic Zinc Company of Australasia Ltd discovered the orebody in 1973. Initially a bullseye anomaly was identified in an aeromagnetic survey. Follow-up auger sampling outlined a base metal soil anomaly prior to diamond drilling intersecting ore in 1974 (Schmidt 1989). Mine production from what was initially known as the Elura orebody began in 1983. In 1998 drilling beneath the mine at over 1000m below the surface intersected mineralisation close to the contact with limestone, which until that time, was not recognised as occurring in the mine area.

The current owners of the mine, CBH Resources Ltd, purchased the mine in 2003. Production is ramping up to a rate of 1.4MT per annum. At June 2005 the Endeavor Mine Resources totalled 17.7MT at 4.9%Pb, 8.7%Zn and 69g/tAg and Reserves 11MT at 4.5%Pb, 7.9%Zn and 66g/tAg. Mine production totals about 24MT.

Regional Geology

The Endeavor mineralisation is contained within the Cobar Basin, which is in turn part of the Lachlan Fold Belt. Basement rocks include Ordovician sediments and Silurian granitic rocks. The basin contains mainly siliciclastic sediments with minor volcanic rocks and carbonates. Sedimentation continued from the Late Silurian until the Early Devonian. Polymetallic mineralisation within the Cobar Basin is thought to have coincided with a period of basin compression and folding (Lawrie and Hinman 1998). The mineralisation is largely discordant and vein or replacement in form. It is associated with silicic, carbonate and chlorite alteration. Most of the major known mineral deposits, including Endeavor, CSA, Peak and Hera are located along a linear structural corridor at least 200km in length (Figure 1). All of these major deposits are located adjacent to protrusions of basement into the Cobar Basin associated with gravity low anomalies. Most mineralisation is hosted by siliclastic marine turbidites.

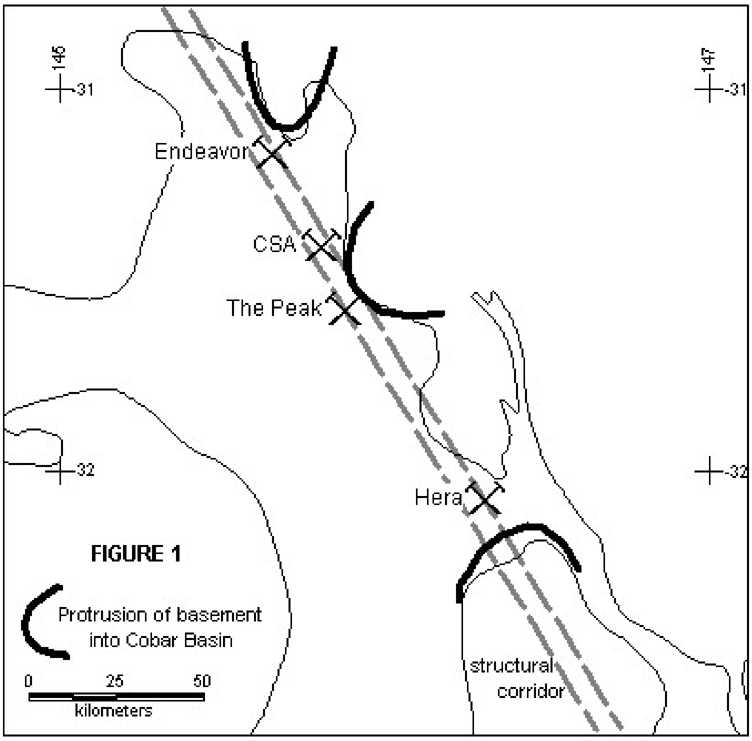


Figure 1: Structural corridor connecting Endeavor, CSA, The Peak and Hera Mines

Stratigraphy

The host rocks at Endeavor consist of a limestone breccia overlain by a turbidite sequence of interbedded shale and sandstone/siltstone. Although the carbonate rocks have been interpreted as belonging to the Brookong Formation of the Kopyje Group (David et al 2000) and the turbidites are thought to be lithologically equivalent of the CSA Siltstone (Schmidt 1989), the regional correlatives of these rocks are uncertain.

The limestone at Endeavor is generally a clast-supported breccia. Fragments are 5 to over 40mm in diameter and are composed of crystalline limestone, crinoid stems, coral and shale.

The sandstone/siltstone beds within the turbidite sequence are 2mm to 1m thick and are generally graded. Laminations and cross bedding are common. Interbedded shale is dark grey and massive to laminated in texture. Minor tuff beds are pale green and 2 to 10cm in thickness. The turbidite sequence is over 1200m in thickness. Generally, this sequence contains approximately 20 to 40 percent sandy/silty beds and 60 to 80 percent shale. Two shale-rich units can be recognised within the turbidite sequence. The Lower Shale is about 200m above the limestone contact and the Upper Shale 700m. Both units are approximately 50m thick and contain less than about 15 percent sand/silt. The contact between the limestone and turbidites is grossly conformable. A transitional unit of about 100m thickness contains black shale with fossiliferous and sandstone-rich beds.

Structure

The general dip of the rocks in the mine area is about 20 degrees to the SW. Several open folds have sub-vertical axial planes that strike NNW. A slaty cleavage sub-parallels the fold axial planes. Folding within about 10m of massive mineralisation is often tight. Fold axial planes deviate from the regional orientation where they sub-parallel the boundaries of apophyses of massive mineralisation.

A number of different fault sets occur in the mine area. All sets are filled with variable amounts of quartz, chlorite, siderite and graphite. Concordant structures are probably the earliest structures in the mine area. These are possibly filled with the thickest veins adjacent to the limestone contact and around anticline axes. A later set of faults and shears parallel the cleavage and axial plane. Steeply dipping, N and NNE faults in turn cut these. These have apparently mainly vertical displacements of up to 50m.

Mineralisation

High-grade massive sulphide mineralisation at Endeavor is enveloped by sulphide stringers, which are in turn enveloped by siderite alteration. The halo of siderite alteration extends for several tens of metres away from sulphide mineralisation and consists of 1 to 2mm diameter clots that preferentially replace sandy beds. Chloritic alteration also occurs.

Above about 900m depth the sulphide stringers form a large continuous lens or sheet which lies in an anticline axial plane. This lens ranges in thickness from 15 to 120m, extends from the surface to 900m at the S end of the mine, and has a strike length of at least 800m. At about 900m depth the mineralisation bifurcates into grossly concordant zones that dip down both the anticline limbs (Figure 2). The body of low-grade sulphides is open along strike in both directions (Figure 3) and down dip on both limbs. Sulphide minerals form two textures within the stringer zone. Stringers of sulphide generally sub-parallel slaty cleavage in the axial plane zone. The stringers are 5mm to 2m thick and mainly consist of pyrite, sphalerite, galena and chalcopyrite. Siliceous alteration sometimes accompanies the sulphide stringers, particularly in the upper parts of the mine. Similar stringers parallel to cleavage also occur in the concordant zones. However, in addition pyrite and base metal sulphides form conformable sulphide blebs that generally replace sandstone/siltstone beds and laminae. These blebs are preferentially distributed close to the cleavage-parallel stringers.

In the axial plane zone, high-grade massive sulphide mineralisation forms lenses within the stringer mineralisation. The steeply dipping N and NNW faults offset what was originally a semi-continuous body (Figure 3). In addition, steep pipe-like thickenings occur within the lenses. The largest of these, the Main Lode, has a diameter of up to 120m and a plunge length of almost 1000m. The massive sulphide lenses have a core consisting of pyrrhotite, sphalerite, pyrite and galena. More pyrite-rich material generally envelops the pyrrhotite-rich core zones. Sulphide textures are both massive and banded. Sulphide banding generally parallels the boundaries of the sulphide lenses and pipes.

Within the axial plane zone, sulphide mineralisation generally appears to be more intense within more sandstone/siltstone-rich sections of the sequence. In long section (Figure 4), it appears the massive axial plane mineralisation lenses out into stringers on the contact with the Lower Shale. Similarly, although not well defined, the Northern Pods appear to thin and lens out upwards on the contact with the Upper Shale. Within the Main Lode, the pyrrhotite core thins within the Upper Shale.

The composition of mineralisation changes vertically and laterally in the mine area. Within the axial plane zone, silver is concentrated in the upper and lateral sections of the high-grade massive lens, probably mainly within sulphosalt minerals. Grades of 300 to 1000 g/t are found compared with an average mine grade of about 70 g/t. Copper is concentrated at the base of the massive axial plane lenses within the centre of the pipe-like thickenings. Grades of over 4 percent are attained compared with an average mine grade of 0.2 percent. Lead and zinc are highest grade within the pyrrhotite cores of massive lenses.

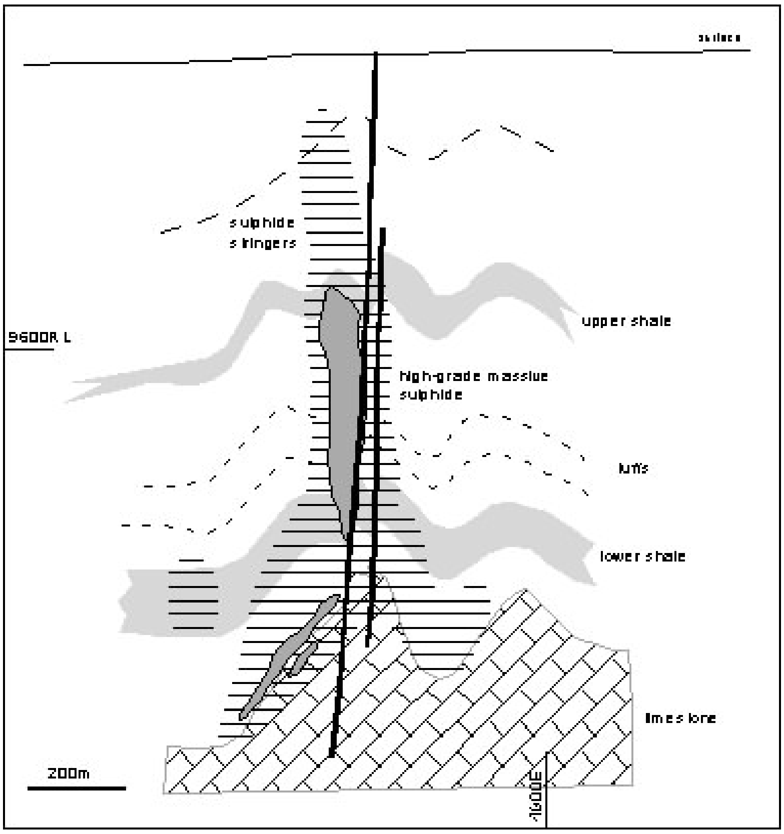


Figure 2: Cross section at 7000N, showing how the mineralisation bifurcates into two concordant zones that dip down both anticline limbs.

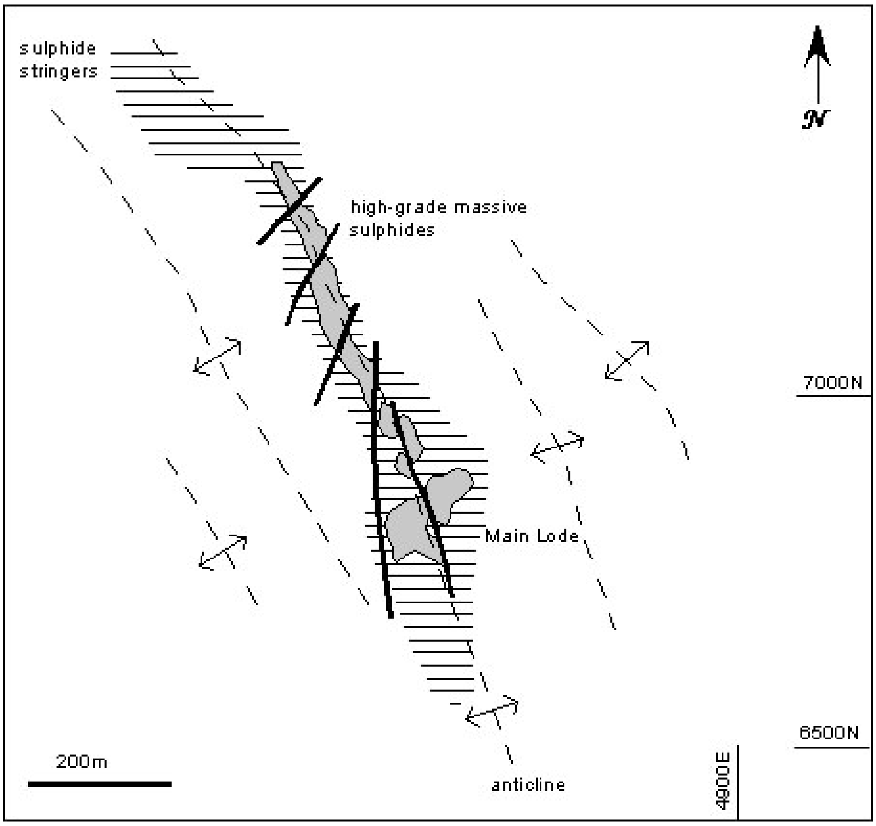


Figure 3: Plan view at 9400RL of the Endeavor Ore Body surrounded by a halo of low-grade sulphide stringers which is open along strike.

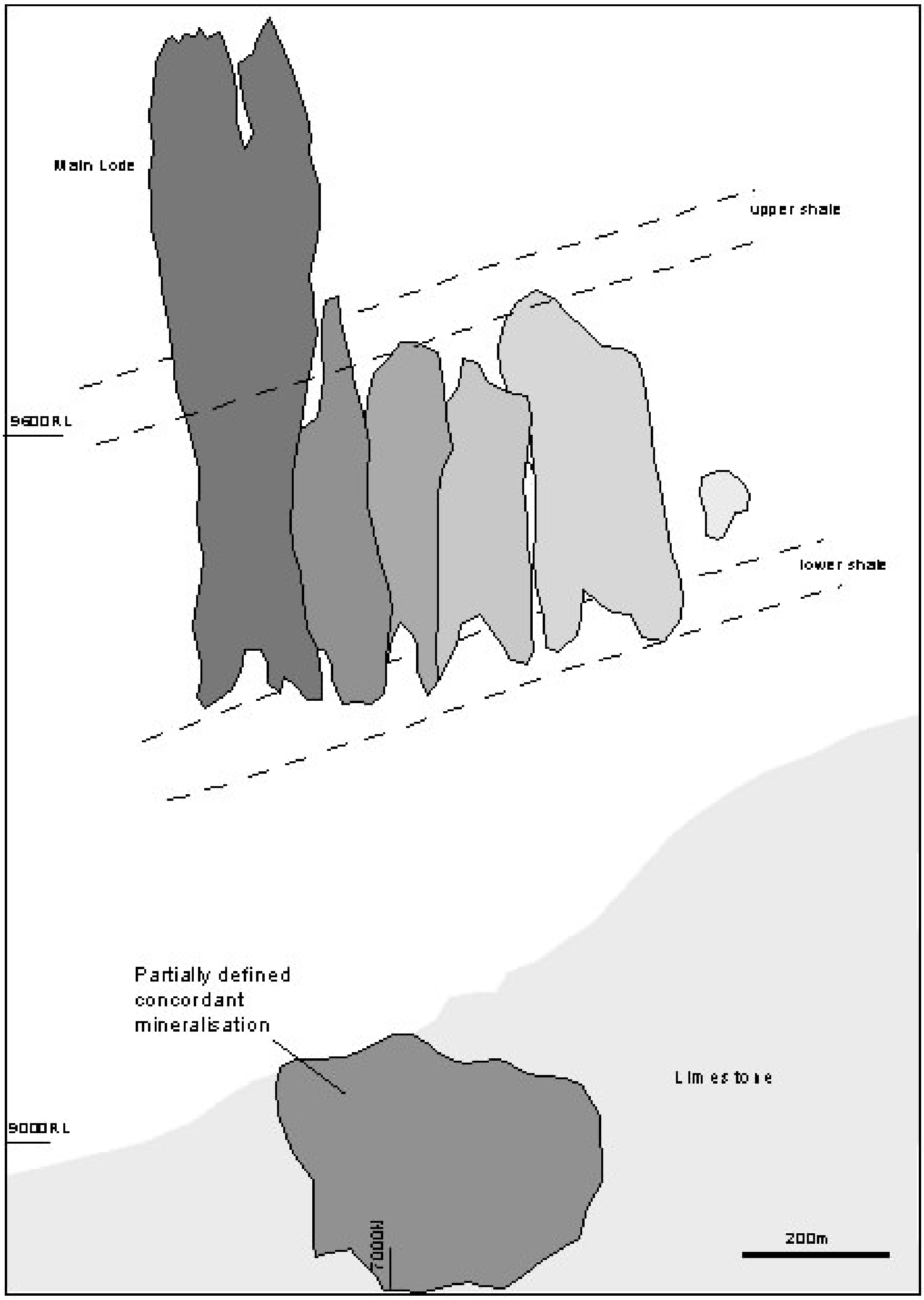


Figure 4: Long section of the ore body with schematic upper and lower shale units and limestone including concordant mineralisation adjacent to the limestone contact.

Exploration

For much of the mine's life, the grades within the stringer zone were sub-economic (less than 10 percent combined Pb and Zn). High metal prices have led to the current investigation into the economics of mining portions of the stringer zone.

Massive sulphide mineralisation has been intersected adjacent to the limestone contact within an envelope of concordant stringers. Due to the relative location of underground workings to the east and up-dip from this mineralisation, previous drilling has not been able to define its thickness and extent. Current drilling is targeting this mineralisation by deep surface drill holes from the west.

Several zones of massive axial plane mineralisation are yet to be closed off. Lenses to the north in particular remain open and are untested by drilling. Stringer mineralisation is open along strike in both directions and down dip on both limbs. These extensive zones are planned to be tested by drilling and an Electro-Magnetic survey using large underground loops and down-hole probes.

Acknowledgements

The authors acknowledge their current co-workers at Endeavor mine and CBH Resources management for their help in producing this paper.

References

David, V., Leevers, P. and Lorrigan, A., 2000, A new look at Elura deposit, NSW. Unpublished report

Lawrie, K.C. and Hinman, M.C., 1998, Cobar-Style Polymetallic Au-Cu-Ag-Pb-Zn deposits. AGSO Jour Aust Geol & Geophys, 17(4), 169-187

Schmidt, D.L., 1989, Elura Zinc-Lead-Silver Mine Cobar. Geol. Soc. Aust. Cobar Field Meeting Oct 6-8, 1989

Webster, A.E. and Lutherborrow, C., 1998, Elura zinc-lead-silver deposit, Cobar. In Geology of Australian and Papua New Guinea Mineral Deposits (Eds: D.A. Berkman and D.H. MacKenzie). 587-592 The Aus IMM Melbourne

THE BOWDENS SILVER DEPOSIT - RENEWED INTEREST WITH AN IMPROVING SILVER PRICE

Ian Pringle

Silver Standard Australia Pty Ltd, 556 Crown Street, Surry Hills, NSW 2010.

Key Words: silver, zinc, lead, epithermal, Mudgee

Introduction

The Bowdens Silver Deposit (BSD) is located close to the NE edge of the Lachlan Fold Belt between Mudgee and Rylstone. It formed as an epithermal silver-base metal deposit within air-fall rhyolitic breccias, ash falls and crystal tuffs. The silver mineralisation is associated with sphalerite and galena as disseminations and as silicic fracture fill. High-grade silver mineralisation also occurs in fracture zones and as sulphide veinlets.

The BSD was discovered by CRAE during regional stream sediment sampling in 1988. By 1992 CRAE had defined an Inferred Resource of 6.2Mt of 85g/t Ag, 0.52% Zn and 0.28% Pb for the ‘Bowdens Gift’ which is the Main Zone South portion of the deposit. In 1994 GSM Exploration Pty Ltd purchased the project and in 1997 GSME was purchased by Silver Standard Resources Inc of Vancouver. Since 1994 drilling has shown the mineralised sequence continues down dip towards the north and west of Main Zone South and remains open at depth and to the west. During 2004 Measured and Indicated Resources were estimated to total 47.6Mt of 52g/t Ag, 0.41% Zn and 0.30% Pb with an additional Inferred Resource of 13.4Mt of 41g/t Ag, 0.32% Zn and 0.21% Pb for a combined total of 97 million ounces of contained silver. These calculations were based on 402 drill holes, a total of 43,644 drill metres, an average drill hole spacing of approximately 30m and a 40g/t Ag cut-off.

Pre-feasibility scoping studies which include metallurgical testwork and mine planning and environmental studies including flora, fauna, archaeology, meteorology, noise control and ground water surveys were completed during 2004 and these are currently being updated by Lycopodium Engineering to incorporate 2005-6 metallurgical testwork undertaken by G&T Metallurgical Laboratories, Canada.

Geology

Mineralisation at BSD occurs within a sequence of rhyolite pyroclastics of the Early Permian Rylstone Volcanics which unconformably overlie fine grained Ordovician meta-sediments and which are overlain by conglomerates, sandstones and coal measures of the Shoalhaven Group (Permian) part of the western edge of the Sydney Basin.

Four distinct, relatively flat lying units are recognised in the pyroclastic sequence. Underlying fine-grained crystal to crystal lithic tuffs are overlain by an ignimbrite flow sequence, which in turn is covered by coarse lapilli tuff and tuff breccia. Thin lenses (generally several metres thick) of vitric tuff occur in the upper part of the pyroclastic sequence. Underlying Ordovician meta-sediments consist of alternating lenses of siltstone and sandstone.

The Main Zone South and Main Zone North parts of the mineralisation are bounded to the east by a N to NNW trending structure, whereas mineralisation at the Bundarra North and Bundarra South Zones are aligned along a parallel structure in the western part of the prospect area. The pyroclastic sequence has been down faulted within a graben-like feature associated with these faults and a set of ESE cross cutting faults commonly form the boundaries to higher grade zones of mineralisation.

Mineralised host rocks include air-fall tuff breccia, ignimbrite and crystal tuff. Mineralisation also extends into Ordovician sediments (for example CRAE drilling intersected 2.2m of 14.4% Zn, 196g/t Ag, 1.4g/t Au and 4.4% Pb from 204.8m in DD89BG39) although most drill testing has been relatively shallow <120m and in many portions of the mineralised system exploration has not determined the depth extent of the mineralisation. Ignimbrite, and some tuff lithologies are welded and show crackle, mosaic and rotational breccia-style textures which can host mineralization within the both breccia clasts and siliceous breccia matrix. Crystal tuff rocktypes show less secondary brecciation and mineralisation in these is commonly finely disseminated within the altered matrix. Later stage mineralisation occurs as crustiform veins up to 10cm wide, often associated with fault zones, and usually containing quartz-carbonate-sulphide assemblages. Areas of more marked silicification and fracturing within welded tuffs may represent prominent pathways for circulating mineralising fluids.

Mineralisation occurs as lensoid zones, stacked within a 20-80m thick package which dips northwards at less than 30 degrees from outcrop at Main Zone South and Bundarra South to depths of over 200m in the northern parts of Main Zone North and Bundarra North. Drilling has shown that the BSD extends more than 600m east-west and 700m north-south. Faults bound the east and north margins of the mineralisation but mineralisation remains open to the west.

Silver Minerals

Silver minerals include tennantite, silver sulphosalts (pearceite-polybasite > pyrargyrite – proustite), silver sulphide (argentite, acanthite) and native silver. Microprobe analyses have identified stephanite / argyrodite, plagionite and cerargyrite. The silver content of the galena has not been determined. The sequence of deposition of the dominant silver phases occurs as: (?Ag-galena) → Ag-tennantite / freibergite → native Ag → argentite / acanthite → pyrargyrite-proustite → pearceite – polybasite.

Geophysics

Magnetic and IP surveys as well as some down-hole electrical logging has been undertaken. This has shown that the contrast between host and mineralised rock is subtle and many geophysical techniques would be of limited help in exploration.

During 2005 a VTEM (time domain) helicopter EM survey was flown by Geotech Ltd over Bowdens and the area covered by Sydney Basin sediments to the north of the deposit. Ken Witherly of Condor Consulting prepared a series of composite profiles showing the EM channels, the EM Flow Conductivity Depth Section (CDS), the TMI and AdTau (time constant) profiles as well as geological sections through the BSD and showed that the mineralisation can be defined in the EM Flow sections where a well defined flat-lying zone of moderate conductivity can be seen in most sections through the deposit.

Alteration

The hydrothermal history of the BSD shows an early stage of fluidized brecciation where pyroclastic fragments were transported, milled and sealed in a quartz-illitic clay-pyrite altered matrix. This breccia event was followed by wallrock replacement and cavity, fracture and breccia filling characterised by an often repeating sequence of quartz → sulphides → carbonate → clay, typical of South-West Pacific carbonate-base metal-gold systems (Corbett and Leach, 1998).

Quartz replacement and deposition occurred during all hydrothermal events. Fine grained early stage quartz is intergrown with illitic clay + pyrite and later quartz is generally coarser grained, clear and contains intergrowths of illitic clay, pyrite, arsenopyrite and/or sphalerite. Adularia replaces primary feldspar, rims fractures and cavities, and is replaced by illitic clays or sericite.

Sulphide content tends to increase during later quartz events and continues into carbonate-dominated alteration. Sulphide minerals are usually deposited as open space fill although they occur as replacements of mafic crystal fragments, feldspar fragments and vitric tuff clasts. Quartz in open spaces is overgrown by sulphide minerals that exhibit an overall depositional sequence of pyrite → arsenopyrite → sphalerite → galena → tennantite (±chalcopyrite) → silver minerals, although there is considerable overlap in this sequence. Sphalerite is the most abundant sulphide. Sphalerite shows general compositional change from Fe-rich cores to Fe-depleted rims, suggesting a general cooling during mineralization. This zoning is generally erratic and repetitive and suggests multiple fluctuations of temperature. Very rare chalcopyrite and other copper sulphides show that the hydrothermal fluids at this level in the system were depleted in copper.

Carbonate is intergrown with, and commonly overgrows quartz and sulphide minerals. Early carbonate phases are manganiferous compared with later carbonate which is iron-rich and finer grained and often forms fine grained colloform bands. Wall rock replacement is dominated by clay minerals which are also prominent as fracture and breccia fill with quartz, sulphide and carbonate minerals. Clay minerals line open spaces and form overgrowths on igneous minerals. Kaolinite occurs as overgrows, partially replaces illitic clay and locally contains marcasite and trace galena and silver minerals.

Silver mineralization occurred at the same time as carbonate alteration and continued into the clay-rich alteration events.

Distribution in Alteration and Mineralisation

An X-ray diffraction (XRD) study of the illitic clay minerals has been undertaken by Terry Leach. This work shows that illite and well-crystalline sericite form a relatively high temperature, N-S trending zone that coincides with a major fault in the western part of the BSD and widens in the south. Clay minerals grade into interlayered smectite – illite (with high smectite content) close to the western margin of the deposit and this indicates rapidly cooling alteration towards the west. Along the east of the BSD broad zones of interlayered illite-smectite, with a progressive increase in smectite content is interpreted as cooling conditions and possibly indicate an outflow zone.

Fe-rich carbonate minerals (siderite, mangano-siderite) dominate in the eastern portion of the prospect area, whereas manganese ± magnesium (rhodochroiste, kutnahorite, ankerite) are the main carbonate minerals identified in samples from the west of the deposit.

Arsenopyrite is common in the south and west of the deposit and marcasite is abundant and associated with Fe-carbonate in the north and east. Using colour index in thin section Terry Leach has shown that Fe-content of the sphalerite follows the distribution of illitic clays and is indirectly related to the temperature of mineralization. Fe-poor sphalerite is indicative of cool conditions and is typical of the north east and shallower levels of the BSD. Fe-rich sphalerite is restricted to the west. Galena is more abundant than sphalerite as the main base metal sulphide at shallower levels, especially in the northeast portion of the deposit. Silver minerals are mainly observed in samples from the north and east where tennantite (Cu-rich silver sulphosalt) occurs at deeper levels and Sb-As-Ag ore minerals (pearceite, pyrargyrite, argentite / acanthite, native silver) are more common at shallow levels.

Depositional Model

The distribution of the mineralisation and alteration indicates that quartz (+- adularia) – illite/sericite –pyrite – arsenopyrite assemblages formed on the northernmost margin of a hydrothermal system where high temperature fluids from south of the BSD flowed northwards along a major structure close to the western side of the deposit and towards the northeast along open structures or fracturing.

Cooler steam heated geothermal waters with a low pH flowed into the volcanic tuff sequence in the north and east with characteristic alteration of siderite – smectite-rich illite clays – Fe-carbonate - marcasite ± kaolinite.

When these two fluid types mixed, iron and base metal suphides were deposited, sulphur activity and pH of the mineralised fluid decreased and silver minerals were deposited. Clay minerals associated with the ore indicate that temperatures of silver – base metal mineralization were less than 150-200ºC.

The Hillgrove Gold-Antimony-Tungsten District, NSW, Australia

---

B. Hooper, P. Ashley and P. Shields

Straits Resources, Lvl 1, 35 Ventnor Avne, West Perth, W.A. 6005

Abstract

Mineral occurrences of the Hillgrove Au-Sb-W district are hosted in late Palaeozoic polydeformed, hornfelsed metasediments and Permo-Carboniferous granitoids of the New England Orogen. In excess of 204 individual occurrences have been identified to date with the mineralisation developed as strike extensive (>20km's of known veining) and potentially depth extensive steeply dipping fissures. These are contained within an elongate area measuring some 9km by 6km in surface dimensions. Recorded gold production of 720,000 ounces along with current resources in the order of 1.3 Million ounces of gold equivalent highlight the significance of this district. Historical antimony production is estimated at in excess of 50,000 metric tonnes. Significant tungsten of over 2000 t in the form of scheelite has also been produced from the field.

Mineralisation is developed in veins, vein breccias, sheeted veins, network stockworks and as alteration sulphide haloes to the main structures. The vast majority of fissures are sub-vertical and vary in widths of up to 20m in places. Paragenetic studies have previously indicated that the earliest mineralising event was a scheelite-bearing phase of quartz veining. Subsequent phases of arsenopyrite–pyrite–quartz–carbonate veining were accompanied by gold and minor base metal sulphides. Alteration is typically sericite–ankerite–quartz. Overprinting stibnite–quartz veining with gold-electrum, aurostibite and arsenopyrite form an important subsequent phase. Veining can be inferred from historical records to extend for vertical depths of over 1 km.

Preliminary structural studies highlight the potential transpressional nature of the orogenic event associated with the Hillgrove mineralisation. Significant north-south oriented shear and fracture zones occur in the deeper exposed regions of field. Large north-east oriented faults with both ductile and brittle characteristics also crosscut the district. The vast majority of mineralised veining has a distinct north-west oriented strike. Ore shoots are typically sub-vertical with internal movement indicators suggesting a component of left lateral movement associated with the latest stibnite–quartz–gold vein and breccia stage. Fibre lineations and slickensides in the plane of the vein are horizontal in the most intense vein zones, and appear to steepen to plunges of >20° where the mineralisation is erratic suggesting an increased component of strain.

Syn-mineralisation lamprophyre dykes have an age range of 247-255 Ma (late Permian-early Triassic) and have temporal and geochemical affinities to the voluminous Moonbi Suite of high-K granitoids. Fluid inclusion studies have indicated homogenisation temperatures in gangue quartz in the range 100°-250°C and that fluids were of low salinity. Metal zonation within the field is variable between the lode systems.

The Hillgrove gold–antimony–tungsten occurrences have strong affinities to many other orogenic gold-antimony deposits elsewhere, particularly in New Zealand, except that the ore mineral assemblage is telescoped, with earlier deeper level mineralisation overprinted at the same structural level by later, shallower mineralisation.

Introduction

The Hillgrove Mineral Field lies in north-eastern NSW, Australia about 20 kilometres east of Armidale (Boyle, 1990; Gilligan et al., 1992). The field covers 9 by 6 kilometres and is dissected by a deep gorge system of up to 500m depth. The field has been mined since the

1870’s and produced over 720,000 ounces of gold with current resources in the order of 1.3 million ounces equivalent. Historical antimony production is estimated at in excess of 50,000 metric tonnes. Over 2000 t of scheelite concentrates have been produced from the field. The Hillgrove mine ceased production in 2002 and went into receivership.

Mineral occurrences of Au-Sb-W are hosted in late Palaeozoic polydeformed, hornfelsed metasedimentary rocks and Permo-Carboniferous granitoids of the New England Orogen (Boyle, 1990; Gilligan et al., 1992). In excess of 204 individual occurrences have been identified to date with the mineralisation developed as strike extensive (>20km’s of known veining) and potentially depth extensive steeply dipping fissures. Mineralisation is focussed in a north-west striking belt between the Chandler and Hillgrove faults (Fig 1.)

Straits Resources purchased the deposit in 2004 and now controls 100% of the mining leases and surrounding exploration tenements. An active exploration program has been ongoing for a couple of years defining resources to re-start the mining operation. Previous exploration has only involved very minor drilling from either underground or on surface and the potential of the field is considered untapped by modern methods. A systematic exploration program with assessment of current underground and surface infrastructure, metallurgical testwork and the development of plans for future mining operations

Exploration has involved an extensive underground and surface exploration campaign of the Hillgrove Mining and surrounding exploration tenements. Drilling to date has been targeted at the Eleanora/Garibaldi, Metz mines and at the Clarkes Gully prospect with significant success leading to infill resource drill outs.

Geology and Structure

Mineralised vein and breccia systems at Hillgrove are hosted in biotite-grade metamorphosed sedimentary rocks of the late Palaeozoic Girrakool Beds (originally shale, siltstone, argillite, greywacke), biotite monzogranite (S-type) of the ~300 Ma Hillgrove Adamellite and granodioritic-dioritic rocks of the early Permian Bakers Creek Diorite Complex. The structures and mineralisation post-date, and are unrelated to any of the host rocks. Syn-mineralisation lamprophyre dykes that are both cut by mineralisation as well as having intruded mineralised structures, are dated at 247-255 Ma (Ashley et al., 1994), thus bracketing the potential age of mineralisation to approximately the Permian-Triassic boundary. The dykes are closely related spatially to mineralised structures, are up to a few metres wide and include minette and vogesite types. Geochemically, the lamprophyres are related to the high-K I-type granitoids of the Permo-Triassic Moonbi Plutonic Suite (Ashley et al., 1994).

Nearly all of the mineralised structures of the Hillgrove region lie between two major east-northeast striking regional structures, the Hillgrove and Chandler Faults (Fig. 1). These structures are largely ductile and mylonitic in character, cutting the granitoids and metasedimentary rocks. Metamorphic grade changes across the Chandler Fault imply significant asymmetric uplift along the northern side of the fault, occurring between 266-256 Ma (Landenberger et al., 1995, Ashley and Craw, 2004). Structural studies highlight the potential transpressional nature of the orogenic event associated with the Hillgrove mineralisation. Significant north-south oriented shear and fracture zones are exposed in the deeper gorges of the region and may have a controlling role in the subsequent development of the mineralised veining that is hosted in brittle structures (Ashley and Craw, 2004). The majority of mineralised veining has a north-west oriented strike, with dips commonly 70° to vertical. Mineralised structures commonly pinch and swell, according to the presence of local dilatational sites (Fig. 2), leading to large variation in widths of mineralised veins and breccias (from < 1cm to several metres). Ore shoots are typically sub-vertical with internal movement indicators suggesting a component of left lateral movement associated with the latest stibnite – quartz – gold vein breccia stage. Fibre lineations and slickensides in the plane of the vein are horizontal in the most intense vein zones, and appear to steepen to moderate plunges of >20 degrees where the mineralisation is erratic suggesting an increased component of strain. Veining can be inferred from historical records to extend for vertical depths approaching 1 km (Fig. 3).

Mineralisation

Mineralisation is developed in veins, vein breccias, sheeted veins, network stockworks and as alteration selvages of disseminated and veinlet arsenopyrite and pyrite adjacent to the main structures. Although mineralised structures are commonly <1 m wide, zones of stockworking and brecciation, plus their accompanying sulphidic halo zone may attain widths of up to 20m in places. Paragenetic studies (Boyle, 1990; Ashley and Craw, 2004) have previously indicated that the earliest mineralising event was a scheelite-bearing phase of quartz veining. Subsequent phases of arsenopyrite–pyrite–quartz–carbonate veining were accompanied by gold and minor base metal sulphides. Alteration is typically sericite–ankerite–quartz and this accompanies the disseminated and veinlet arsenopyrite and pyrite zones. Overprinting stibnite–quartz veining with gold-electrum, aurostibite and arsenopyrite form an important subsequent phase. The sulphidic haloes about the mineralised structures vary from being narrow and tight, to up to 20 m wide. In these zones, it has been shown that gold grades (with little or no accompanying Sb) can be significant, with gold hosted “invisibly” in the sulphides. Arsenopyrite is the main host to invisible gold, although a smaller proportion is also hosted in pyrite that tends to be of arsenical composition (Ashley et al., 2000). The disseminated gold halo about mineralised structures is being sampled and drilled in detail to define the grade. Mineral concentrates derived from the sulphidic halo material have proven to yield good gold recoveries from pressure oxidation treatment, followed by conventional cyanidation.

The presence of the sulphidic halo about mineralised structures and the other changes to wallrock mineralogy have led to the development of geochemical alteration haloes that can extend for up to tens of metres. The alteration-mineralisation process has led to addition of Au, Sb, As, S, CO2, K and Rb, with depletion of Na and Sr (Ashley and Craw, 2004). Fluid inclusion studies have indicated homogenisation temperatures in gangue quartz in the range 100°-250°C and that fluids were of low salinity (Comsti and Taylor, 1984). Metal zonation within the field can be inferred on the basis of past production to be from Au-As at depth to Sb-Au-As at shallower levels, with minor scheelite occurring throughout the production interval. Structural, alteration and mineralisation characteristics of Hillgrove accord with many other orogenic gold deposits, although Hillgrove is unusual in potentially having formed progressively during orogenic uplift leading to a telescoped array of vein systems with overprinting of earlier mineralisation by later (e.g. W by As-Au by Sb-Au).

A detailed three dimensional model of the previous mining and sampling has been developed that is assisting in understanding of the various mineralised systems. The veins cross cut lithology but can vary markedly in their nature, vein styles, alteration, width and grades of Au, Sb, As and W (Fig. 4).

Conclusions

The Hillgrove gold–antimony–tungsten occurrences have strong affinities to other orogenic gold-antimony deposits except that the ore mineral assemblage is telescoped, with earlier deeper level mineralisation overprinted at the same structural level by later, shallower mineralisation. The mineralised vein systems have a strong structural control and there is considerable potential for (a) extension at depth, (b) extension along strike of known structures and (c) discovery of new blind systems at depth or under regolith cover. There is also considerable opportunity to develop significant gold production from the arsenopyrite-pyrite halo about mineralised structures and to investigate production of antimony (stibnite) concentrates again to take advantage of currently buoyant world antimony prices. Straits Resources will for the first time attempt to unlock the big picture of the Hillgrove mineralised system and its potential to be a multi-million ounce gold district.

Detailed plans, including costings, for the refurbishment of existing plant and infrastructure are being finalised for potential start up in 2007.

References

Ashley, P.M., Cook, N.D.J., Hill, R.L. and Kent, A.J.R. 1994. Shoshonitic lamprophyre dykes and their relation to mesothermal Au-Sb veins at Hillgrove, New South Wales, Australia. Lithos 32, 249-272.

Ashley, P.M. and Craw, D., 2004. Structural controls on hydrothermal alteration and gold-antimony mineralization in the Hillgrove area, NSW, Australia. Mineralium Deposita. 39, 223-239.

Ashley, P.M., Creagh, C.J. and Ryan, C.G. 2000. Invisible gold in ore and mineral concentrates from the Hillgrove gold-antimony deposits, NSW, Australia. Mineralium Deposita, 35, 285-301.

Boyle, G.O. 1990. Hillgrove antimony-gold deposits. In: Hughes, F.E. (ed.) Geology of the mineral deposits of Australia and Papua New Guinea. Australasian Institute of Mining and Metallurgy, Monograph, 14, 1425-1427.

Comsti, E.C. and Taylor, G.R. 1984. Implications of fluid inclusion data on the origin of the Hillgrove gold-antimony deposits, N.S.W. Proceedings of the Australasian Institute of Mining and Metallurgy, 289, 195-203.

Gilligan, L.B., Brownlow, J.W., Cameron, R.G. and Henley, H.F. 1992. Metallogenic study and mineral deposit data sheets Dorrigo-Coffs Harbour 1:250 000 metallogenic map. Geological Survey of New South Wales, Sydney, 509 pp.

Landenberger, B., Farrell, T.R., Offler, R., Collins, W.J. and Whitford, D.J. 1995. Tectonic implications of Rb-Sr biotite ages for the Hillgrove Plutonic Suite, New England Fold Belt, N.S.W., Australia. Precambrian Research, 71, 251-263.

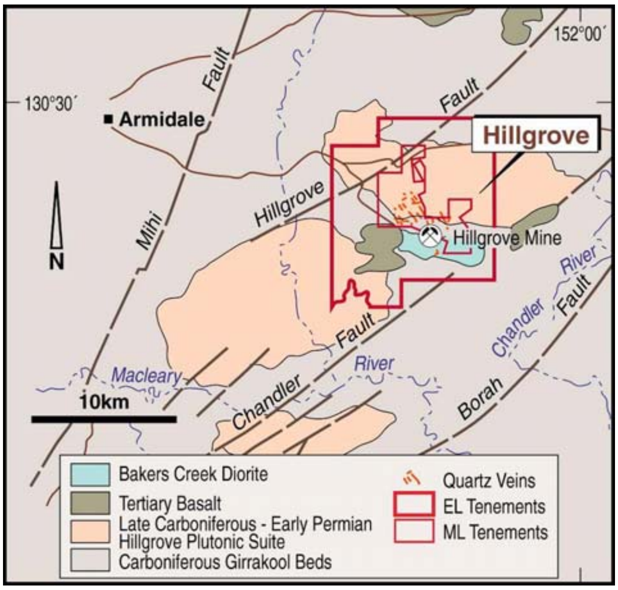


Figure 1: Location and geology of the Hillgrove region.

Figure 2: Mineralised structure hosted in dilatational jog, with quartz-stibnite-gold vein infill and adjacent vein breccia zone. Width of image is approximately 1 m.

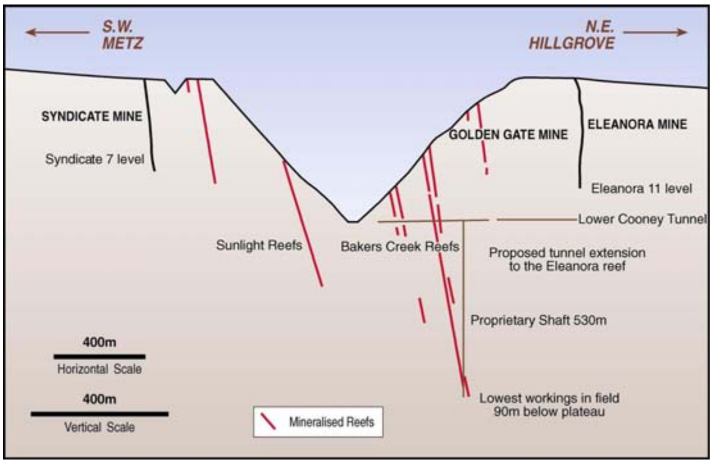


Figure 3: Schematic cross-section from SW-NE across the Bakers Creek gorge at Hillgrove. The main structures are steeply dipping and extend to depths of several hundred metres to 1 km.

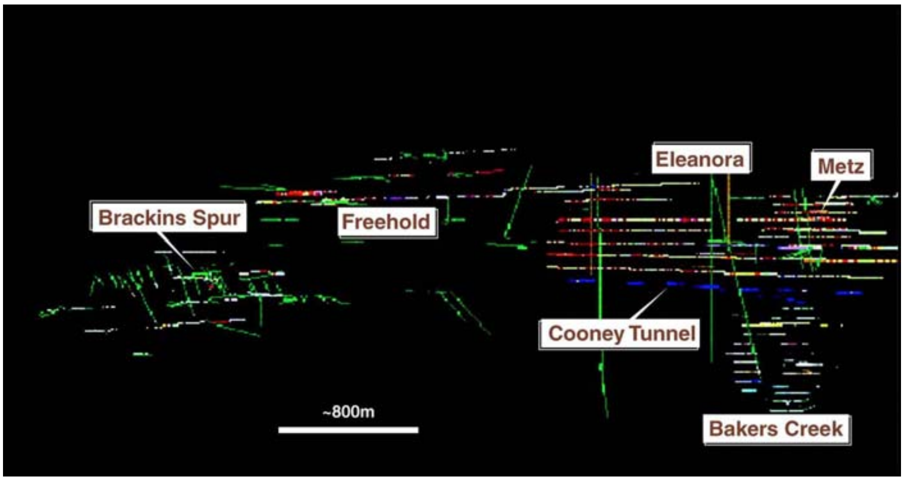


Fig.4. Three-dimensional image of underground workings and drillholes at Hillgrove, colour coded with Gold.

Intrusion-Related Gold Systems in the New England Fold Belt – The Tooloom Example

Brett McKay and Bradley Wake

Malachite Resources NL, Suite 1502, Keycorp Tower B, 799 Pacific Hwy, Chatswood, NSW 2067

Key Words: Intrusion-related gold system, breccia, Tooloom, I-type, reduced, magmatic, hydrothermal

Intrusion-related Gold Systems

Intrusion-related gold systems (IRGS) are a relatively newly defined class of economically important gold deposits based largely on well-studied examples in the Tintina Gold Belt of Yukon/Alaska (eg. Thompson et al., 1999, Thompson & Newberry 2000, Lang et al., 2000). Whilst some debate and confusion has surrounded the nomenclature of these systems since initial recognition, a generally widely accepted set of geologic and geochemical criteria have now been established to define this model. General characteristics, according to Thompson et al. (1999) and Lang & Baker (2001) include:

- a metal assemblage variably combining Au with Bi, Te, W, Mo, As, Sb with a low sulphide content (<5%) and reduced ore mineral assemblage typically comprising arsenopyrite, pyrrhotite and pyrite and lacking magnetite or hematite;
- common metal and deposit style zoning centred on a central mineralising intrusion (Figure 1);
- spatial and/or temporal relationship with moderately reduced, I-type, intermediate to felsic intrusions;
- carbonic to rarely saline hydrothermal fluids;
- restricted zones of hydrothermal alteration;
- a continental tectonic setting inboard of inferred convergent plate margins;
- located in provinces best known for W and/or Sn.

Furthermore, IRGS systems are characterised by a range of mineralisation styles, both proximal and distal to the mineralising intrusion, as illustrated on Figures 1 and 2. These include:

- sheeted veins and stockworks;
- breccias;
- disseminated deposits;
- skarns;
- replacements; and
- distal base metal bearing fissure veins.

Vertical metal zoning is common and tends to differ from shallow to deeper systems with W±Mo at depth and Au-Bi at shallower levels (Figure 2). Shallower systems are often expressed as breccias with sericite-carbonate alteration more abundant at these depths. Furthermore, stibnite is more common in distal and high-level deposits, with Bi often characteristic of deposits in or close to plutons (Thompson & Newberry, 2000). However, some distal deposits locally contain elevated Bi. These criteria contrast significantly with geologic models for Cu-Au porphyry deposits, although some overlap is apparent with orogenic gold deposits.

Intrusion-related gold systems have been documented in relatively few districts around the world, however, the model is increasingly being applied to known gold systems with some success. The main documented IRGS provinces, according to Lang & Baker (2001), are the Tintina Gold Belt of Yukon/Alaska (Donlin Ck, Fort Knox, Pogo, Shotgun), the Bolivian

Polymetallic Belt (Kori Kollo), the Palaeo-Tethys Closure (encompassing deposits in China, Kazakstan, Czech Republic, Spain and Portugal) and the somewhat isolated occurrences of Eastern Australia in North Qld (Kidston, Red Dome) and north-eastern New South Wales (Timbarra in the New England Fold Belt). Of particular interest to this paper is the occurrence of IRGS in the New England Fold Belt (NEFB) and how the Tooloom Gold Project could represent a large, previously unrecognised IRGS in Eastern Australia.

The Tooloom Example

The Tooloom Gold Project is located within the NEFB in far northeastern NSW, approximately 130 km south southwest of Brisbane (Figure 3). Alluvial gold was first discovered in 1857 and within a few years up to 10,000 people were mining predominantly alluvial gold from the Tooloom valley. Alluvial and small-scale hardrock mining operations continued into the late 1860’s until the Gympie gold field was discovered, resulting in the majority of miners leaving Tooloom. Apart from some small-scale alluvial mining which has ceased only in recent years, Tooloom largely remained forgotten as a gold field until the involvement of Malachite Resources, which has re-discovered the Tooloom district in recent years. The Tooloom goldfield was first published on Government geological maps only in 2001, four years after Malachite began work in the area.

The Tooloom Gold Project lies within the Emu Creek Block of the southern NEFB. The oldest rock unit exposed in the project area is the Late Carboniferous – Early Permian Emu Creek Formation, comprising gently folded, uncleaved, interbedded, terrestrial to shallow marine sedimentary sequences and minor volcanic rocks (Brown et al., 2001). Massive, medium-grained, magnetic, calc-alkaline, intermediate to felsic, I-type intrusions of the Late Permian to Early Triassic Clarence River Supersuite intrude the Emu Creek Formation within the project area. These include the Jenny Lind Granite and a number of previously unrecorded diorite, granodiorite, tonalite, dolerite and gabbro intrusions. Monzogranite and leucogranite intrusions of the Early Triassic Moonbi Supersuite intrude the Emu Creek Formation and Clarence River Supersuite (Thompson, 1976; Bryant et al., 1997; Mustard, 2004) in the vicinity of the project. These are generally weakly magnetic, high-K, calc-alkaline, I-type intrusions associated with vein and disseminated gold (Timbarra; Mustard, 2001), molybdenum (Glen Eden; Soumarin & Ashley, 2004) and tin (Taronga; Suppel et al., 1998) mineralisation in the southern NEFB.

Four main intrusive centres (Phoenix, Cullens, Joes Gully and Frasers) have been defined at Tooloom, each of which is associated with a number of significant gold occurrences, both within and adjacent to the intrusive complexes. At the Joes Gully, Cullens and Frasers intrusive centres, gold resides in narrow, sheeted quartz veins and stockworks within Emu Creek Formation sedimentary rocks and adjacent to doleritic dykes. Alteration associated with the veins is weakly expressed as a narrow centimetre-scale selvage. Visible gold can be seen in outcropping quartz veins at prospects surrounding the Frasers intrusive centre, with gold values up to 100 g/t. More work is required to unequivocally link the mineralised systems at Joes Gully, Cullens and Frasers to the IRGS model. However, the style of mineralisation and close spatial association to intrusive phases at these prospects suggests the formation of a magmatic hydrothermal system related to these intrusives.

The Phoenix intrusive centre is the most significant IRGS discovered to date within the Tooloom project area. Phoenix was discovered by following up multiple, anomalous gold (+20 ppb) BLEG stream sediment samples collected as part of a regional exploration program. Mapping and prospecting up these creeks discovered outcropping hydrothermal breccia, named the Phoenix Breccia. Initial gold values from rock chip samples of the breccia were low (0.2 - 0.4 g/t Au), and subsequent soil sampling showed that gold in soil values over the breccia were anomalous but patchy and of low tenor. These factors are presumably the main reason why this system lay undiscovered for so long! The Phoenix Breccia lies on the northern side of an annular, moderately strong IP-chargeability anomaly and a coincident gold-arsenic-antimony-bismuth-copper soil geochemical anomaly measuring 1 km in diameter, as illustrated on Figure 4. The IP anomaly extends to at least 400 m depth, equating to at least one billion tonnes of mineralised rock. The coincident IP and geochemical anomaly reflects a diffuse stockwork of quartz-carbonate-sulphide veinlets in patchy sericitic-altered, quartz-biotite-hornfelsed clastic sedimentary rocks of the Emu Creek Formation carrying low-grade gold-sulphide mineralisation (0.1-0.5 g/t Au). A 2 km diameter aeromagnetic low overlaps the mineralised system at Phoenix (Figure 4). Mapping defined the surface expression of the breccia to have a lensoid shape with a strong northeast – southwest structural orientation.

A zone of intense crackle brecciation/fracturing extends to the southwest of the breccia and includes a second significant Au-Bi-As-Cu soil geochemical anomaly. This zone, known as the Creek Zone, lies within a northeast striking structural corridor which encloses the Phoenix Breccia. Future work is planned to further define this mineralised zone.

A combined total of 26 RC and diamond drill holes have been completed at Phoenix to date. All holes drilled have encountered anomalous gold mineralisation in the breccia body or in Emu Creek Formation sedimentary rocks. Initial drilling was based on a 'Cadia-type' porphyry model, although more recent drilling focussed on the breccia pipe once its IRGS affinities were recognised. Drilling has defined sharp, near-vertical margins to the breccia body on the southeast and northwest contacts, however this body remains largely open to the northeast and southwest and at depth. The breccia has a true width of 85 m at its widest point, an outcrop length of 300 m and a northeast elongate pipe-like geometry that extends to at least 500 m vertical depth. The breccia is characterised by polymictic, angular to subrounded clasts ranging in size from less than 1 cm to several metres. Open space accounted for 5 to 20 vol% of the breccia prior to partial or complete cementation by at least two stages of quartz-carbonate-sulphide infill. The sulphide assemblage is dominated by arsenopyrite-pyrite with stibnite at shallower levels. Stibnite and pyrite tend to become subordinate with depth, with pyrite often replaced by marcasite. Clasts show little evidence of significant vertical displacement and often exhibit a "jigsaw texture". Clast lithologies are dominated by Emu Creek Formation sandstone and siltstone, however, dolerite, quartz-feldspar porphyry, feldspar porphyry and tonalite/granodiorite (70K Tonalite) clasts are also evident, particularly at depth. Hydrothermal alteration within the breccia consists of variably developed sericitisation, most intense on the northwest side of the breccia. The increased intensity of alteration tends to correspond with increased sulphide content and better gold grades, most likely related to higher permeability due to increased open-space on this side of the breccia. This side has the most potential for higher-grade shoots. Multiple broad intersections from the breccia include 48 m @ 2.21 g/t Au and 42 m @ 1.78 g/t Au from separate holes in the most recent drilling program. There is a clear association of gold with bismuth, arsenic and antimony mineralisation throughout the breccia and the presence of stibnite, with grades up to 8.3% Sb over 1 m, adds significant extra value.

A newly defined tonalite-granodiorite intrusive, know as the 70K Tonalite, has been mapped at Phoenix. This intrusive lies directly to the northwest of the Phoenix Breccia, however the breccia pipe itself is thought to be located within the hornfelsed aureole of a deeper seated, as yet unrecognised, mineralising intrusion. The 70K Tonalite phase appears to be pre-brecciation as fragments of tonalite are found within the breccia. Possible evidence for a magmatic-hydrothermal system contributing to the formation of the breccia pipe at Phoenix is provided from the modelling of aeromagnetics and IP-chargeability data over the prospect. These data show anomalous responses attributed to an annulus of moderately magnetic, sulphidic-alteration (disseminated and veinlet pyrrhotite, pyrite and arsenopyrite) within biotite-grade siliceous-hornfels of the Emu Creek Formation. This feature lies within a magnetic low that might represent a blind intrusion located below the southern margin of the Phoenix breccia pipe (Figure 4). The presence of widespread hypogene pyrite-pyrrhotite mineralisation associated with the biotite-grade hornfels, and the occurrence of locally anomalous bismuth, arsenic, antimony and copper geochemistry in soils, further supports the presence and influence of a mineralising intrusion. The actual mineralising intrusion, however, is possibly a weakly magnetic leucogranite of the Moonbi Supersuite which may intrude the Emu Creek Formation and the 70K Tonalite below the Phoenix breccia pipe. Further evidence for a magmatic-hydrothermal association is provided by analogy with the Timbarra gold deposit, located about 60 km to the south-southwest. Timbarra is hosted in the carapace of a leucogranite member of the Moonbi Supersuite. This intrusion-related gold deposit has a distinctive metal association that is very similar to that at Phoenix, and its formation has been clearly linked to a magmatic hydrothermal system directly related to the host intrusion (Mustard, 2004).

The relatively low Au-Bi correlation (<0.5), the high Au-As correlation (>0.8), the abundance of stibnite and arsenopyrite, and the patchy distribution of Bi throughout the Phoenix system suggest the breccia pipe maybe located mid-way between the proximal and distal deposit types (i.e. <1 km from source mineralising intrusion) as classified by Thompson & Newberry, 2000 (see Figure 2). Furthermore, and in accordance with these criteria, the Phoenix gold deposit most likely formed at a high level, with significant potential implied for a range of other deposit types associated with IRGS districts. This includes the possibility of significant zones of gold mineralisation occurring beyond the breccia pipe into peripheral stockworks, other unexposed or blind breccia bodies, zones of replacement-style mineralisation in reactive metasedimentary rocks, or mineralised buried intrusions (see Figures 1 and 2).

Additional exploration at Phoenix will be focussed on deeper drilling to better define the gold deposit hosted by the breccia body along strike and at depth, and ideally to discover the source mineralising intrusion. Additional targets ready for drill testing include a 40 m wide shear zone located adjacent to the Phoenix Breccia which exhibits stibnite occurring as “paint” and “rosettes” of needles on fractures, which could have behaved as a second conduit for mineralising fluids. Identical forms of stibnite have been observed within fertile structures at the Hillgrove Au-Sb mine located 220 km south of Tooloom.

IRGS in the New England Fold Belt

The metallogeny of the NEFB is characterised by hundreds of occurrences of gold, tungsten, antimony, tin, molybdenum and base metals, particularly in the southern NEFB (see Figure 5). A strong spatial and temporal association exists between various styles of mineralisation and a suite of post-orogenic, Mid-Permian to Early Triassic, I-type, calc-alkaline, reduced, low-magnetic, felsic- to intermediate intrusives (Stroud et al., 1999; Stroud, 1999; Gilligan & Barnes, 1990). Some examples of these intrusive phases in the NEFB are the Moonbi Supersuite, the Clarence River Supersuite, the Uralla Supersuite, the Nundle Supersuite, the Gundle Belt, the Coastal Belt and various unnamed leucogranite intrusives. Deposit styles associated with these intrusives include veins, stockworks, pipes, disseminations, greisens and skarns (Gilligan & Barnes, 1990). Examples include the Timbarra gold deposit (disseminations), the Kingsgate Mo-Bi deposit (pipes, veins and disseminations), the Glen Eden Mo-W-Sn deposit (breccia pipes and stockworks) and Taronga Sn deposit (sheeted veins) (Gilligan & Barnes, 1990). The combination of favourable granite geochemistry, the widespread occurrence of IRGS-affiliated mineral deposits and the presence of gold systems with IRGS affinity (Timbarra and Tooloom), highlights the IRGS prospectivity of the NEFB.

To put this into a ‘fold-belt’ scale exploration perspective, compare the history of discovery in the neighbouring Lachlan Fold Belt (LFB). Companies such as Kennecott, Anaconda and Phelps Dodge intensively explored the LFB in the1960’s and 1970’s for porphyry copper deposits using the “Arizona light-bulb” model. The failure of these companies to discover any significant porphyry copper deposits ultimately led to NSW being declared unprospective for porphyry deposits. Success came later with the recognition of a new model related to Ordovician shoshonitic intrusives, leading to the discovery of significant deposits at Northparkes, Cadia and Lake Cowal. By comparison, the NEFB has had very little exploration, especially through the direct application of a wide-ranging geological model. The NEFB in Queensland hosts significant gold deposits, such as Cracow, Gympie and Mt Morgan (see Figure 3). In spite of that, the NSW part of the NEFB seems to be widely regarded as unprospective for large gold deposits. The application of the IRGS model will no doubt help to reinvent the NEFB as highly prospective for large gold deposits. Phoenix could do for the NEFB what Northparkes did for the LFB!

REFERENCES

Ashley, P.M., Creagh, C.J., and Ryan, C.G., 2000. Invisible gold in ore and mineral concentrates from the Hillgrove gold-antimony deposits, NSW, Australia. Mineralium Deposita 35, 285-301.

Ashley, P.M., and Craw, D., 2004. Structural controls on hydrothermal alteration and gold-antimony mineralization in the Hillgrove area, NSW, Australia. Mineralium Deposita 39, 223-239.

Baker, E.M., and Tullemans, F.J., 1990. Kidston gold deposit, In: Hughes, F.E. (ed), Geology of the mineral deposits of Australia and Papua New Guinea: Australian Institute of Mining and Metallurgy Monograph 14, pp. 1461-1465.

Baker, E.M., and Andrew, A.S., 1991. Geologic, Fluid Inclusion, and Stable Isotope Studies of the Gold Bearing Breccia Pipe at Kidston, Queensland, Australia. Economic Geology 86, 810-830.

Baker, T., Pollard, P.J., Mustard, R., Mark, G., and Graham, J.L., 2005. A comparison of granite-related tin, tungsten, and gold-bismuth deposits: implications for exploration. SEG Newsletter 61, 10-17.

Blevin, P.L., and Chappel, B.W., 1995. Chemistry, origin, and evolution of mineralised granites in the Lachlan Fold Belt, Australia: The metallogeny of I- and S-type granites. Economic Geology 90, 1604-1619.

Brown, R.E., Henley, H.F., and Stroud, W.J., 2001. The Warwick – Tweed Heads 1:250,000 Sheet Data Package. Geological Survey of New South Wales, GS2001/087.

Bryant, C.J., Cosca, M.A.., and Arculus, R.J., 1997. 40Ar/39Ar ages of Clarence River Supersuite intrusions from the northern portion of the New England Batholith, southern New England Orogen. In: Ashley, P.M., and Flood, P.G. (eds), Tectonics and metallogenesis of the New England Orogen: Alan H. Voisey Memorial Volume. Geological Society of Australia Special Publication 19, pp. 242-253.

Bryant, C.J., Arculus, R.J., and Chappell, B.W., 1997. Clarence River Supersuite:250 Ma Cordilleran tonalitic I-type intrusions in Eastern Australia. Journal of Petrology 38(8), 975-1001.

Champion, D., 2005. Prospects Look Good in North Queensland. Ausgeo News: Geoscience Australia Newsletter 79.

Gilligan, L.B., and Barnes, R.G., 1990. New England Fold Belt, New South Wales – Regional Geology and Mineralisation, In: Hughes, F.E. (ed), Geology of the Mineral Deposits of Australia and Papua New Guinea. Australian Institute of Mining and Metallurgy, pp. 1417-1423.

Goldfarb, R.J., Ayuso, R. Miller, M.L., Ebert, S.W., Marsh, E.E., Petsel, S.A., Miller, L.D., Bradley, D., Johnson, C. and McClelland, W., 2004. The Late Cretaceous Donlin Creek deposit, southwestern Alaska – controls on epizonal formation. Economic Geology 99, 643-671.

Hart, C.J.R., McCoy, D., Goldfarb, R.J., Smith, M., Roberts, P., Hulstein, R., Bakke, A.A., and Bundtzen, T.K., 2002. Geology, exploration and discovery in the Tintina gold province, Alaska and Yukon. Society of Economic Geologists Special Publication 9, 241-274.

Hart, C.J.R., 2005. Classifying, Distinguishing and Exploring for Intrusion-Related Gold Systems. The Gangue: Geological Association of Canada, Mineral Deposits Division Newsletter 87.

Lang, J.R., Baker, T., Hart, C.J.R., and Mortensen, J.K., 2000. An exploration model for intrusion-related gold systems. Society of Economic Geology Newsletter 40.

Lang, J.R., and Baker, T., 2001. Intrusion-related gold systems: the present level of understanding. Mineralium Deposita 36, 477-489.

Meares, R.M.D., Lowder, G.G., White, M.J., Wake, B.A., and Vickers, M.D., 2004. The Tooloom Gold Project, NSW – 'Forgotten but not gone!' Rediscovering a 147-year-old gold field. In Proceedings of PACRIM 2004, Adelaide, pp. 333-338 (AusIMM, Melbourne).

Mustard, R., 2001. Granite-hosted gold mineralisation at Timbarra, northern New South Wales, Australia. Mineralium Deposita 36, 542-562.

Mustard, R., 2004. Textural, mineralogical and geochemical variation in the zoned Timbarra Tablelands pluton, New South Wales. Australian Journal of Earth Sciences 51, 385-405.

Scheibner, E., and Basden, H., ed., 1998. Geology of New South Wales – Synthesis. Volume 2 – Geological Evolution. Geological Survey of New South Wales, Memoir Geology 13 (2), 666 pp.

Sillitoe, R.H., 1985. Ore-related breccias in volcanoplutonic arcs. Economic Geology 1467-1514.

Somarin, A.K., and Ashley, P., 2004. Hydrothermal alteration and mineralization of the Glen Eden Mo-W-Sn deposit: a leucogranite-related hydrothermal system, southern New England Orogen, NSW, Australia. Mineralium Deposita 39, 282-300.

Stroud, J., 1999. New England Geology and Mineral Potential. Minfo: New South Wales Mining and Exploration Quarterly 63. Department of Mineral Resources. pp 2-6.

Suppell, D.W., Barnes, R.G., and Scheibner, E., 1998. The Palaeozoic in New South Wales – geology and mineral resources. AGSO Journal of Australian Geology & Geophysics, 17 (3), 87-105.

Thompson, J.F.H., and Newberry, R.J., 2000. Gold deposits related to reduced granitic intrusions. Society of Economic Geology Reviews 13, 377-400.

Thompson, J.F.H., Sillitoe, R.H., Baker, T., J.R., Mortensen, J.K., 1999. Intrusion-related gold deposits associated with tungsten-tin provinces. Mineralium Deposita 34, 323-334.

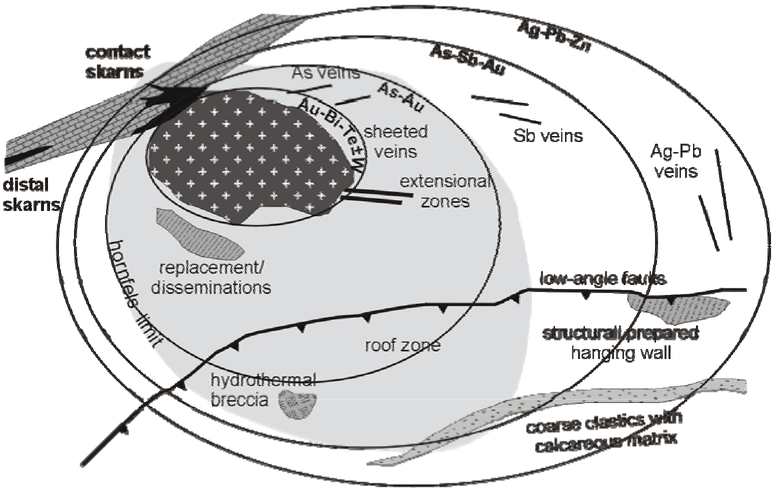


Figure 1 – General plan model of intrusion-related gold systems illustrating various mineralisation styles, locations and outward metal zoning. (Modified from Hart et al., 2002)

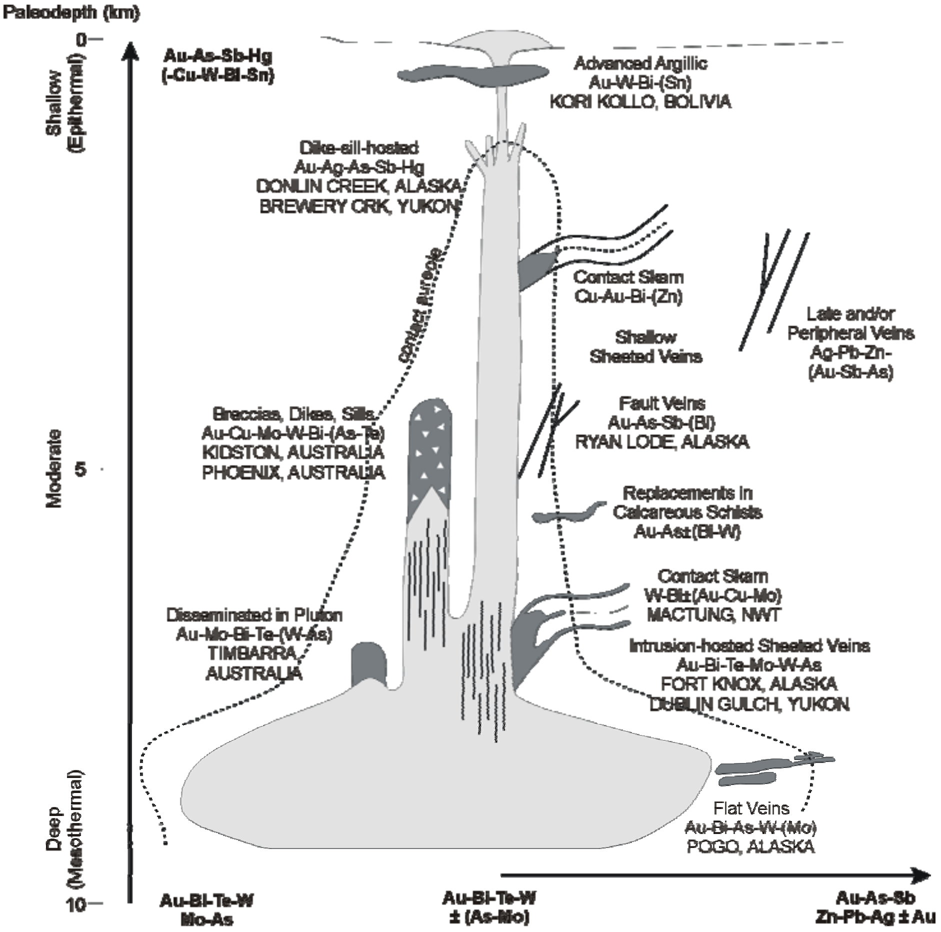


Figure 2 – Schematic model for intrusion-related gold systems showing lateral and vertical zonation in mineralisation styles, and interpreted position of the Phoenix Breccia. (Modified from Lang et al, 2000)

Figure 3 – Location of major gold deposits within the New England Fold Belt.

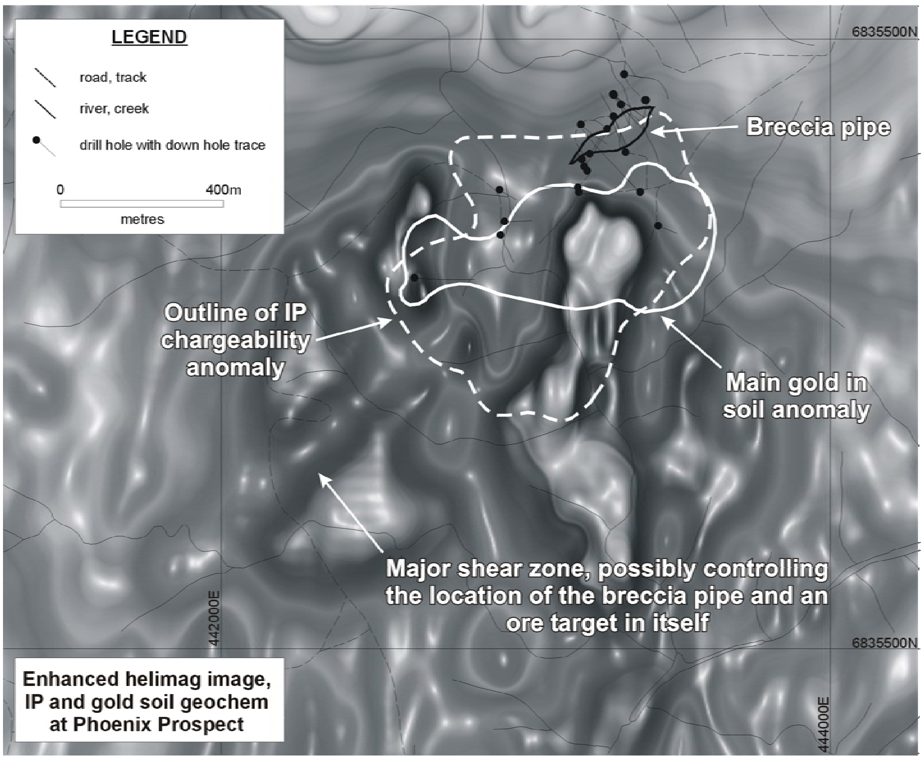


Figure 4 – Phoenix prospect plan map illustrating gold-in-soil and IP anomalies, location of the Phoenix Breccia and enhanced helimag response (lighter grey = low).

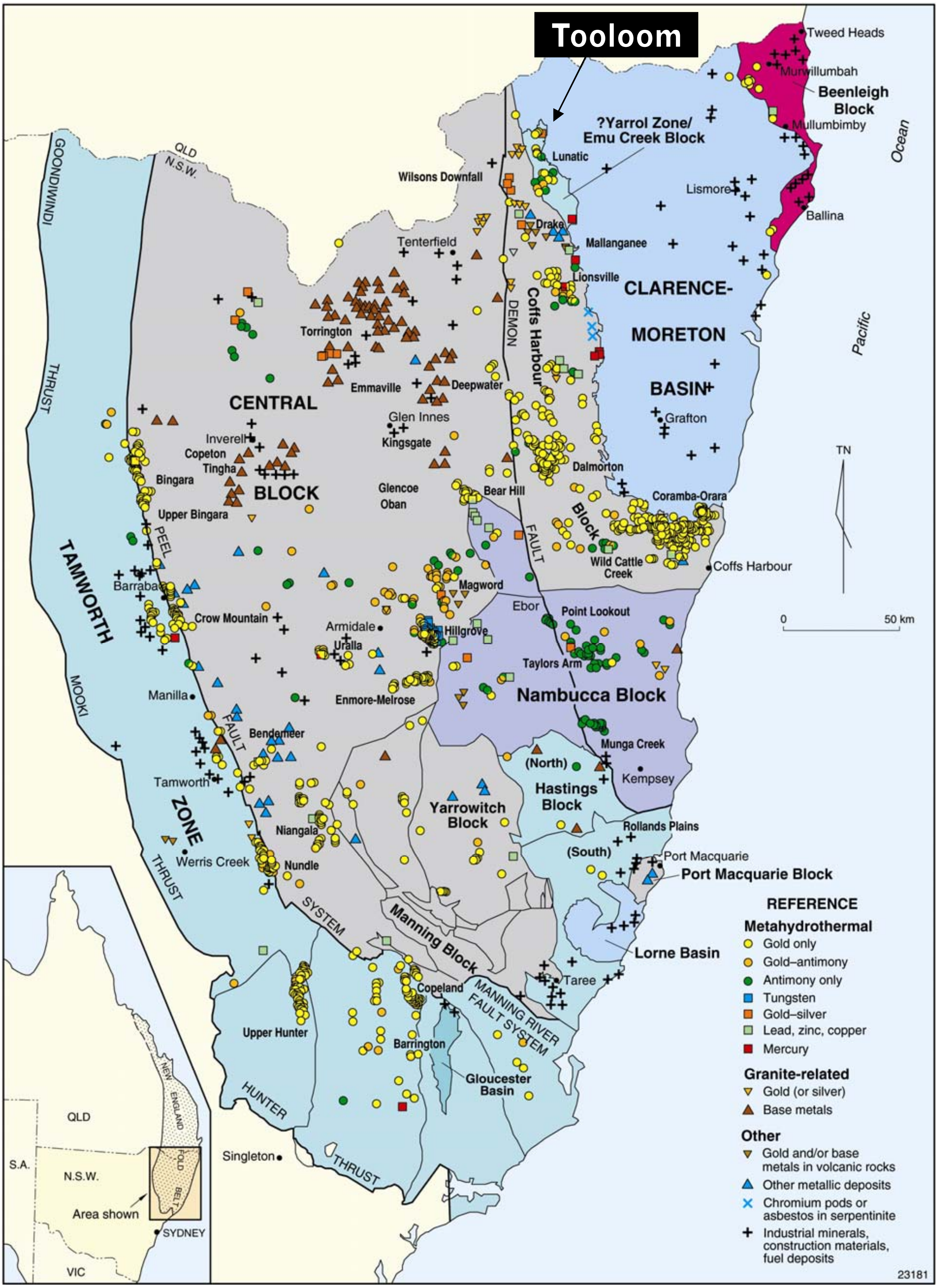


Figure 5 – New England Fold Belt showing mineral occurrences and location of the Tooloom Gold Project (Mineral occurrences map reproduced with permission from NSW Department of Mineral Resources Minfo Magazine).

Preliminary results from the Thomson-Lachlan Deep Seismic Survey, northwest New South Wales

R.A. Glen[1], R.J. Korsch[2], R.D. Costelloe[2], Y. Poudjom Djomani[1] & R. Mantaring[1]

[1] New South Wales Department of Primary Industries – Mineral Resources, PO Box 344, Hunter Regional Mail Centre NSW 2310
[2] Predictive Mineral Discovery Cooperative Research Centre, Geoscience Australia, GPO Box 378, Canberra ACT 2601

Background

The Thomson Orogen is one of the five orogenic belts that form the Tasmanides of eastern Australia (Glen 2005). Although it occupies a vast area of western and central Queensland, very little is known about the orogen since it is covered by recent sediments as well as by the Mesozoic Eromanga Basin. Regional gravity and aeromagnetic data, suggest that the Thomson Orogen also extends south into NSW, occupying the far northwestern part of the state between Tibooburra and northeast of Bourke. This frontier of NSW geology is the focus of investigation by the Geological Survey of NSW because of its possible mineral potential coupled with the presence of mafic to intermediate igneous rocks reported from drill holes around the village of Louth.

The metallogenic implications of a major east-west gravity high, curvilinear aeromagnetic highs and igneous rocks in the southern part of the Thomson Orogen, and relationships with the Lachlan Orogen to the south, were the focus of the 2005 Thomson-Lachlan deep seismic reflection survey that forms a key part of the New South Wales Department of Primary Industries (NSWDPI) Exploration NSW Initiative. Other partners in the project are Geoscience Australia and the Predictive Mineral Discovery Cooperative Research Centre.

Objectives & Aims of Project:

The seismic project had both economic and scientific objectives.

The economic objectives were:
- To investigate the potential for a new metallogenic province north of the Thomson-Lachlan boundary, characterised by possible arc and ocean-crust related gold and base metal deposits.
- To investigate the potential for Mississippi Valley style silver and zinc deposits along the margins of the Mt Jack High, south of the boundary between the orogens.
- To collect key new data on the Nelyambo Trough, a key Devonian basin, with hydrocarbon potential, immediately south of the boundary.
- To investigate the potential for new Cobar-style deposits south of the boundary and examine the linkage between the between the Lachlan and Thomson orogens and evolution of the Cobar Basin and its rich base metal and gold deposits.

Tectonic aims of the survey were to:
- Investigate the nature and location of the east-west boundary between the Lachlan and Thomson orogens in north central New South Wales.
- Establish whether this boundary was part of a complex Delamerian or Benambran convergent margin.
- Establish the crustal geometry of this boundary, and interpret it in terms of north-south (repeated) ?oblique collisions through the Palaeozoic.
- Examine the possible link between evolution of the Tasmanides and intracratonic deformation of the Alice Springs Orogeny.
- Interpret the source of the second highest gravity anomaly, with associated magnetic highs.

Three traverses were sited to cross a ‘simple’ east-west section of the southern Thomson Orogen, where it is marked by a major east-west gravity high and linear magnetic highs that extend as far south as the southern edge of the Thomson Orogen defined from gravity data. These traverses crossed the boundary with the Lachlan Orogen and into the Devonian Nelyambo Trough and the Mt Jack High to the south.

Coupled with existing drill core data and proposed new drilling to basement, the seismic reflection survey was designed to reveal critical data on the crustal architecture across this major tectonic boundary. This in turn will allow us to model the geological history of the adjacent parts of the two orogens. Defining the tectonic framework will enable metallogenic models of this region to be placed on a more sound footing.

Background Geology

Palaeozoic geology in the vicinity of the seismic survey is mostly concealed beneath thin cover of alluvium or the southern part of the Mesozoic Eromanga Basin. The geology of the Thomson Orogen and the Thomson-Lachlan boundary itself are inferred from aeromagnetic and gravity data, supplemented by very sporadic outcrop (mainly to the east in a structurally complex area between Louth and Bourke) and drill holes.

State-wide aeromagnetic and gravity data indicate a major and abrupt change in tectonic grain from north-south in the south to curvilinear east-west in the north. This change is inferred to represent the boundary between the Thomson Orogen and the Lachlan Orogen. It lies just south of the second highest gravity anomaly in NSW with its coincident, curved aeromagnetic linears. The similarity of the gravity responses north of this boundary with those of accreted gold- and copper-rich Ordovician Macquarie Arc sampled by seismic reflection profiling in 1997 and 1999 (Glen *et al*. 2002) suggests that the boundary may be a convergent margin, marked by the possible development of island arc and ocean crustal igneous rocks. The southern edge of this anomalous curvilinear east-west zone coincides with the inferred Olepoloko Fault (Stevens 1991) and the Louth-Eumarra Shear Zone (Glen *et al*. 1996).

Thomson Orogen:

The southern part and southern boundary of the Thomson Orogen have curvilinear east-west trends that are convex to the south. Gravity data show a three-fold broad subdivision into a northern high, a central low and southern high that decreases in intensity towards the Thomson-Lachlan boundary. The central low reflects the presence of Late Devonian strata in the Paka Tank Trough in the east and probable granites farther west. The southern high coincides with mafic to intermediate igneous rocks between Louth and Bourke in the east, and these rocks are also inferred to underlie the gravity ridge to the west. The southern flank to this high is underlain by sedimentary rocks, some possibly turbiditic.

Available drill hole data show that the igneous rocks include volcaniclastic sediments, mafic to intermediate volcanics, gabbros and ultramafics. At least some of these rocks, at Louth and at Mt Dijou and Bald Hills (which we here suggest lie just north of the Thomson-Lachlan boundary), have oceanic island basalt (OIB) chemistry (K. Dadd Macquarie University written comm.). Uncertain age data suggests a possible Ordovician age near Louth. Recently, late Early Ordovician conodonts have been identified from inter-pillow material at Bald Hills (I. Percival unpublished palaeontology report 2006).

Granites and calcsilicates in thermal metamorphic aureoles occur in the eastern part of Thomson Orogen (eg at Doradilla, where granite and a porphyry dyke have been both dated as Triassic by Lance Black, pers. comm.).

Key high-grade metamorphic rocks occur in a couple of localities: kyanite-bearing in the east and sillimanite amphibolite facies in the west.

A key point is that Late Devonian sedimentary rocks occur in both orogens. This implies that the two orogens were most likely assembled before deposition of these rocks, and that the last deformation is post Late Devonian, probably Carboniferous in age.

Known mineral deposits include Doradilla southeast of Bourke and those around Mt Dijou south of Bourke.

Lachlan Orogen:

The Lachlan Orogen near the seismic line has a four-fold stratigraphic subdivision (Glen *et al*. 1996).

- The youngest rocks are mid to Late Devonian continental sandstone, shale and conglomerate of the Mulga Downs Group. The thickness may approach 4km. This unit crops out in the Nelyambo Trough and also on the Mt Jack High.
- Below the Mulga Downs Group are latest Silurian to Early Devonian rocks of the Cobar Supergroup. These were deposited in the Cobar Basin and on two flanking shelves, the Kopyje Shelf to the east and the Winduck Shelf to the west. These sediments probably thin over the Mt Jack High.
- Basement to the Cobar Supergroup consists of three units: Silurian granites, Ordovician turbidites of the Girilambone Group, and in one locality in the southeastern part of the Mt Jack High, hornfelsed Late Ordovician graptolitic shale probably part of the Bendoc Group. Turbidites of the Girilambone Group are associated with local mafic volcanics; serpentinites also lie along major faults.

Seismic Acquisition

The seismic data were acquired in August-September 2005 along 3 lines using vibrator trucks as the energy source. The lines mostly followed shire roads and station tracks. The seismic acquisition was carried out by ANSIR: the National Research Facility for Earth Sounding, who provided the seismic equipment and expertise during field acquisition. ANSIR's facility manager, Terrex Seismic Pty. Ltd. conducted the field acquisition. ANSIR used an ARAM 24-bit 240 channel recording system in conjunction with three HEMI-60 (60,000 lb) peak force vibrators as the source.

An experimental program, designed to compare a number of source and recording parameters, was undertaken at the beginning of the survey. Experiments included monosweep and varisweep sweep configurations, different sweep frequencies, sweep length and source configuration. Several of the basic acquisition parameters, such as group interval, CDP fold, vibrator point interval and record length were selected from Geoscience Australia's experience of the previously acquired data in hard rock environments.

Seismic line 05GA-TL01, 99.2 km long, is oriented northeast-southwest and follows the northern bank of the Darling River. This line is entirely within the Lachlan Orogen and, for the most part, traverses the Nelyambo Trough and the Mt Jack High.

Seismic line 05GA-TL02, 115.5 km long, is oriented north-south and ties in with the northeast end of line TL1. It investigated the Thomson-Lachlan boundary. The line extends to the north to examine the magnetic and gravity high and the southwestern extension of the Paka Tank Trough.

Seismic line 05GA-TL03, 73.2 km long, is oriented north-south, and was planned to investigate the Thomson-Lachlan boundary and cross a narrow part of the Nelyambo Trough, to terminate on the Mt Jack High in the Lachlan Orogen. Drought-breaking rain resulted in the shortening of traverse 05GA-TL3 by approximately 8 km in the north.

A total of 288 km of 2D seismic data were thus collected.

Preliminary Geological Interpretation

05GA-TL01

- Mid to Late Devonian sedimentary rocks in the Nelyambo Trough thicken to the southwest, to a thickness of at least 6-7 km. This sedimentary package is cut by northeast dipping thrusts.
- The Mt Jack High is located further south than predicted from gravity data alone, and represent a complex thrust zone that cuts the mid-Late Devonian rocks.
- There is a highly reflective lower crust.
- The Moho is relatively flat at ~32 km.

05GA-TL02

- The Thomson-Lachlan boundary dips north and cuts through the entire crust.
- The Moho lies at a depth of ~32 km under the Lachlan Orogen, but is deeper (~48 km) under the Thomson Orogen. This raises the question as to whether the Moho has been downwarped or faulted.
- The seismic character of the crust is very different under the two orogens.
- There is up to 5 km of mid to Late Devonian sedimentary rocks in the Nelyambo Trough.

05GA-TL03

- The Thomson-Lachlan boundary is a major planar fault dipping to north and cutting deep into the crust.
- The Nelyambo Trough contains at least 5 km of mid to Late Devonian sedimentary rocks.
- A probable Early Devonian half graben lies beneath the mid to Late Devonian sedimentary rocks.
- The Mt Jack High is defined by northwest-directed thrusting over the Nelyambo Trough, which occupies a triangle zone between inwardly dipping thrusts.

Preliminary Tectonic and Economic Implications

1. The boundary between the Thomson and Lachlan orogens is a north-dipping fault zone/shear zone that cuts down through the crust. Latest movement was in the Carboniferous, part of the Kanimblan Orogeny, and related also to north-south shortening of the Alice Springs Orogeny.
2. North-south interactions between the Thomson and Lachlan orogens during the Palaeozoic were probably responsible for the north-south components of shortening and extension recorded in the Lachlan Orogen (Glen 2005).
3. Mid to Late Devonian strata in the Nelyambo Trough seem to be underlain by ?Early Devonian strata preserved in rift graben. These graben thin onto the Mt Jack High.
4. The Lachlan Orogen has a very reflective lower crust, which is not seen in the seismic lines in the Lachlan Orogen to the east (Glen *et al*. 2002), but is seen in the Eromanga-Brisbane seismic transect in southern Queensland (Finlayson *et al*. 1990). This raises the question as to whether the Girilambone Group is actually part of the Thomson Orogen.
5. The greater thickness of reflective lower crust (?mafic granulites) in the Thomson Orogen raises questions as to whether it was doubled up on the north-dipping bounding thrust? If so, this must have been in response to a collision to the north (in Southern Queensland).
6. At present, we are uncertain how much of the east-west gravity high in the Thomson Orogen is due to this thickened crust and how much to volcanics in the upper crust.
7. The OIB volcanics in the Thomson Orogen probably formed as seamounts on oceanic crust.
8. While the ultimate tectonic setting of the southern Thomson Orogen is still unclear, it may have constituted an east-west convergent margin towards which seamounts of different ages were being carried as a result of seafloor spreading.
9. Identifying this margin, any possible arc and the suture itself remain priority issues.

10. Economic targets include more Girilambone-style deposits associated with mafic to intermediate volcanic rocks in the southern Thomson Orogen, MVT type deposits on the flanks of the Mt Jack High and enhanced hydrocarbon prospects in anticlinal and other structures in the Nelyambo Trough.
11. The significance of the Doradilla style of deposits requires reinvestigation within the crustal architecture and tectonic framework derived from the deep seismic reflection data.

References

FINLAYSON, D.M., WAKE-DYSTER, K.D., LEVEN, J.H., JOHNSTONE, D.W., MURRAY, C.G., HARRINGTON, H.J., KORSCH, R.J. & WELLMAN, P. 1990. Seismic imaging of major tectonic features in the crust of Phanerozoic eastern Australia. *Tectonophysics*, **173**, 211-230.

GLEN R. A. 2005. The Tasmanides of eastern Australia. *In*: Vaughan A. P. M., Leat P. T. & Pankhurst R. J. *Terrane Processes at the Margins of Gondwana*. Special Publication of the Geological Society, London **246,** 23-96**.**

GLEN R. A., CLARE A. & SPENCER R. 1996. Extrapolating the Cobar Basin model to the regional scale: Devonian basin-formation and inversion in western New South Wales. *In*: Cook W. G., Ford A. J. H., McDermott J. J., Standish P. N., Stegman C. L. & Stegman T. M. *The Cobar Mineral Field - A 1996 Perspective.* Spectrum Series Australasian Institute of Mining and Metallurgy, Melbourne, **3/96,** 43-83**.**

GLEN R. A., KORSCH R. J., DIREEN N. G., JONES L. E. A., JOHNSTONE D. W., LAWRIE K. C., FINLAYSON D. M. & SHAW R. D., 2002. Crustal structure of the Ordovician Macquarie Arc, eastern Lachlan Orogen, based on seismic reflection profiling. *Australian Journal of Earth Sciences*, **49**, 323-348.

STEVENS B. P. J. 1991. Northwestern New South Wales and its relationship to the Lachlan Fold Belt. *Abstracts Geological Society of Australia,* **29**, 50.

The NSW Thomson Orogen Project: New Frontiers in Exploration

John Greenfield[1], Patrice de Caritat[2], Steve Hill[3], and William Reid[1]

[1]NSW Department of Primary Industries- Mineral Resources Division, Maitland, NSW
[2]CRC LEME, Geoscience Australia, Canberra, ACT
[3]CRC LEME, University of Adelaide, Adelaide, South Australia

Key Words: Thomson Orogen, Tibooburra, low-density geochemical survey, Eromanga Basin, regolith, mobile metal ions

Introduction

The Early Palaeozoic NSW Thomson Orogen is covered by a shallow blanket of Cretaceous Eromanga Basin. The orogen has untested potential for orogenic gold, arc-related polymetallic, and MVT base metal deposits. CRC LEME, in conjunction Geological Survey of NSW and Geoscience Australia, is conducting a multi-disciplinary study including regolith mapping and baseline geochemistry to help reduce risk for mineral exploration in this greenfields province.

Background and aims of the project

There has long been an awareness of the potential of the Thomson Orogen as a new metallogenic province. With the focus of the Geological Survey of NSW (GSNSW) now shifting to new frontiers and new provinces for mineral exploration, the opportunity has arisen to consolidate existing knowledge and collect new data to help better understand the Thomson Orogen, with the aim of opening up new opportunities for mineral explorers.

In conjunction with the GSNSW and Geoscience Australia, the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRCLEME) has undertaken a three year project (2005-2008) to provide regolith and baseline geochemistry coverage across the Thomson Orogen in NSW.

What and where is the Thomson Orogen?

The Thomson Orogen is one of the most poorly understood orogenic belts in Australia. It covers a vast area, mostly throughout south-central Queensland, but extends into northwestern NSW (Fig. 1). Named by Kirkegaard (1974) after the Thomson River in central Queensland, it is part of the greater Tasmanides of eastern Australia. New geochronology data suggest the Thomson Orogen has undergone a history distinct to the Lachlan Orogen (Draper, 2005). Neoproterozoic to Middle Cambrian sedimentation and ~ 500 Ma deformation recognized in the Thomson Orogen is more akin to the Kanmantoo and Adelaide fold belts. A felsic magmatic/volcanic event at ~470 Ma that is not recognized in the Lachlan Orogen, as well as an abrupt change in structural grain at the contact between the orogens suggests some differences in their early Palaeozoic histories (Draper, 2005). The orogens share a similar post-Middle Devonian history, with deformed orogenic rocks unconformably overlain by epicratonic Late Devonian infrabasins. The Thomson Orogen is in turn overlain by the Permian Cooper Basin and Mesozoic Great Australian Basin (which incorporates the Eromanga Basin).

The NSW Thomson Orogen Project area

The NSW portion of the orogen incorporates the entire southern margin with boundaries against the Delamerian and Lachlan orogens (Fig. 1). The exact boundary of the orogen is unclear and is interpreted from gravity and magnetic signatures, and thus the project area incorporates a buffer zone that takes in the Thomson Orogen margin and parts of the Lachlan and Delamerian orogens (Fig. 1). The area of interest for this project covers eleven 1:250 000 sheets: the entire Urisino, Yantabulla, Enngonia, Bourke, Louth, and White Cliffs sheets; and parts of the Milparinka, Cobham Lake, Walgett and Angeldool sheets.

Based on drilling and seismic data, the depth to pre-Mesozoic basement below sea level in the project area shallows irregularly from approximately 1050m in the northwestern corner to zero at basement exposures along the southern margin. For the majority of the project area, the interpreted depth to basement is a maximum of 250m (Packham and Jovenski, 2001).

Metallogenic Potential of the project area

In terms of the metallogeny of the project area, gold endowed Late Cambrian inliers exposed in the west of the project area (Tibooburra area) suggest that there is potential for orogenic gold mineralization. Limited drilling has revealed quartz veining in altered metasediments throughout the NSW Thomson Orogen, including sulfide mineralization associated with quartz veining in deformed phyllites on the Urisino 1:250 000 sheet.

The presence of basalts (with ocean island chemistry) and serpentinites in the project area (Louth Volcanics) suggest that the orogen has the potential to host arc and ocean-crust related gold and base metal deposits. Gold-base metal deposits around Mt Dijou, south of Bourke, and tin deposits associated with the Triassic Doradilla Granite are also within the interpreted Thomson Orogen boundary.

Project Methods

A prime objective of the project is to provide baseline geochemical coverage across the region. However, since the orogen is predominately covered by Mesozoic and younger sediments, it is essential to understand how basement mineralization may be geochemically expressed through this cover. To this end, the project is divided into three related modules:

a) Regolith landscape evolution

This research aspect, led by the CRCLEME team at the University of Adelaide, in conjunction with CRCLEME, attempts to shed light on the 3D landscape and morphotectonic evolution of the Mesozoic to Cainozoic cover rocks and regolith. To date, research has concentrated on the Tibooburra area because of the quality of basement and Mesozoic outcrops and the availability of known orogenic gold occurrences. This work provides a test bed for our knowledge of the regolith and geochemical responses throughout the Thomson Orogen.

b) Regolith mapping

Drawing on the more detailed mapping and research from the University of Adelaide and in-house expertise, GSNSW has developed a rapid, desktop-based regolith mapping technique that is being applied to the Thomson Orogen. The maps not only provide concise transport and compositional information, but also infer the provenance of the regolith materials, and therefore indicate a weighted likelihood of basement signature at the surface.

c) Baseline geochemistry

The low-density geochemical survey team is based out of Geoscience Australia in Canberra, working in conjunction with CRCLEME, and applies the methodology recently developed and tested in the Riverina region (Caritat *et al.*, 2005) and elsewhere. Sampling locations for the Thomson survey are guided by defining and prioritizing catchments across the project area. The main medium used for the survey is overbank sediments, taking a near-surface (0-10cm depth) and B-C horizon samples (10cm interval at ~60-90cm depth) from near the outlets or spill points in each catchment. This provides a well-sorted, fine-grained material broadly representative of major rock types outcropping or subcropping in the catchment, from a consistent sample medium.

Biogeochemical samples have also been collected at or near the overbank sample localities from a variety of plant communities including Black Box, Coolibah, Bimble Box and River Red Gum.

MMI Technologies, based out of Perth, have also kindly provided to prepare and analyse (through ALS Chemex) 100 free samples using their partial leaching technique. Using this technique, loosely-bound mobile metal ions (MMI) are separated and analysed from a near-surface soil sample (10-25cm depth), providing a window into possible metal sources at depth. It is thought that a combination of convection, capillary rise and evaporation (plus other possible mechanisms) causes upward migration of mobile metal ions from a metal-rich source such as an orebody, which result in a near-surface soil anomaly of loosely bound metal ions directly above the metal source (Mann *et al.*, 2005). This is the first time the MMI technique has been used in conjunction with a regional baseline geochemical survey, and the results should provide not just a test of comparability between the concentrations and distribution patterns obtained from the analysis of overbank sediments, plants and loosely bound metals, but also a better understanding of element sources, sinks and mobility in the project area and a regional context for more detailed future geochemical surveys.

Results and projected outputs

To date, the project has produced:

- Four research papers on the Tibooburra area (Davey and Hill, 2005; Gibbons and Hill, 2005; Hill *et al.*, 2005; Hill, 2005)
- One 1:25 000 regolith landform map (Mt Browne and Mt Poole inliers, in Davey, 2005)

- Two honours theses (Davey, 2005; Gibbons, 2005)
- Four 1:100 000 regolith provenance sheets (Tibooburra, Olive Downs, Milparinka, Yantara). These sheets have been submitted to cartography, and preliminary versions will soon be publicly available
- Collection and field portable XRF analysis of overbank samples from 76 catchment sites across the Thomson Orogen, plus about 80 gold and 40 fluorine analyses (standard XRF and ICPMS analyses are in progress at Geoscience Australia and ALS Chemex). Further sampling will be conducted in October 2006.

In the next two years, the outputs of the project will include:

- Two 1:25 000 regolith maps (New Bendigo Inlier, Warratta Inlier)
- At least two more honours theses
- GIS digital database release as DVD- including all geological, geochemical, geophysical and cadastral data available from the NSW Thomson Orogen, including all relevant reports and papers
- Explorers Guide- a practical guide to exploration techniques in the Thomson Orogen and far-western NSW.

References

Caritat, P. de, Lech, M., Jaireth, S., Pyke, J. & Lambert, I., 2005. Riverina geochemical survey – A National First. AusGeo News, 78, 6 pp. (June 2005). [http://www.ga.gov.au/image_cache/GA6632.pdf]

Davey, J. and Hill, S.M., 2005. Regolith and Landscape Evolution of the Mt Browne and Mt Poole inliers, WNSW. In: Roach, I.C. (ed.) Regolith 2005, CRC LEME Perth.

Davey, J., 2005, Geomorphology of a neotectonic intracratonic basin margin: the long-term landscape evolution and regolith geology of the Mt Browne and Mt Poole Inliers, northwestern New South Wales. BSc (Hons), Adelaide University.

Gibbons, S., 2005, Regolith Carbonates of the Tibooburra - Milparinka Region, Northwest NSW: Characteristics, regional geochemistry and mineral exploration implications. BSc (Hons), Adelaide University.

Gibbons, S. and Hill, S.M., 2005. Regolith carbonates of the Tibooburra-Milparinka region, WNSW. In: Roach, I.C. (ed.) Regolith 2005, CRC LEME Perth.

Hill, S.M., Chamberlain, T., and Hill, L.J., 2005. Tibooburra, western NSW. In: Anand, R. and de Broekert, P. (eds), Landscape Evolution Across Australia. CRC LEME, Perth

Hill, S.M., 2005. Far Western NSW. In: Anand, R. and de Broekert, P. (eds), Landscape Evolution Across Australia. CRC LEME, Perth

Kirkegaard, A.G., 1974, Structural elements of the northern part of the Tasman Geosyncline. In Denmead, A.K., Tweedale, G.W. and Wilson, A.F. (Editors): The Tasman Geosyncline: A Symposium. Geological Society of Australia, Queensland Division, Brisbane, 47-62.

Mann, A.W., Birrell, R.D., Fedikow, M.A.F., and Souza, H.A.F., 2005, Vertical ionic migration: mechanisms, soil anomalies, and sampling depth for mineral exploration. Geochemistry: Exploration, Environment, Analysis, 5, 201-210.

Packham, G.H., and Jovenski, A., 2005. Eromanga Basin Petroleum Data Package. 2nd edition, NSW Geological Survey Report GS2001/203.

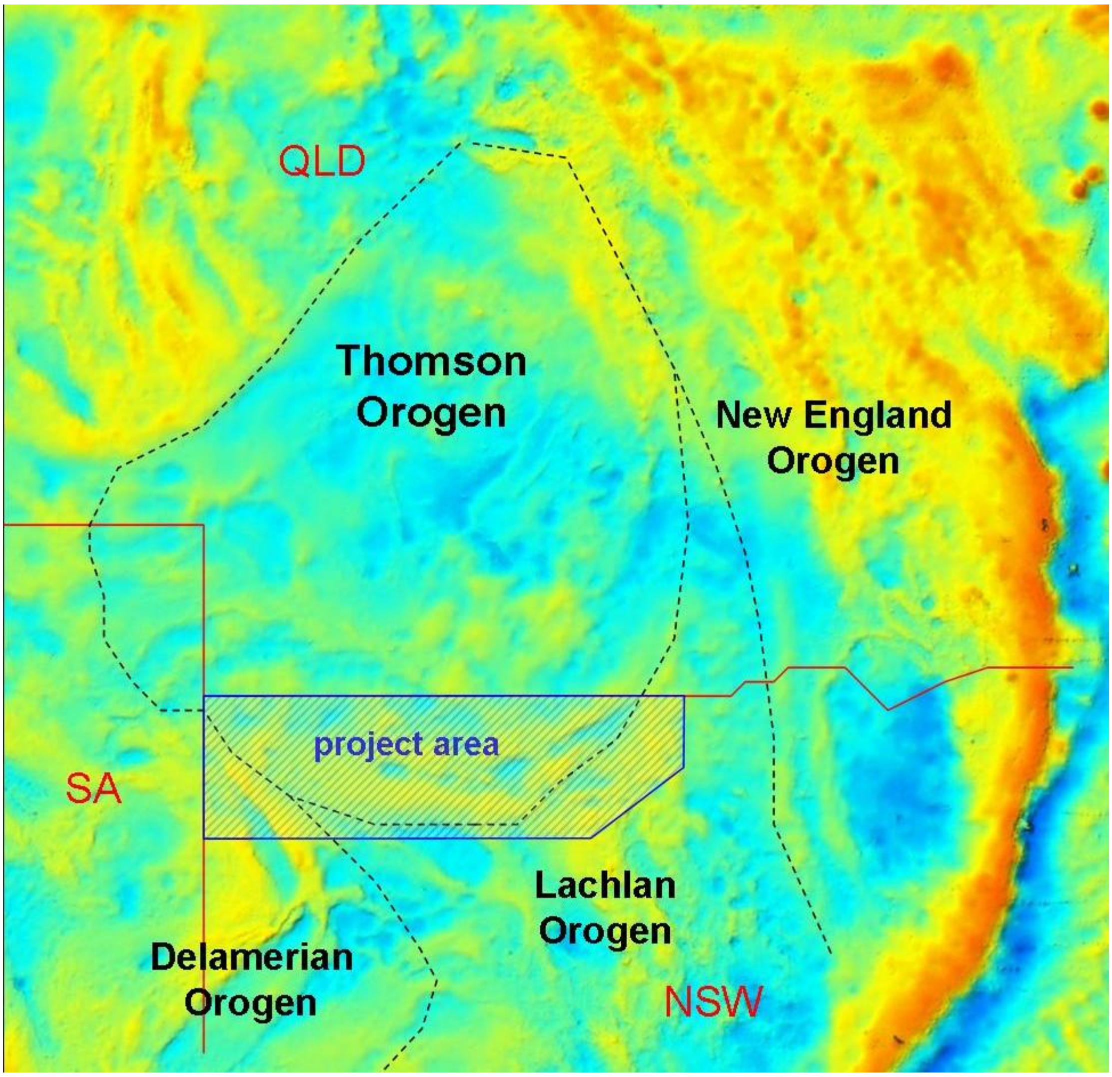


Figure 1. Locality diagram (superimposed on gravity image), showing the project area (shaded box) within the context of major orogen boundaries of eastern Australia (dashed lines), and state borders (lines). Note that state borders and orogen boundaries are approximate only.

EXTENSIONS OF THE BENDIGO AND STAWELL ZONES IN NEW SOUTH WALES

Michael Hallett

Geological Survey of NSW, 516 High St, Maitland NSW 2320

Key Words: geophysics, magnetic, gravity, tectonics, Murray Basin, Bendigo, Stawell, gold

Abstract

Interpretation of data from three new airborne magnetic and radiometric surveys in the Murray and Riverina regions of New South Wales has revealed many underlying bedrock features in a region covered by a blanket of Cainozoic sediments.

The new airborne magnetic data, in combination with regional gravity data contributes to a greater understanding of the geometry and evolution of basement geology through the definition of structural zones and defines major faults, granitic bodies, inferred basins and igneous centres. The magnetic and gravity data suggest that the Bendigo, Stawell and Glenelg structural zones defined in Victoria continue north into New South Wales and that the Tabberabbera Zone terminates at a Middle Devonian granite southeast of Hay. A new zone, named the Hay–Booligal Zone is interpreted to consist dominantly of Early Devonian volcanic sequences.

These new data suggest economic potential in the Murray–Riverina region in the form of orogenic gold associated with an extension of the gold-rich Bendigo Zone from Victoria under the Murray Basin in New South Wales. The extension of the Stawell Zone into the Murray region of New South Wales suggests the possibility of orogenic gold associated with tholeiitic basalt domes in the aureoles of granites.

References

Brown, C. M. and Stephenson, A. E., 1991. Geology of the Murray Basin southeastern Australia. Bureau of Mineral Resources, Bulletin 235, 430pp.

Cameron, R. G., 1996. Pooncarrie 1:250 000 geological map, Geological Survey of New South Wales, Sydney.

Cameron, R. G., 1997. Booligal 1:250 000 Geological Sheet, SI/55-5. Geological Survey of New South Wales, Sydney. ISSN 1326-8872.