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PREFACE

The Cobar region is a major metallogenic province within the Lachlan Fold Belt and remains highly prospective for further discoveries of significant mineral resources. Exploration in this region has been hampered by a complex regolith, with deep weathering and extensive transported cover components, as well as by the style and geometry of the deposits. This workshop aims to bring together geoscientists with knowledge of the region to present, discuss and exchange current ideas and experiences on the most effective approaches to exploration. The workshop will also showcase some of the results from the almost completed Girilambone (Cobar-Bourke) Project. This joint study by the Cooperative Research Centre for Landscape Environments and Mineral Exploration and the New South Wales Department of Mineral Resources has investigated the regolith and its geochemistry in the previously poorly known Girilambone terrain to the east of Cobar.

A workshop format has been deliberately chosen to promote free and informal discussion. A large component of the workshop will be conducted in the field. The program will include an initial presentation session outlining the geological and regolith setting of the region followed by a half-day field trip to examine regolith materials, landscape features and exploration issues. There will then be a full day of presentation and discussion sessions based on the themes of exploration techniques and approaches and exploration case studies. This will be followed by a one-day field trip across the Girilambone terrain examining sites investigated by CRC LEME and the NSW DMR.

The organising committee would like to thank the CRC LEME, the Cobar Branch of the AusIMM and SMEDG for underwriting the workshop. We also thank the corporate sponsors for their support as well as the presenters and attendees who will guarantee the success of the workshop. Thanks also to the various other people who have helped out behind the scenes. Particular thanks to Jenna Leonard who helped with compilation of the Proceedings volume.

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THE SURFACE GEOCHEMICAL EXPRESSION OF CONCEALED MINERALISATION, TRITTON COPPER DEPOSIT, GIRILAMBONE DISTRICT

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INTRODUCTION

The Tritton Copper Deposit is located in the Girilambone District of New South Wales, in the central western portion of the Lachlan Orogen and at the eastern margin of the Cobar Basin. Tritton is 24 km south-west of Girilambone, which is approximately 620 km northwest of Sydney and 44 km from the town of Nyngan at 31°24'S and 146°43'E. Copper and gold mineralisation is hosted by metasediments of the Girilambone Group of Ordovician age, with other known deposits occurring elsewhere in the region at Girilambone, Hermidale and Tottenham. A resource of up to 9 Mt of ore has been identified by deep diamond drilling, conducted by previous co-owners, Nord Pacific Limited and Straits Resources Limited. Mining and development of the Tritton copper resource is underway under the direction of present owners and operators, Tritton Resources Limited.

The present study examines the surface geochemical expression of mineralisation over the concealed Tritton Copper Deposit in regolith relatively undisturbed by prior mining activities. It is in effect a retrospective study granted that the position of sulfide mineralisation at depth has been well defined by exploration and resource delineation drilling. Previous geochemical investigations utilising samples from RAB drilling, vacuum drilling and soil surveys have identified spurious anomalous zones and failed to identify a convincing surface geochemical expression of the Tritton Copper Deposit. This study reports the multi-element geochemical expression of concealed mineralisation obtained by analysis of residual soils across the up-dip and up-plunge extension of known mineralisation and discusses the implications for geochemical exploration in the Girilambone district.

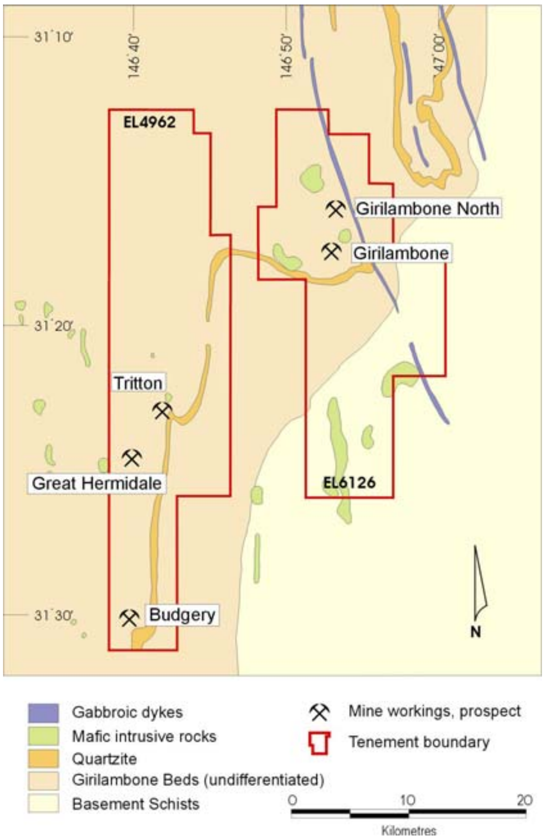

Figure 1. Regional geological map of the Tritton area.

GEOLOGY, MINERALISATION AND REGOLITH SETTING

Tritton lithologies include strongly foliated, bedded and laminated quartz to quartzo-feldspathic sandstone, quartzite, shale, phyllite, chert and a number of small mafic volcanic units, and intrusive rocks (Figure 1). A series of late-stage Silurian to Devonian gabbroic dykes cross-cut other Girilambone lithologies in a NW orientation and low-grade metamorphism has resulted in low to moderate greenschist facies assemblages, with abundant chlorite, muscovite, sericite, quartz and minor epidote (Fogarty, 1998).

Mineralisation at Tritton occurs in three zones, upper, central and lower, which are continuous for up to 450 m in strike length, up to 35 m wide and open at depth below 1000 m (Fogarty, 1998). The mineralisation strikes at approximately 028°, dips to the east at 20° to 70° and plunges to the south. Mineralisation of the upper zone is hosted by and wholly within a quartzite unit which continues to surface level, although the upper-most extent of mineralisation reaches to approximately 180 m below the present land surface (Figure 2). Primary mineralisation consists of massive pyrite and chalcopyrite, occurring as pipe-like massive sulfide zones, similar to the steeply dipping structurally controlled primary metal sulfide deposits of Girilambone and Girilambone North. Unlike the nearby Girilambone deposits, no secondary mineralisation is developed within the weathered profile of the Tritton Copper

Deposit. Grades vary within the Tritton deposit, with Cu grades in the upper zone generally quite high at approximately 5% Cu (and locally up to 20 - 30 % Cu), and 1% Cu in the parts of the lower zone. Chlorite, carbonate and epidote alteration assemblages are common throughout the Tritton deposit, with siderite alteration in the hanging wall closely associated with sulfide mineralisation (Berthelsen, 1998). To date a reserve of 4.383 Mt at 3.1% Cu, 0.23 g/t Au and 9.93 g/t Ag has been delineated.

The Tritton area landscape is one of low relief within an erosional regime. Outcrop is scarce and is typically weathered quartz greywacke and quartzose schists, the occurrence of which is limited to a series of north-trending silicified ridges and dendritic ephemeral drainages. A thinly developed surface cover of locally derived transported soil has developed over a truncated weathering profile, which extends up to 100 m from the surface. Minor gossan preservation is apparent approximately 800 m to the north of Tritton in the vicinity of the historic Budgerigar mine site.

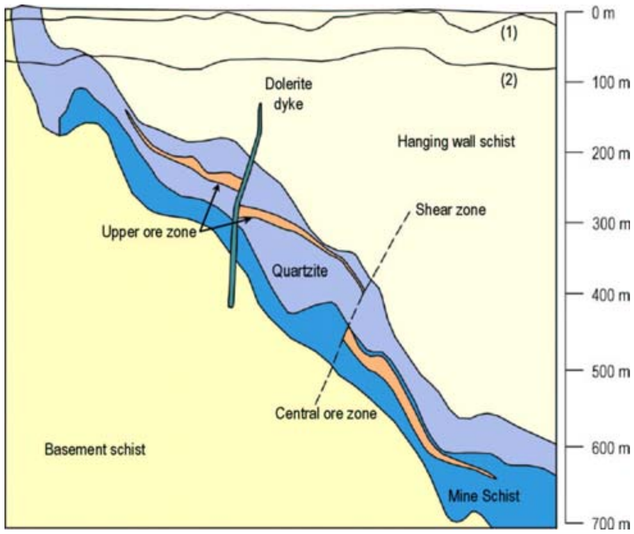

Figure 2. Schematic geological cross section of the Tritton prospect, looking NE. (1) and (2) refer to the base of complete oxidation and top of un-weathered rock respectively. (After Fogarty, 2001).

SOIL GEOCHEMICAL SURVEYS

Residual soils were sampled from three survey lines traversing the up-dip and up-plunge extension of Cu mineralisation. Samples were obtained from the residual C-horizon at depths of 0.2 to 1.3 m at closely spaced intervals of 40 m centred on the vicinity of known mineralisation and at intervals of greater than 80 m extending to 'background' areas for a total traverse length of up to 2500 m (Figure 3). A reasonably extensive angular quartz lag layer was observed at depths of 0.3 m or more, below which bulk samples were collected, and provided a common horizon for sampling of equivalent soils across the sampling traverses. A fine (<63 μm) and coarse (<2 mm) fraction were analysed by Instrumental Neutron Activation Analysis (INAA). Previous sampling of B-horizon soils was conducted by former owners, Nord Resources, over two lines (29200 N and 29300N) and were analysed by various 'total' analysis and proprietary methods, Regoleach and DeepLeach. Table 1 summarises the various geochemical data, soil size fractions and respective analysis methods for all soil geochemical surveys of the Tritton deposit. In total, 107 soil samples were collected, analysed and compared with previous soil geochemical surveys and sampling conducted in conjunction with the current study by Nord Resources.

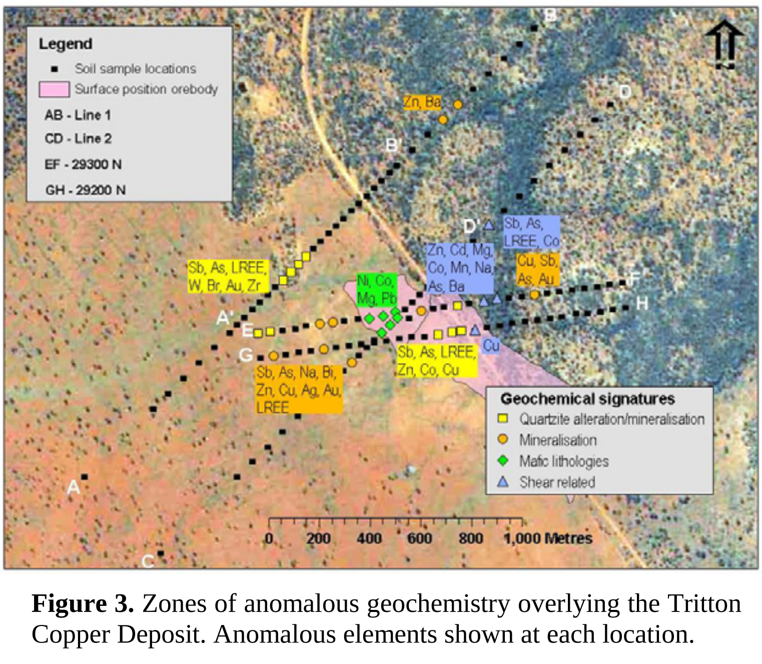

Figure 3. Zones of anomalous geochemistry overlying the Tritton Copper Deposit. Anomalous elements shown at each location.

Figure 3 shows three zones of anomalous geochemistry identified from soil geochemical surveys of the current study and previous soil geochemical investigations. Elevated response for the elements Sb, As, LREE, W, Br, Au, Zr, Zn Co and Cu were identified in areas of quartzite outcrop in the up-dip and up-plunge extension of known mineralisation. Similarly, several sites near to the up-dip western extent of the upper ore lens exhibit anomalous Sb, As, Na, Bi, Zn, Cu, Ag, Au and LREE. Lines 29300 N and Line 2 show an increased response for the elements Ni, Co, Mg and Pb which are thought to relate to mafic lithologies which cross cut the upper zone of mineralisation.

Table 1. Soil sampling, sample fraction and geochemical analysis method by sample traverse. Samples collected as part of the current study are indicated by bold type for Line identification.

Line ID	No. of samples	Fraction	Lab	Analysis Methods
29200N 29300N	30 30	<5 mm, B-horizon	ALS Chemex, Orange	Aqua Regia digest, ICP-AES, Deep Leach 2 & 11
29300N	30	<5 mm, B-horizon	ALS Chemex, Orange	Regoleach
29300N	30	<5 mm, B-horizon	ALS Chemex, Orange	Aqua Regia digest, AAS
29300N	30	<5 mm, B-horizon	ALS Chemex, Orange	HCl digest, ICP-AES
Line 1 **Line 2**	21 21	< 2mm, C-horizon	ALS Chemex, Orange	Aqua Regia digest, AAS
Line 1 **Line 2** **29300N**	12 38 31	< 2mm, C-horizon	Becquerel Laboratories, Lucas Heights	INAA
Line 1 **Line 2** **29300N**	38 38 31	<63 µm, C-horizon	Becquerel Laboratories, Lucas Heights	INAA

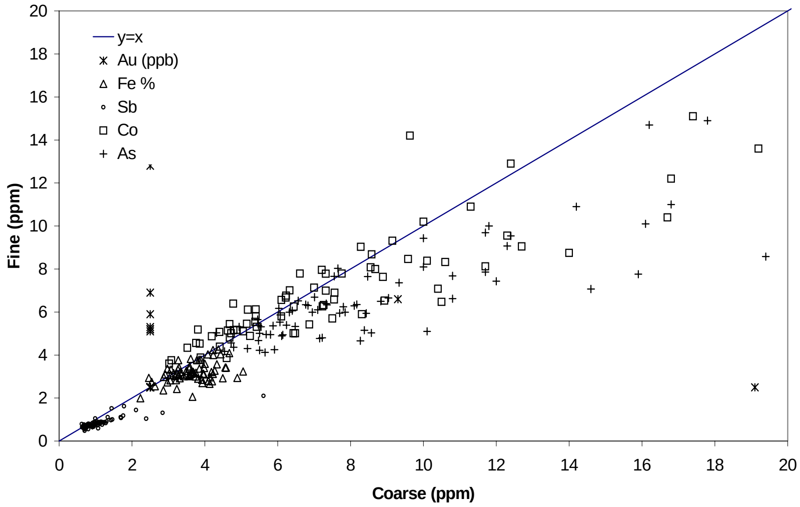

Figure 4. Coarse versus fine fraction geochemical response for selected elements.

Figure 4 shows the elemental response for selected indicator elements determined by INAA for coarse and fine fraction soils. An increased response for the ore-related elements was identified for the coarse fraction (<2 mm) over the fine fraction (< 63 um) which may indicate a dilution effect from finer material such as clays, fine quartz particles or aeolian material. Tate *et al.* (this volume) have noted the influence of aeolian material in this region, thus geochemical determination of fine fraction soils may give a diluted result.

WEATHERED PROFILE GEOCHEMISTRY

In addition to soil sampling, regolith and unweathered rock were sampled from RC drill chips and diamond drill core from exploration, resource and metallurgical testing drill holes. This enabled detailed investigations of regolith, lithology, ore-forming processes and metamorphic alteration to be conducted. Four main lithology types, quartzose, chloritic, mafic and sulphide mineralised, were recognised in the Tritton drill hole samples. Each of these lithologies displays characteristic geochemical signatures which, once identified, were used to determine the origin of anomalous surface geochemistry.

Geochemical and petrographic analysis of primary mineralisation has revealed primary chalcopyrite-pyrite mineralogy with increased geochemical response in the elements Cu, S, Fe, Co, Au, Zn, Sb, As, Mo, Se and Ag, with a lesser response for the elements Te and W. Strong leaching has removed most ore-related elements from the weathering profile, which has been partially truncated by more recent erosion since the time of regolith development.

Of the elements identified from soil geochemical investigations as being anomalous, the elements La, Sm and Eu (LREE) and Ba, Br, Na, W and Zr were found to represent a lithogeochemical signature of outcropping quartzite rather than a mineralisation signature. Furthermore, enrichment of REEs are observed to be a function of regolith processes rather than alteration related to mineralisation or rock-forming processes.

CONCLUSION

Previous surface geochemical investigations of the Tritton Copper Deposit have failed to identify a convincing surficial signature of concealed mineralisation. However, this study has identified anomalous Sb, As, LREE, W, Br, Au, Zr, Zn, Ag, Na, Bi , Co and Cu contents in the up-dip and up-plunge extension of the upper zone of copper sulfide mineralisation by geochemical analysis of residual soils. A second soil geochemical anomaly characterised by anomalous Ni, Co and Mg was identified directly above deep-seated Tritton mineralisation and may be related to a series of cross-cutting mafic dykes which intersect the upper and central zones of mineralisation. A known association of mafic bodies with Cu sulfide mineralisation is recognised from this and other deposits, thus providing a secondary indicator suite of elements for geochemical exploration of primary Girilambone-style Cu mineralisation. Investigations of the Tritton lithologies in the weathered and unweathered portions of the profile identified anomalous concentrations of LREE, Ba, Br, Na, W and Zr related to lithological variations rather than mineralisation. Thus, the mineralisation is identified in residual soils by anomalous concentrations of the elements Sb, As, Bi, Cu, Au and Zn.

Comparisons of various soil size-fractions used for geochemical analysis revealed an elevated response in the coarse fraction (<2 mm), which suggests the use of the coarse fraction would be favourable for maximising the geochemical response and reducing dilution associated with finer fractions.

Although previous geochemical investigations found similar chemical associations, in those studies it was unclear whether the apparent anomalism was related to mineralisation, lithology, local structure or due to random variation (Rutherford, 1998). The extension of sampling traverses up to 2.5 km in length has shown that the anomalism identified by this and previous studies is confined to areas of known mineralised locations and can hence be considered to represent mineralisation.

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EXPLORATION IN THE COBAR GOLD FIELD: A 2004 PERSPECTIVE

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INTRODUCTION

The Cobar Gold Field (CGF) has been defined as a 10 kilometre long belt of historical workings and mines, which extends northerly from the Peak Mine (southeast of Cobar) to the Tharsis workings (north of Cobar). The Gold Field occurs on the eastern margin of the Devonian Cobar Basin and has produced in excess of 2.75 million ounces of gold and 200,000 tonnes of copper since mining commenced 134 years ago. (Stegman, 1996) The ore bodies currently being mined within the Cobar Gold Field by Peak Gold Mines Pty Ltd include New Occidental, New Cobar and Perseverance.

After the sale of Peak Gold Mines Pty Ltd by Rio Tinto to Canadian based gold mining company Wheaton River Minerals, exploration in the Cobar Gold Field and within 100 km of the Peak mill received renewed focus. This paper aims to identify the key features of the known ore deposits within the Cobar Gold Field and describe how similar deposits could be discovered.

TARGETING PARAMETERS

Mineralisation style

The Cobar Gold Field deposits comprise a complex overprinting system of pyrrhotite, vein silica and chlorite alteration associated with mineralising brittle and ductile events. Deposit styles range from being gold rich and relatively base metal poor veins systems at New Occidental to gold, silver and base metal (Cu, Pb, Zn) rich silica veins and vein sulphide at Peak and Perseverance deposits. A number of orebodies, such as the New Occidental, New Cobar, Chesney, Great Cobar and Gladstone outcrop, while others exhibit geochemical or geological expressions at surface but the orebodies themselves are concealed i.e. Peak ~250m and Perseverance at ~900m.

Table 1. Comparison of metal content and mineralisation style of deposits within the Cobar Goldfield (adapted after Stegman, 2000)

	New Occidental	Peak	New Cobar	Great Cobar	Chesney
Bismuth	1200ppm	20-50ppm	100-200ppm	20-50ppm	100-200ppm
Copper	0.1%	0.7%	0.65%	2.5%	1.5%
Lead	0.1%	1.0%	<0.1%	<0.1%	<0.1%
Zinc	0.1%	1.0%	<0.1%	<0.1%	<0.1%
Fe sulphide	<1%	>5%	2-5%	2-5%	2-5%
Magnetite	<0.1%	Absent	1%	1-2%	1%
Geophysical Signature	Strong IP, airborne magnetic, DHEM	Adjacent to large magnetic response from pyrrhotite at Deep Whip, but non magnetic, IP, DHEM	Moderate airborne magnetic, IP, DHEM	Very strong airborne magnetic, IP, DHEM	Discrete airborne magnetic, IP
Ore style	Cryptocrystalline silica veins with minor overprint of sulphide (Gossan Lens)	Massive sulphide, sulphide and silica Au +/- Cu veins	Crustiform quartz-magnetite veins, quartz breccias with overprinting chalcopyrite	Late quartz-magnetite veins with overprinting quartz breccias, chalcopyrite, sphalerite and galena.	Early quartz-magnetite in eastern gold lode, quartz breccia with vein style chalcopyrite and pyrrhotite in Main Lode

Mineralisation within the Cobar Gold field is typically concentrated along or in close proximity to major north-north west trending faults. These include the Peak shear system, the Great Chesney Fault, the Great Cobar Fault and the Queen Bee Fault. Historically, exploration has been concentrated along these structures.

Orebody size and orientations

The known economic orebodies have a variety of sizes and shapes, however the footprint of the ore bodies have several common features. The bodies are generally extensive in the vertical direction while the horizontal extent is usually limited to a strike length of between 250 metres (New Occidental) and 400 metres (Perseverance/ Great Cobar).

Table 2. Cobar Gold Field orebody dimensions

Orebody	Horizontal extent	Vertical Extent
Peak	~300m	750
Perseverance	~350 - 400m	750 (open)
New Occidental	250m	1200m
Chesney	300m	950m
New Cobar	350m	800m
Great Cobar	350 - 400 m	1000m

Signatures

- *Geochemical – Au Bi Cu Pb Zn*

Early gold mineralisation at New Cobar, Peak and Perseverance and to a limited extent, New Occidental is strongly associated with, but partially correlated to the later introduction of copper. There is also a partial, but compelling correlation between bismuth and gold as well as bismuth with copper - silver. The exception to this is at New Occidental where the gold – bismuth correlation is strong while the gold – copper, copper – bismuth correlation is much weaker. This suggests that at an orebody scale, it is possible that a later bismuth mineralising event remobilised earlier gold, and both were remobilised by an even later copper - silver event. (Gatehouse, 2001). Late lead and zinc mineralisation occurs at most of the Cobar Gold field deposits, but generally in minor amounts (Table 1). Geochemistry from RAB samples over the CGF is dominated by **Au, Cu,** Pb, Zn, W, Mo trends between New Occidental and Fort Bourke (Great Chesney Fault), while the Peak – Comstock zone is characterised by **Au, Bi, Cu,** Pb, Zn, Ag, Mo. (Arundell, 2001); key elements in bold

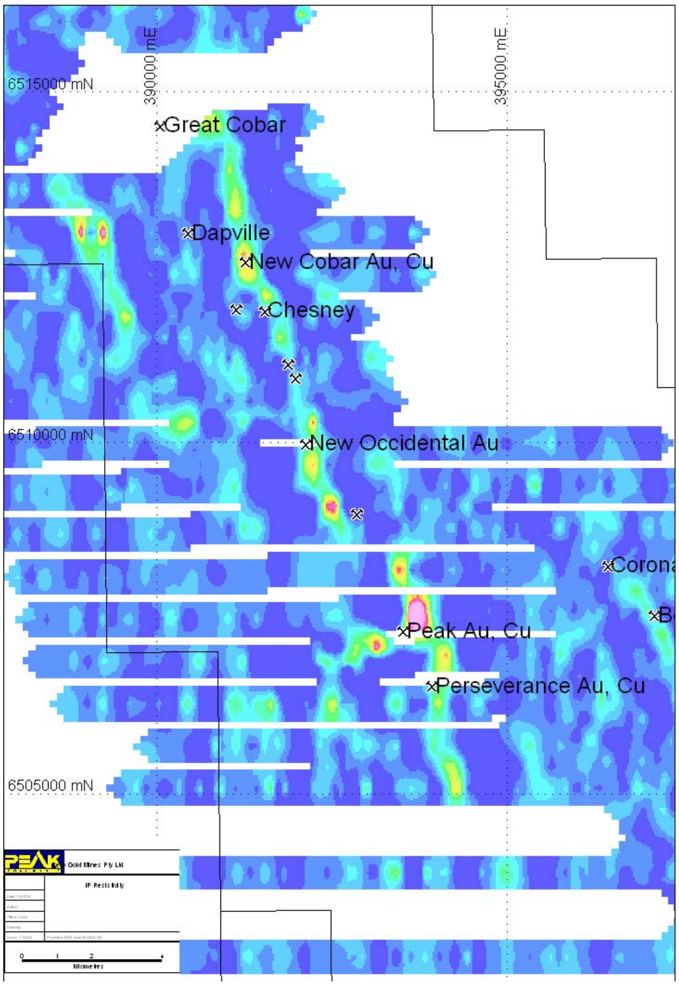

Figure 1. Regional IP and Cobar Goldfield Mines.

- *Geophysical – IP, Mag, Gravity, EM*

Most of the Cobar goldfield deposits exhibit significant magnetic anomalies in airborne surveys. At a local scale the source of the magnetic minerals differ between deposits. At New Cobar and Chesney, primary magnetite occurs closely associated with early gold deposition, while at Peak and Perseverance there is a spatial relationship between pyrrhotite and gold – copper ores.

As an exploration tool, IP provides a good vector to mineralised structures (Figure 2). South of Peak mine the major mineralising structures are defined by significant pyrrhotite alteration which is clearly visible as magnetic highs. However, sulphide alteration exclusive of significant pyrrhotite is also clearly visible in the regional IP dataset.

Terrain corrected gravity appears to provide direct detection of sulphide-bearing ore bodies and ore zones. The gravity response is also strongly influenced by silicification and other lithological characteristics. This makes it useful as a mapping tool particularly for defining zones of silicification in areas of thin cover. One may also argue that if significant silicification were present, the rock would be resistive to weathering and outcrop i.e. The “Peak” hill, New Occidental, New Cobar.

Electromagnetic techniques are an important part of exploration within the CGF. Surface EM techniques have historically been unsuccessful due to a highly conductive “overburden” found over most of the Cobar area. Peak Gold Mines has trialled, with mixed success, CSAMT (controlled source audio magneto telluric) over the CGF deposits from south of Perseverance to the north of New Cobar. This technique has successfully delineated the known deposits, however anomalies generated by the technique have not translated into significant mineralisation to date. Down hole surveying, however, has been very successfully as an exploration technique. The early understanding of the Perseverance orebody was largely due to DHEM. Each deep diamond drill hole drilled from surface was DHEM surveyed and provided direct vectors to the separate lenses at Perseverance. More recently, a DHEM anomaly detected below the current Peak orebody teased geologists for several years until 2003 when PK83 was drilled. The hole intersected some 7m true width of the down dip extension of the Western Lead-Zinc lode (0.24g/t Au, 0.6% Cu, 4.3% Pb, 7.4% Zn and 9.4 g/t Ag), and 5m true width of visible gold grading 114 g/t Au (screen fire assay). In all, three DHEM surveys over a period of 4 years were combined to locating this ore zone.

- *Geology, Stratigraphy, Structure*

There have been several studies and papers written on the general geology of the Cobar Goldfield. Stegman and Pocock, 1996, Hinman, 1992 and Cook, 1996 provide a solid background to the geology. It is not intended to reproduce that information here, rather to emphasise the empirical relationships observed between stratigraphy and structure that can assist exploration at a local (mine) and a regional (basin wide) scale.

Regional structural controls together with stratigraphy play key roles in the formation of Cobar Goldfield style deposits. Some of the key features of the deposits can be explained by a combination of structural and stratigraphic/lithological controls. This includes the northerly plunge of the ore zones and the margins of economic mineralisation, both up and down plunge within the plane of the host shear. The plunge is parallel to the S2 stretching lineation (Stegman et. al., 1996, Broadbent, 2001), implying dip-slip displacement along the host shears. The relative displacement of stratigraphy along individual structures also appears consistent with dominantly dip-slip movement. The position of the deposits along the shears is strongly controlled by dilation due to competency contrasts. Simply, there are two styles of competency contrast controls observed in the CGF: sediment-sediment (sandstone against siltstone); and sediment-rhyolite. Each of the goldfield deposits has it own unique combination of the two. In a broad sense, it is this rheological contrast that controls the vertical extents of each deposit as well as their position along the shear. A shallow southerly pitch of stratigraphy against the shears appears to control the vertical extents of economic mineralisation. At Peak, the pitch is 18° progressing to 45° at Perseverance Zone A, then steepening to 70° south of Perseverance Zone D. At Peak and Perseverance the position of the rhyolite, which on a local scale is sub-parallel to stratigraphy, provides excellent competency contrast and complex geometries producing high grade gold mineralisation.

Detailed knowledge of the stratigraphy of the Chesney Formation and to a lesser extent, the Great Cobar Slate is required to understand the stratigraphic controls. The Chesney formation (DNC) is divided into 4 main groups (DNC 1 through DNC4). DNC1, also known as the transition unit is a laminated siltstone and is defined at the first occurrence of thin sandy beds. DNC2 is the first occurrence of thickly bedded sandstones, while DNC3 is generally poorly bedded siltstones with minor sandstones. DNC4 is a thickly bedded unit of sandstones and is locally conglomeratic around the Queen Bee area. The Great Cobar Slate (DNG) is a thick sequence of poorly bedded siltstones, however, in the New Cobar area where the geology is better known, a poorly bedded sandstone unit (Western Sandstone member, DNGS) intersects the New Cobar mineralisation. While there are differences between all the deposits, the common constraint is either a competent sandstone unit (DNC2, DNGS) or the Peak Rhyolite.

Without exception, all of the CGF deposits have very deep mineralised roots. For example, deep drilling at New Occidental has intersected highly altered and mineralised zones at depths greater than 1200 metres from surface. This seems to suggest that mineralising fluids have all been sourced vertically rather than laterally.

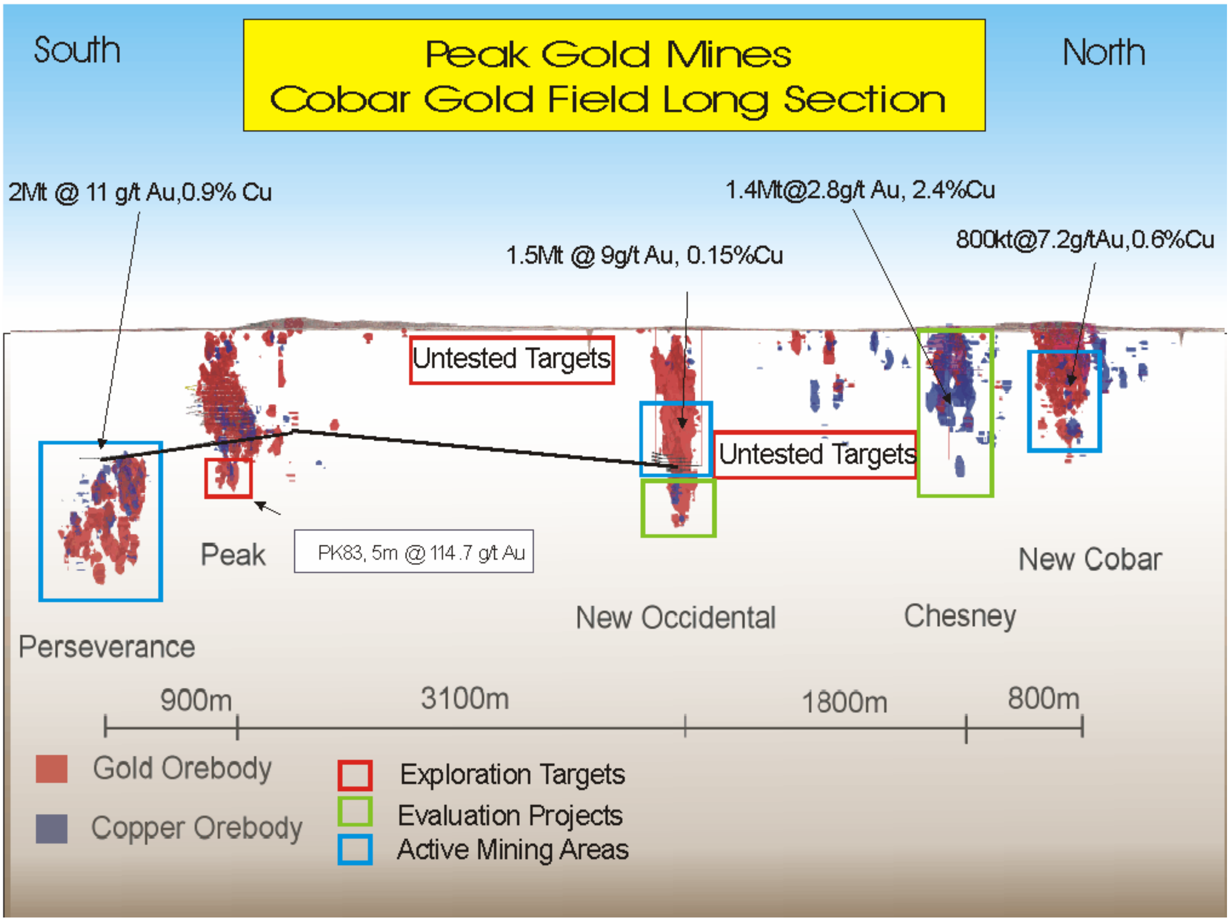

Figure 2. Longsection of Cobar Goldfield Deposits from Perseverance to New Cobar.

STRATEGY

During the last 12 months our exploration strategy has been to maintain a three-tiered approach. Firstly, known deposits have been evaluated by more closely spaced drilling: in the case of New Cobar, this work has led to a feasibility study with a plan to develop the project in 2004. Perseverance “Zone D” drilling has continued to a point where an inferred resource of 1Mt @ 12.4 g/t Au and 0.6% Cu has been outlined to date. This has increased the global resource of Perseverance to 2Mt @ 11g/t Au and 0.9% Cu. New Occidental Deeps and Chesney are currently being evaluated; encouraging results have been returned

Known mineralisation and other historic workings within the goldfield are being revisited. Deposits such as Great Cobar, Gladstone, Dapville, Queen Bee and Young Australia are being studied to outline opportunities for further economic discoveries within striking distance of existing underground development.

Further afield, the Queen Bee fault and Rookery Fault systems are being reviewed with the knowledge gained and data collected from many years of exploration within the Cobar Basin.

CONCLUSIONS

Cobar Goldfield deposits are elongate down dip with a general northerly plunge. Orebody geometries are controlled by ore fluid movement directions (parallel to S2 mineral lineation and dip slip movement) and the intersection of stratigraphy/lithology (ie DNC2 and rhyolite). Exploration techniques that can detect CGF style mineralisation, include magnetics, gravity, DHEM, IP and multi element geochemistry. Gold mineralisation is early with either syn- or near syn-bismuth fluids. Copper mineralisation has remobilised some gold bearing ores together with bismuth. Copper mineralisation is more widespread and prevalent than gold-bismuth.

Down hole EM is an integral part of the exploration toolbox. Data from multiple holes is used to more accurately vector towards EM targets.

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GRANITES OF THE BOURKE-BYROCK-BREWARRINA REGION

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Few studies have been conducted on the granites of the Bourke-Byrock-Brewarrina region of NSW. Previous petrographic work has classified the Midway Granite at Doradilla as A-type (Plimer, 1984) and many of the felsic granites as S-types. No previous geochemical investigations have been undertaken with the exception of the Glenariff Granite. In this study, reconnaissance sampling has been undertaken on most of the known granite exposures to provide a preliminary overview of the granites of this region and their place within the Lachlan Orogen.

Despite the paucity of outcrop, several granite exposures are present in the area (Figure 1). These have been informally named for convenience. A suite of samples from surface and drill core samples has been examined for chemistry, petrography (see Appendix) and magnetic susceptibility to ascertain granite type, compositional character and metallogenic potential.

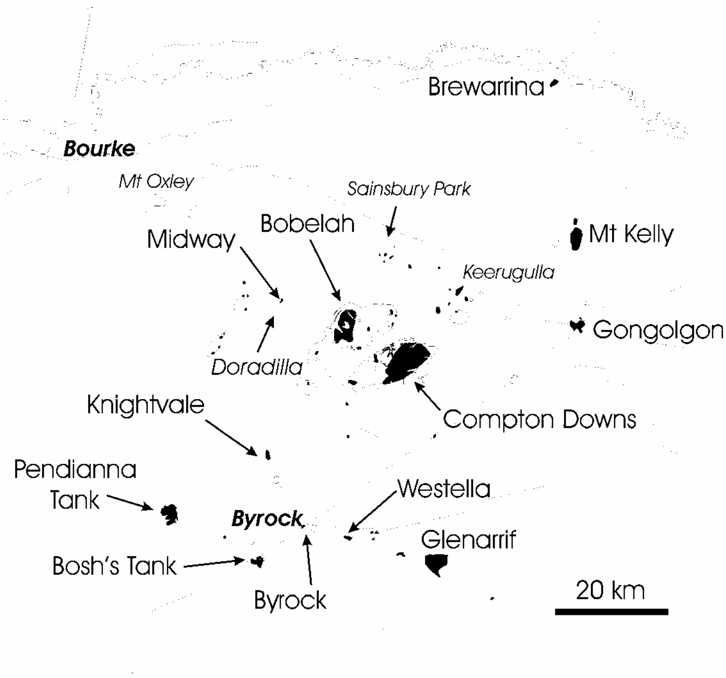

Figure 1. Location of granites (plain text) in Bourke-Byrock-Brewarrina region. Filled areas indicate granite exposure, open areas indicate buried or inferred exposures. Geological locations mentioned in text italicized, settlements in bold italics. Base map after Aung *et al.,* 1996.

The granites of the region can be divided into several groups: magnetite-bearing granodiorites to granites (Compton Downs, Bobelah, Knightvale); poorly magnetic to non-magnetic biotite-dominant granites (Mt Kelly, Pendianna Tank, Westella, Bosh's Tank, Byrock); highly evolved, texturally diverse and high silica granites (Gongolgon, Midway); weakly magnetic pink feldspar granite (Glenariff); and a peraluminous granite (Brewarrina).

Field based classification for most of the granites is not easily afforded using magnetic susceptibility or mineralogy. The Brewarrina Granite is unambiguously S-type because of the presence of prominent fresh cordierities and foxy-red biotite in hand specimen. The other biotite-dominant felsic granites can be classified as I-types on account of the presence of rare amphibole and the presence of allanite (stable in metaluminous melts). Xenotime is common in these granites as well. Some granites have been previously classified as A-types on account of their felsic character, textures and presence of allanite and late crystallising biotite (Plimer, 1984; unpublished company reports). However all granites in the region lack the low Mg/(Mg+Fe), and high Ba, HFSE (Nb, Zr) and 10000*Ga/Al ratio diagnostic of high temperature aluminous A-types. There are no peralkaline trends apparent. Where low Mg/(Mg+Fe) and high 10000*Ga/Al values are present these are demonstrably the products of extended fractional crystallization. Textural evidence such as miarolitic cavities, which are usually cited in favour of an A-type classification are actually indicative only of high volatile contents and early volatile saturation during crystallization at low confining pressures (Blevin, Candela, 1995) and merely attest to the high level nature of these granites.

CHEMISTRY

The granites of the region are dominantly felsic with SiO_2 contents above 70 wt % and most close to, or at the granite minimum (76 – 77 wt %; Figure 2). The exceptions are the Compton Downs and Knightvale Granites with SiO_2 contents between 61 to 66 wt %. All samples can be considered high-K calc-alkaline, while only the Brewarrina Granite has an Alumina Saturation Index (Al/(Na+Ca+K)) above 1.1, consistent with its peraluminous mineralogy.

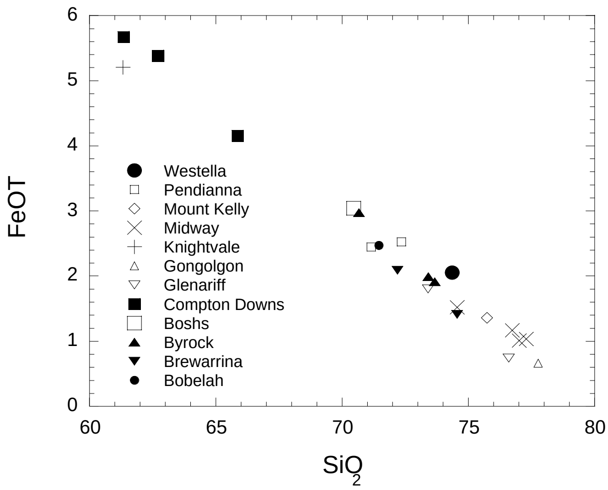

Figure. 2. FeO (total) versus SiO_2 for the granites of the Bourke-Byrock-Brewarrina region.

Some granites show strong fractional crystallization at or near minimum melt conditions, producing extreme enrichments in Rb and other incompatible elements (REE, Y, Nb, Ta, U, Th). Removal of plagioclase results in the removal of Eu, causing distinct Eu anomalies in these strongly fractionated magmas (Figure 3). Enrichments of Be and Cs are also present in the Gongolgon and Midway Granites. The miarolitic microgranites of the Glenariff Granite, although not as fractionated as the Midway and Gongolgon Granites report elevated values for Sb, Ag, Bi and Cu consistent with the evolution of mineralised fluids during crystallization.

Extensive B metasomatism of the cover rocks over these granites is possible and may be a useful guide to the presence of buried granites. Tourmaline is a peraluminous mineral stable only in the late stages of the crystallization of felsic granites. Crystallisation of tourmaline is hindered by the paucity of Fe in the melts, B being preferentially transported by the fluid phase into the surrounding rocks. Anomalous F, Be and Cs may be present as well.

DATING

The Byrock Granite has been dated at 390 Ma, Pendianna Tank at 392 Ma and Compton Downs at 403 Ma using K-Ar (Evernden and Richards, 1962; Webb, 1974 using the old calibration). Lead isotope studies at Doradilla by Carr *et al.* (1995) yielded a Pb model age of 295 Ma with a low $^{207}Pb/^{204}Pb$, indicative of unevolved isotopic compositions. This Carboniferous age is at variance with the assumed Siluro-Devonian age of the other granites. Given the extreme fractionated character of the Midway Granite, it is difficult to determine whether it is different in age and/or origin from the other granites of the region. The possibility that the mineralisation is younger than the granite is not plausible given that it is of a type that would be expected from a Midway-type magma.

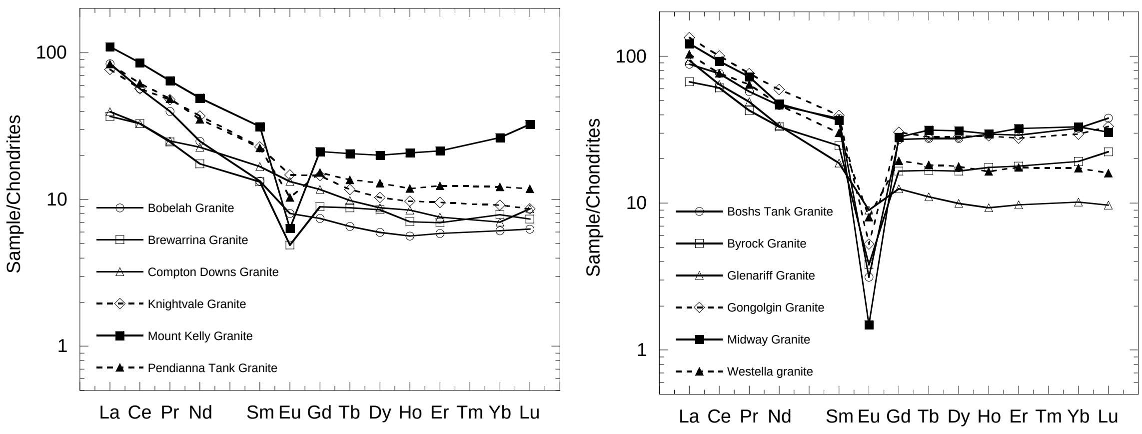

Figure 3: REE patterns for the Bourke-Byrock-Brewarrina granites. Note extreme fractionation in some samples due to extended fractionation of plagioclase.

GEOPHYSICS

The granites of the region present special problems for their recognition and mapping by geophysical means. They outcrop poorly, and the nature of the transported regolith in the region makes radiometric interpretation problematic. In addition, the granites are not strongly oxidized or magnetic (Figure 4). Even the most magnetic granite, which also has the highest Fe_2O_3/FeO ratio (Knightvale) can only be regarded as moderately oxidized, as are the Compton Down and Bobelah Granites. Mount Kelly gives a weak magnetic response. The other granites give paramagnetic responses, which is a function of the presence of Fe in minerals other than magnetic oxides or pyrrhotite. Petrographic observations indicate that the low magnetic susceptibility is an intrinsic property of these granites reflecting their relatively low oxidation state, and does not represent subsolidus or hydrothermal destruction of magmatic magnetite. Destruction of magnetite through deformation recrystallisation may be important in some areas. The magnetic highs associated with some granites (*e.g.*, Bobelah, Compton Downs) may relate to either more mafic parts of these granites or to magnetic wallrocks (metamorphosed or hydrothermally altered).

The Gongolgon Granite is probably responsible for the prominent radiometric high extending SW from the settlement. Other small radiometric highs occur over the Brewarrina Granite and the Westella Granite. The Westella Granite also lacks a magnetic response in contrast to the Glenariff Granite, there being a break between the two. The magnetic high associated with the Knightvale Granite is very small, indicating this is a stock of relatively small dimensions. A circular magnetic high immediately to the SW of Byrock village is unlikely to be due to the felsic Byrock granite.

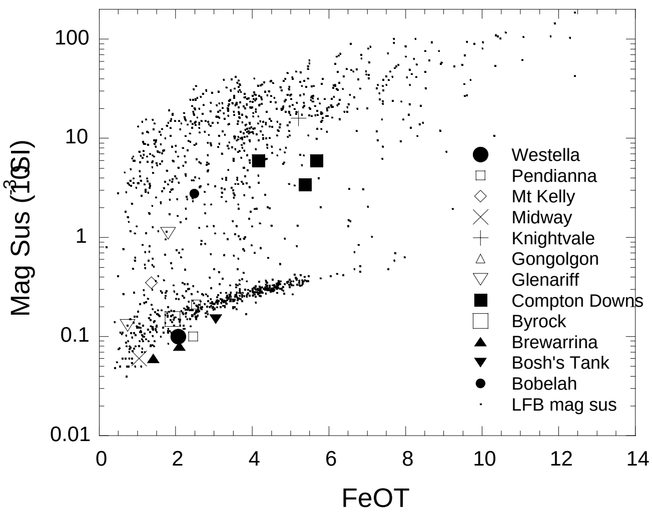

Figure 4. Magnetic susceptibility of the granites compared with other granites of the Lachlan Orogen.

METALLOGENY

On the Bourke 1:250 000 sheet mineralisation known to date is, with one exception, restricted to numerous very minor occurrences which have resulted from prospecting activity since the late 1800's. Historically the most significant deposit was the Doradilla copper mine which produced 20 tonnes of Cu at a grade of 11.2% Cu. (Byrnes, 1993).

The exception is the immense Sn resource (estimates range up to 50 million tonnes of contained Sn at a grade of 1% Sn) in the Doradilla area which resulted from exploration by North Broken Hill in the 1970's. An extensive complex zoned skarn is developed at the contact of a fractionated felsic granite with a sequence of carbonates. Unfortunately the deposit is metallurgically refractory with most of the Sn being present in silicates – andradite, clinopyroxene, malayaite (Plimer, 1984) – a "metallurgist's orebody" in the making.'

The extremely fractionated Midway Granite at Doradilla is the type of intrusive that would be expected to be associated with Sn mineralisation. However, the lesser fractionated, weakly oxidized I-type granites on the Bourke sheet have the potential to host or be related to Au mineralisation. Tin has also been reported from bores in the Kenilworth area, and occurrences of W and Pb-Zn are spatially associated with many of the granites. Low grade Cu associated with a granodiorite at "Knightvale" was drilled by CRA in the 1970s.

DISCUSSION

The Midway Granite is an extreme example of extended fractional crystallization of metaluminous (I-type magmas). It has high concentrations of Nb, Ta, Th, U, Y-REE, Sn and W. In terms of Rb content, the only other I-type granites of the LFB with which the Midway Granite is comparable are granites in Tasmania (the Coles Bay granites, Ben Lomond, Renison) and perhaps the Thologolong Granite along the NSW-Victorian border (Figure 5). Other comparable I-types are present in the New England Orogen (*e.g.,* Mole Granite) and the Carboniferous I-types of the Georgetown-Herberton-Chillagoe region of northern Queensland. Most of

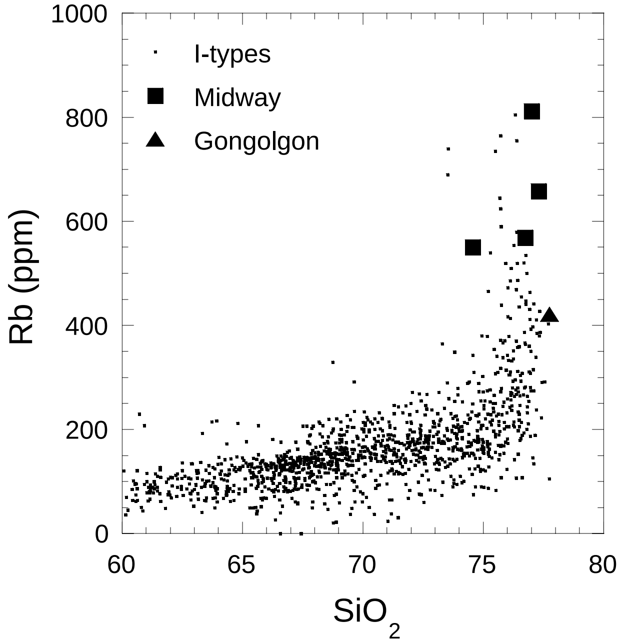

Figure 5. Rb versus SiO_2 plot of I-type granites of the Lachlan Orogen showing Midway and Gongolgon Granites. These granites are the product of extreme fractionation.

these granites (with the notable exception of the granites of Coles Bay and central Victoria) are associated with substantial Sn (± W, Mo, Bi, Pb, Zn, Ag and Au) mineralisation.

The Doradilla Sn system and the Midway Granite do not appear to represent an easterly displaced portion of the Wagga Tin Belt. Tin mineralisation in the Wagga Tin Belt is almost entirely associated with the Silurian Koetong Supersuite of S-type granites, which extends from the Tallebung region between Nymagee and Condoblin to northern Victoria. Tin mineralisation associated with I-types however does occur in the Wagga Sn Belt at Woolshed Valley at Beechworth in the extreme southern end of the Wagga Tin Belt. The age of the Doradilla system is still unconfirmed. The S-type granite at Brewarrina contrasts with the I-type character of the other granites. On the Structural Framework Map of NSW (Scheibner, 1996), it falls within the Brewarrina Block and may represent different source materials to those to the south, *e.g.*, a thick sequence of sediments at depth.

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APPENDIX: PETROGRAPHIC OBSERVATIONS

Knightvale. Amphibole (green to green brown) > biotite. Euhedral titanite forms prominent crystals, and large strongly pleochroic secondary epidote crystals replacing biotite and amphibole are prominent. Apatite, zircon and opaques.

Compton Downs. Euhedral amphibole commonly with felted cores after pyroxene. Biotite in subequal amounts. Apatite, zircon, allanite and opaques. Narrow, tourmaline-bearing pegmatites and epidote-albite alteration veins are present in the area of the Compton Downs Granite where Pb-Ag showings had been previously reported (Colin Plumridge, pers. comm., 2003).

Bobelah. Deformed where sampled. Biotite and minor amphibole (diminished in abundance by deformation). Secondary weakly pleochroic epidote.

Bosh's Tank. White alkali feldspars; subhedral to tabular biotite plates, with some minor subhedral amphibole. Apatite, long zircon crystals, and large metamict allanites to 1mm. Some minor secondary epidote and titanite.

Pendianna Tank. White alkali feldspars; subhedral to tabular biotite plates similar to Bosh's Tank. Radiation haloes in biotite are prominent. Possible scraps of amphibole. Low Fe_2O_3/FeO and magnetic susceptibility. Relatively large apatite crystals and zircons. Trace opaques.

Byrock. Medium to coarse grained, blocky to tabular biotites >> minor amphibole. Microcline twinned white alkali feldspar with well developed perthite in places. Very minor opaques. Abundant enclaves typically in swarms and pillowed masses indicative of injection. In thin section they comprise fine to medium grained lathy to tabular plagioclase, biotite and amphibole set in larger interlocking crystals of quartz and alkali feldspar. Xenoliths of metamorphosed country rock are also present. Prominent subhedral titanite crystals, in some places replacing amphibole. Very few opaques. Glomerporphyritic phenocrysts of plagioclase have been partially replaced by albite.

Westella. White alkali feldspar-bearing granite, deformed where sampled. Blocky biotite, locally recrystallised in zones of granoblastic quartz and feldspar. Pale to dark blue tourmaline is present in thin section and occurs as prominent segregations and pegmatitic veins in outcrop.

Mount Kelly. Grey-white alkali feldspar-bearing granite with biotite and rare amphibole. Apatite, zircon, metamict allanite, xenotime and some minor opaques.

Gongolgon. Quartz forms blocky subhedral crystals with pronounced re-entrants, have inclusions around their margins and outgrowths of small tabular K-feldspars and plagioclases oriented tangentially to the quartz boundary. Graphic intergrowths are well developed in the groundmass and miarolitic cavities range from mm to cm scale. These are filled with quartz, muscovite, late biotite and tourmaline. Greisenous patches of muscovite and quartz are present. Andalusite has been previously been reported, but it may be more likely topaz, because high F contents promote topaz over andalusite as a late stage peraluminous phase. Xenotime, apatite and zircon.

Midway. Felsic intrusives at Doradilla comprise the Midway Granite, occurring as outcropping granite and as granite intersected in drill core, and a swarm of altered quartz-feldspar porphyry dykes. The granite is texturally variable, has miarolitic cavities, late crystallizing biotite and scattered tourmaline and secondary muscovite. Vapour-rich fluid inclusions are prominent in places. In the drill intersection (DH EM-10) the contact zone of the granite comprises a 15 m wide zone of fine grained granite with small pegmatitic layers and stockscheiders, then a 20 m zone of fine to medium grained granite gradational into the main zone of porphyritic to seriate granite. These textures and textural progradation is typical of volatile rich fractionated granites. The porphyry dykes are strongly altered (often with sulfides) and commonly tourmalinise their wall rocks. Thin slivers of tourmalinised wall rock are common in the dykes. This is indicative of the low melt viscocity due to high B contents. The dykes and granite themselves are low in tourmaline as they are not peraluminous magmas and have very low Fe and Mg contents, forcing B to partition into exsolving fluids and react with Fe and Mg bearing wall rocks.

Glenariff Granite. Distinct from the other granites in having salmon-pink alkali feldspar. Biotite present. Fluorite, zircon, apatite, opaques. Late stage infilled miarolitic cavities are sparsely developed. Microgranite zones with interconnected miarolitic textures are well developed.

Brewarrina. White feldspar granite with typical foxy-red biotites. Cordierites (to 5 mm) are very fresh or variably altered to muscovite/sericite and pinite.

CHEMISTRY, AGE AND METALLOGENY OF THE GRANITES AND RELATED ROCKS OF THE NYMAGEE REGION, NSW.

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INTRODUCTION

The Nymagee 1:250,000 sheet has a diverse range of mineral deposits and igneous geology. Volcanic and related sedimentary packages were grouped into the Cobar Supergroup, which comprises two belts extending down the western (Mount Hope Group) and eastern (Kopyje Group/Canbelego-Mineral Hill Belt) sides of the Nymagee 1:250,000 sheet. New chemical, petrographic and dating studies have enabled these belts to be recognised as two distinct magmatic belts. This reassignment has implications for understanding the geological relationships, metallogeny and geophysics of the region.

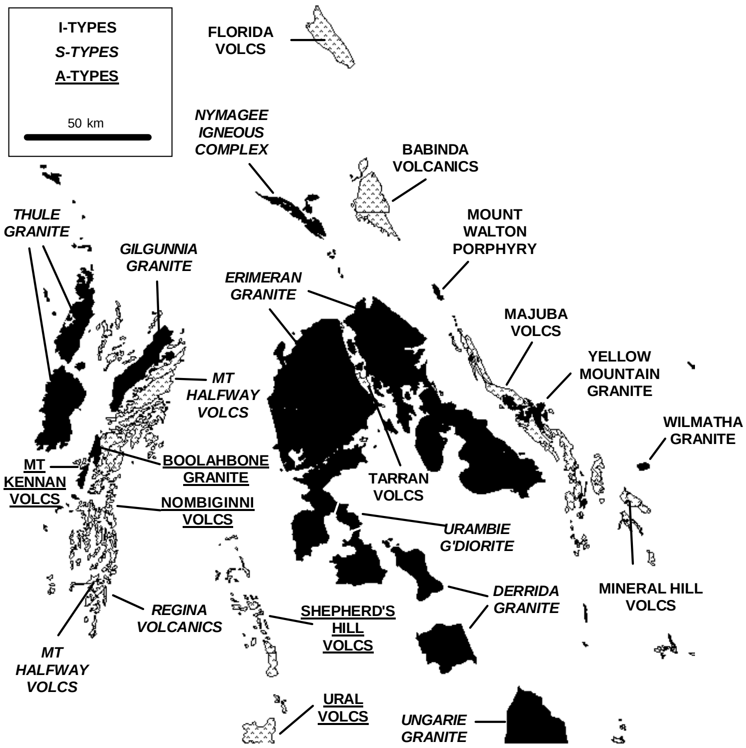

Figure 1 Distribution and character of Palaeozoic igneous rocks of the Nymagee 1:250000 sheet.

THE WESTERN (MOUNT HOPE) BELT

The western (Mount Hope) belt comprises both S-type and A-type volcanics and intrusions. The S-type Gilgunnia Granite and Mount Halfway Volcanics are closely related petrographically and chemically. The granite ranges from medium to coarse-grained equigranular granite with fine-grained aplitic phases. Cordierite and quartz inclusions are present in both the granites and volcanics. Microgranodiorite to porphyritic latite masses and dykes are associated with the Gilgunnia Granite. These are hornblende and magnetite bearing and the genetic relationship to the granite is unclear. The S-type Thule Granite is distinct from the Gilgunnia Granite and is very highly evolved and fractionated. It is an equigranular to porphyritic, coarse-grained biotite-muscovite and muscovite granite. Micrographic phases, pegmatites, aplites and greisens are also developed. The Regina Volcanics, which host the mineralisation at Mount Hope have not been examined in this study.

The A-type rocks of the Mount Hope belt comprise the Boohlabone Granite, and Mount Kennan and Nombiginni Volcanics. In addition to these the Shepherds Hill Volcanics on the Nymagee 1:250,000 sheet and the Ural Volcanics on the Cargelligo 1:250,000 have also been recognised as aluminous A-types (Blevin, 2003), as have parts of the Gurragong Volcanics further to the southeast (Blevin, 2003). These new occurrences result in the recognition of an extensive new A-type province in the Lachlan Orogen. A common feature of these rocks is high Ba, Zr, Nd, Ga and Zn, consistent with high temperature partial melting, and generally felsic compositions.

I-TYPE ROCKS OF THE TARRAN VOLCANICS AND CANBELEGO-MINERAL HILL BELT

The formerly assigned S-type volcanics of the Canbelego-Mineral Hill Belt (Mineral Hill, Majuba, Florida, Babinda and Canbelego Volcanics) have been reassigned as felsic I-types and grouped informally as the “Majuba supersuite”. These are related temporally and chemically with several felsic I-type intrusions (Mount Walton Porphyry, the Wilmatha and Yellow Mountain Granites, and unnamed porphyry dykes in the region of Mineral Hill). The oxidised I-type Tarran Volcanics exploit the Rookery Fault System and other structures that cut the Erimeran Granite. These volcanics and related intrusive rocks comprise megacrystic alkali feldspar-bearing rhyolite dykes with prominent magmatic allanite.

Volcanics of the "Majuba supersuite" comprise predominantly shallow water marine felsic pyroclastics with lesser lavas. They are I-type, felsic and rhyolitic in character with minor rhyodacite, dacite and rare andesites. The volcanics are intercalated and gradational to sandstones, conglomerates and limestones, with some of the units being dominantly clastic. The related intrusives range from mildly porphyritic granitic stocks to strongly porphyritic bodies with very fine, aplitic to spherulitic micrographic groundmasses, all indicative of high level emplacement and volatile exsolution. Interconnected miarolitic textures are also present within the Wilmatha Granite. The intrusives are all potassic, and have pink alkali feldspar when fresh. Fluorite is present within the Mount Walton Porphyry and rhyolites in the "Freytag Dome" adjacent the Mineral Hill Mine. Biotite is usually the only ferromagnesian silicate phase present. Fe_2O_3/FeO data and feldspar colour indicate the intrusives to be oxidised, however they are not strongly magnetic because of their very felsic character.

THE NYMAGEE, ERIMERAN, DERRIDA AND URAMBIE GRANITOIDS

The Nymagee Igneous Complex (NIC) comprises a group of felsic intrusives with associated foliated and migmatitic rocks. The main intrusive phases are equigranular and porphyritic in character and comprise muscovite-biotite adamellite and biotite-muscovite granite. Elevated Sn values (20 - 40 ppm) are present and compositional trends are indicative of fractional crystallisation. Compositional data, in particular high P and Nb, and low Y contents distinguishes the NIC from surrounding S-types.

The Erimeran Granite is a diverse mass with both strongly foliated and massive undeformed phases. Dominant phases include porphyritic medium to coarse-grained biotite granite, porphyritic biotite microgranites and equigranular muscovite-biotite granite. Other phases include aplite, pegmatite and greisen. The less felsic portions contain cordierite and biotite, while biotite only, or biotite-muscovite assemblages are the most common. Magmatic topaz-bearing microgranite units are present in places. The diversity of compositional types and variable deformation across the unit suggest that it is polyphase and probably has a multistage history of intrusion. S-type microgranite dykes mark the WNW trending Crowl Creek lineament across the granite.

The other S-type granites on the Nymagee 1:250,000 sheet, the Derrida Granite and Urambie Granodiorite, are the most northerly members of the Koetong Supersuite, which extends along the Wagga-Omeo Zone back to northern Victoria. The Erimeran Granite and NIC are compositionally distinct from this supersuite. However, the least evolved chemical analyses of the Thule Granite do correspond very closely with those of the Koetong Supersuite and support a genetic association.

COMPOSITIONAL CHARACTER AND GEOPHYSICAL PROPERTIES.

Compositional distinctions recognised between the I- and S-type groups are shown in Figure 2. The granites are dominantly silica-rich (felsic), high-K, and compositionally evolved (high Rb/Sr, low K/Rb). Extreme fractionation is present in both the Thule and the Erimeran Granites. Fractionation in these volatile (F and B) rich magmas has resulted in decreasing SiO_2 coupled with increasing Rb (Figure 3). The Tarran Volcanics, although high-K and felsic, are not as compositionally evolved, having higher K/Rb and much lower Rb/Sr than other units at equivalent SiO_2 values. The Tarran Volcanics also have higher Th, La, Ce, Ce/Y (i.e. high LREE/HREE), Nb; and markedly lower Y than other I-types within the Nymagee 1:250,000 sheet area. Mafic rocks are rare and comprise minor dolerite dykes and the small Parkville Gabbro to the west of the Walkers Fault Zone. The dykes are geochemically distinct in having elevated HFSE, REE and Y, and low K/Rb, similar to the more silicic Tarran Volcanics.

Geophysical contrasts between the units are also apparent and relate directly to compositional character. The S-types are pink on combined U-Th-K images (e.g. Fleming and Zhang, 1999) due to the attenuation of Th, while the I-type Tarran and Majuba supersuite volcanics and related intrusions are white on account of elevated K, U and Th channels. The oxidised Tarran Volcanics give a high magnetic response while the weakly to moderately oxidised Majuba supersuite rocks give a more attenuated response on account of their high SiO_2, low Fe nature. The S-types are invariably reduced. Three magnetic highs are present over the Erimeran Granite in its central and southeastern portions. A comprehensive magnetic susceptibility survey across the Erimeran Granite (Isaacs, 2000) confirmed that the granite is non-magnetic (ilmenite series) in those areas with an average magnetic susceptibility reading of $\sim 0.1 \times 10^{-3}$ SI units. The Tarran Volcanics have a higher magnetic susceptibility with an average of $\sim 7 \times 10^{-3}$ SI units. Poorly exposed gabbroic-diorite dykes in the southeastern lobe of the Erimeran have higher values of ~15 × 10^{-3} SI units. The magnetic highs observed over the Erimeran Granite are the result of Tarran-related and oxidised gabbroic-diorite magmas at depth. The prominent "Melrose High" just off the southeastern fringe of the granite is due to a buried oxidised I-type intrusion ("Fountaindale Granodiorite") and a related magnetite-bearing alteration system that was initially drilled in the 1960s (AOG, 1968). Gravity data from the area suggests that the Erimeran Granite is relatively thin because it does not significantly lower the gravity in comparison with the surrounding sediments despite its very felsic character (Isaacs, 2000).

SHRIMP AGE DATING

Age dating has been undertaken on the NIC, Erimeran Granite, Tarran Volcanics, Wilmatha Granite, and dykes from the Mineral Hill mine area. A range of previously determined ages exist for the NIC (457 to 409 Ma) using K-Ar and Rb-Sr techniques (Pogson and Hilyard, 1981) making the estimation of a reasonable magmatic emplacement date impossible. Isaacs (2000) attempted to date the NIC using zircons. A bimodal distribution of ages was evident. The first grouping at ~600 Ma corresponds to inherited zircons from the source rocks of the NIC. The second grouping of ~500 Ma could either be the crystallisation age of the magma (unlikely) or another grouping of inherited zircons from a different aged source. A single zircon with an age of 425 ± 28 Ma was analysed and this may also represent the magmatic crystallisation age. Zirconium is relatively insoluble in strongly peraluminous magmas and zircon inherited from the source rocks tends to remain as discrete crystals rather than dissolving into the magma. The Rb-Sr isotope data of Webb (1978) was recalculated using the zircon dates in order to estimate a reasonable magmatic age for the NIC. Recalculating the Rb-Sr data at 500 Ma and 450 Ma, yields impossible and improbable initial $^{87}Sr/^{86}Sr$ ratios of 0.696 and 0.7083 respectively. A magmatic crystallisation age of 425 Ma yields a reasonable initial $^{87}Sr/^{86}Sr$ ratio of 0.7145, suggesting that the true magmatic crystallisation age of the NIC must lie within the lower range of ages determined from the zircon dating.

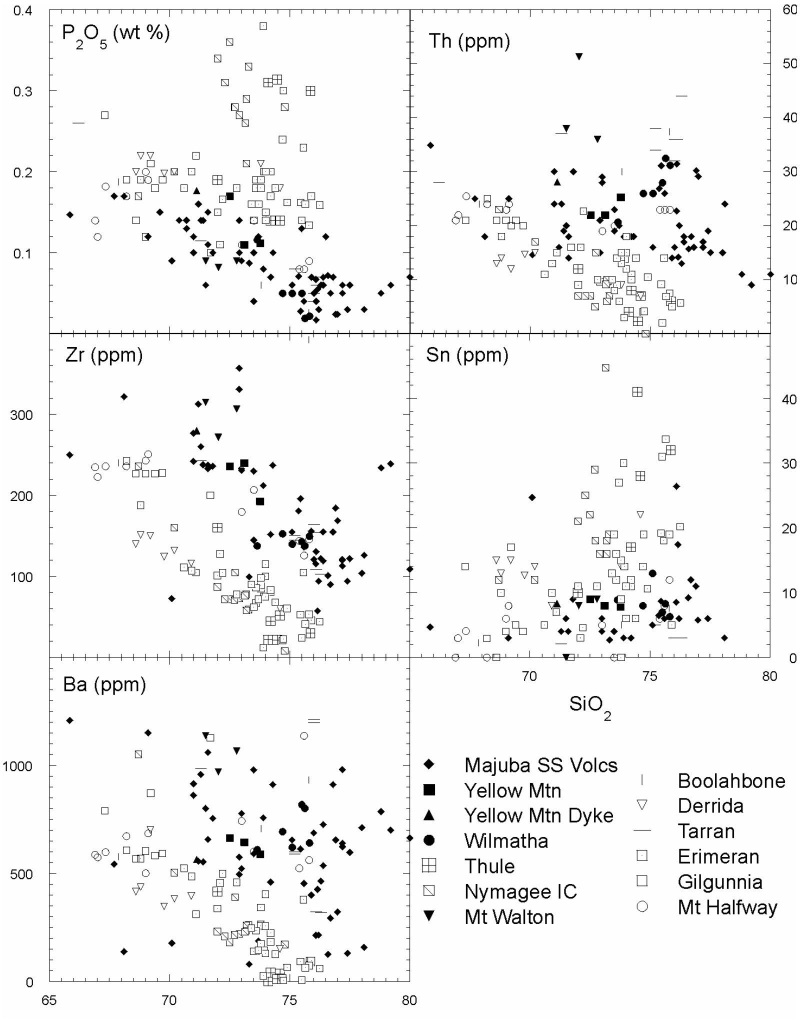

Figure 2. Harker Variation diagrams of igneous units from the Nymagee 1:250,000 Sheet. Note separation of "Majuba supersuite" volcanics and related intrusives from S-types. (Data from Blevin (unpubl), Spandler (1998), Isaacs (2000), Chappell, (unpubl), Pogson (Cobar-Nymagee Chemrock Database (unpubl)).

The Erimeran Granite had been dated at 419 Ma by the Rb-Sr method by S. Shaw (pers. comm. in Pogson 1991; no error reported). K-Ar dates of 412 ± 6 Ma and 415 ± 6 Ma obtained by Pogson and Hilyard (1981) probably represent reset ages due to Ar loss during a subsequent thermal event. Zircon U-Pb dating by SHRIMP undertaken by Isaacs (2000) yielded an age of 434 ± 4 Ma on clear rims of well-formed magmatic zircons from an undeformed fresh phase of the Erimeran Granite. Unpublished Sr isotope data (S. Shaw, pers comm., 1999) has been recalculated using this age to obtain an initial $^{87}Sr/^{86}Sr$ ratio of 0.7091.

The Tarran Volcanics overlie the Erimeran Granite non-conformably and are crosscut by dolerite dykes. They have been previously regarded as Devonian (MacRae, 1984) and the presence of greenschist metamorphism and mild deformation indicates an Early Devonian age or older. Isaacs (2000) obtained a 433 ± 4 Ma age for the Tarran Volcanics, statistically equivalent to the 434 ± 4 Ma obtained for the intruded Erimeran Granite. Both volcanics and granite are clearly different in their emplacement styles and cross cutting relationships, however, only a small time interval between the two is indicated. Both Erimeran and Tarran zircon samples do not represent the same population as both have distinctly different morphologies and U and Th contents.

In the Mineral Hill region Spandler (1998) obtained a 422 ± 4 Ma SHRIMP age on the Wilmatha Granite, east of Mineral Hill Mine, a 421 ± 3 Ma age on a quartz-feldspar porphyry mass intruding Girilambone sediments 3 km west of Mineral Mine, and 428 ± 4 Ma on a clast of porphyritic and micrographic textured hyperbyssal intrusive in a diatreme-like rock crosscutting the Mineral Hill Volcanics. Attempts to separate zircons from the Mineral Hill Volcanics yielded a small number of water worn grains of indeterminate provenance.

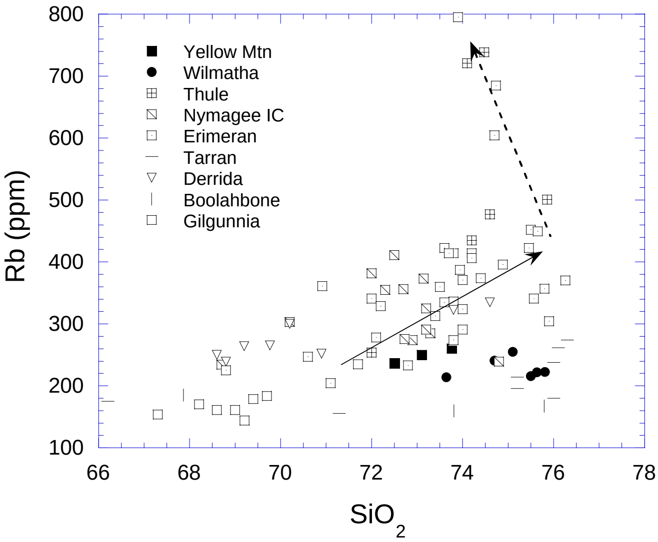

Figure 3. Rb versus SiO_2 showing extreme fractional crystallisation trends (dashed line) in the Erimeran and Thule Granites. Rubidium increases while SiO_2 decreases due to high magma volatile contents (F, B).

All these ages, with the exception of the NIC, are older than expected. In the Mineral Hill area, the new SHRIMP ages are at variance with fossil data on sediments within the volcanic sequence that suggest Pridoli to Lochkovian/mid Pragian ages (ie. Early Devonian; Suppel and Gilligan, 1993 and references cited therein). However, the fossils are poorly preserved and a mid to even early Silurian age range is plausible, in keeping with the SHRIMP data (Des Strusz, pers. commun., 1998).

METALLOGENY

The metallogeny of the “Majuba supersuite” and related intrusions along the Canbelego-Mineral Hill Belt is usually commented on as an afterthought following discussion of mineralisation styles at Cobar and in the Mount Hope Belt (Shuttleton, Nymagee, Mount Hope etc). In that light, mineralisation within the Canbelego-Mineral Hill Belt is usually regarded as being submarine volcanic exhalative, or metahydrothermal epigenetic, in origin.

The Canbelego-Mineral Hill Belt is magmatically distinct from the western members of the Cobar Supergroup and its metallogeny is more typical of magmatic hydrothermal associations with high level I-type igneous rocks. Related deposits include the Overflow Mine (Au-Ag-Pb-Cu-Zn) at Bobadah and the Yellow Mountain Mine (Zn-Pb-Ag-Cu-Au) both in the Majuba Volcanics; the Anaconda (Cu-Zn-Ag-Au) and other mines within the Baledmund Formation in the Melrose area; the Mineral Hill deposit (Cu-Au-Pb-Zn-Ag-Bi) in the Mineral Hill Volcanics, and small Cu, Au and Bi showings around the Wilmatha Granite. The Hera prospect near Nymagee (Skirka et al., 2004), a vein type Au, Pb, Zn deposit hosted by sediments of the Mouramba Group, may also lie within this framework.

The one operating mine in the area under review is Triako Resources’ Mineral Hill deposit, which produces ca. 50,000 ozs Au per annum. This is a structurally controlled, quartz vein Au, Cu, (Bi) system with relatively restricted chloritic alteration hosted by Silurian (425 Ma) volcanics and sediments. The volcanics are predominantly lapilli tuffs that are thought to have been deposited as pyroclastic flows in a shallow submarine environment. The sediments include carbonates, and replacement, magnetite-rich, high grade Au “skarnoid” and Pb-Zn “manto” style mineralisation is present. The deposit was discovered in the early 1900’s and worked intermittently on a small scale into the 1950’s. The current underground operation dates from 1995. Mineral Hill has been the subject of extensive exploration since the 1960's with the exploration model seeming to reflect the flavour of the decade. Thus in the 60's a porphyry copper model, in the 70's a VHMS model, in the 80's an epithermal model. Currently it is considered to be a telescoped, mesothermal, magmatic-hydrothermal vein system with links to a felsic intrusive at depth – the only evidence for which are clasts of a microgranite in a diatreme-like body cutting the host sequence. The clasts are, however, geochemically and geochronologically similar to the Wilmatha Granite some seven kilometres to the east of the mine, which has associated minor Au, Cu, Bi skarn mineralisation. There is further indirect evidence from the interpretation of airborne magnetics by Peter Gunn that suggests the possible presence of an intrusive body at a depth of approximately 1 km below the mine area. Evidence for intrusive related gold in the district is found further to the north at the Fountaindale prospect – a gold-bearing I-type granodiorite within the very large Melrose magnetic anomaly. Exploration in this belt should not be based solely on Cobar or Mount Hope style deposit models.

Typical S-type granite ore element associations (Sn-W) are curiously not well developed within the Erimeran or Thule Granites. The apparent absence of alluvial Sn placers in creeks draining these granites is also noteworthy. The Blackfellows Dam U prospect in the Erimeran Granite is typical of lower temperature U-bearing base metal lodes in Sn provinces. The Tallebung and Whytes Sn-W deposits have previously been regarded as being genetically related to the Erimeran Granite, but are probably related to unexposed members of the Koetong Supersuite. The Derrida Granite (adjacent to the Tallebung deposits) and Urambie Granites are members of the Sn-mineralised Koetong Supersuite, and the Derrida Granite becomes quite fractionated to the south of the Nymagee 250K sheet near the Lachlan River (Blevin, 2003). Small Mo showings in the Erimeran Granite are unusual for S-types. Fault-controlled Ag-Pb occurrences at Mount Tinda in the south-eastern lobe of the Erimeran Granite are spatially associated with prominent magnetic highs, and it is possible that all these occurrences are related to oxidised (I-type) intrusions at depth.

The several prospects associated with the A-type Mount Keenen (Wagga Tank, Fenceline), Shepherd's Hill (Mundoe Prospect), and Ural (Browns Reef) Volcanics have a common metal association of Zn-Pb-Cu-Au-Ag. Zinc is elevated in the chemistry of A-types. The Mount Kennan Volcanics are host to several deposits including the Wagga Tank Prospect (Zn-Pb-Cu-Au-Ag), and other smaller Pb-Zn, Cu and Au prospects. Although previous studies have concluded that they are volcanogenic or Cobar-type deposits (Suppel and Gilligan, 1993), a magmatic hydrothermal origin is preferred.

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A METHODOLOGY FOR REGOLITH-LANDFORM MAPPING IN REGIONAL MAPPING PROGRAMS

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BACKGROUND

Regolith landform mapping has been undertaken within the Byrock 1:100 000 map sheet (8136) area, resulting in the compilation of a regolith landform map and preliminary GIS. This project was a regolith landform pilot study and new regional geological mapping in the Cobar-Bourke area will commence shortly. The Byrock 1:100 000 map sheet area is located in northwest NSW. The sheet includes the village of Byrock, which is located between Nyngan and Bourke. The bedrock of the area is known to contain units of the ?Ordovician Girilambone Group as well as possible extensions of the prospective, Siluro-Devonian Cobar Basin rocks.

From a regolith landscape perspective the Byrock 1:100 000 map sheet area represents the transitional zone between an erosional terrain and a depositional terrain. Higher topographic relief areas are located in the southern, erosional portion of the map area while generally flat, low topographical, depositional areas occur in the northwest. Rock outcrop is sparse and largely covered by transported and *in-situ* regolith materials. The constructed Byrock regolith map demonstrates how an understanding of basement geology helps in the interpretation of surficial regolith and resultant landforms.

AIMS OF THE PROJECT

The regolith mapping project aimed to produce a range of integrated products, including regolith landform maps and interpreted solid geology and outcrop maps. A further aim of the project was to determine the 3D nature of the regolith and examine geochemical characteristics of major regolith landform units using samples from aircore drilling.

MAPPING METHODS

Airborne geophysical data were collected in 1995 by the NSW Department of Mineral Resources over the Bourke area at a flight height of 60 m and an interline spacing of 250 m. The airborne magnetic and radioelement data were acquired as part of the Discovery 2000 exploration initiative and were manipulated in ArcView 3.2 and ERMapper 6.1.

Confirmation of initial regolith-landform discrimination was gained through landform and regolith field inspection. As the majority of the area had undergone deep weathering, aeromagnetic data proved the most useful geophysical dataset for interpreting the weathered zone. Magnetic character was also used to identify lithological units, some fault zones and major rock unit boundaries. Gravity data proved to be of limited value due to its coarse nature and the lack of contrast between the specific gravity of different rock units. When interpreting lithological boundaries, radiometric datasets were less useful than the aeromagnetic data due to a lack of resolution inherent with the technique as well as the presence of extensive transported cover. However, radiometric data were useful in the differentiation of regolith-landform types. The digital terrain model (DTM), while locally affected by extremely thick vegetation, proved to be of great value for regolith mapping by allowing the identification of landform units in inaccessible areas. Interpretation of Landsat 7 satellite imagery distinguished various surficial materials.

While remote sensing is a useful adjunct to mapping it, cannot replace field mapping when distinguishing rock/regolith units and identifying boundary relationships. In general, many of the rocks exposed within the Byrock sheet are highly weathered and have limited exposure. Careful interpretation of subtle textural features preserved in the weathered material was required.

The area is covered by 1:50 000 colour aerial photographs flown in 1992. Older black and white photographs and Landsat images were used to provide a first pass overview interpretation, which was scanned and added to the GIS project. The colour aerial photographs were also scanned and corrected for photo-distortion by registering them against a digital base map. Interpretation of the colour air photography and geophysical datasets further refined regolith-landform units. Polygons were digitised 'on screen' using ARC GIS software. An example of the air photos and remotely acquired data is given in Figure 1.

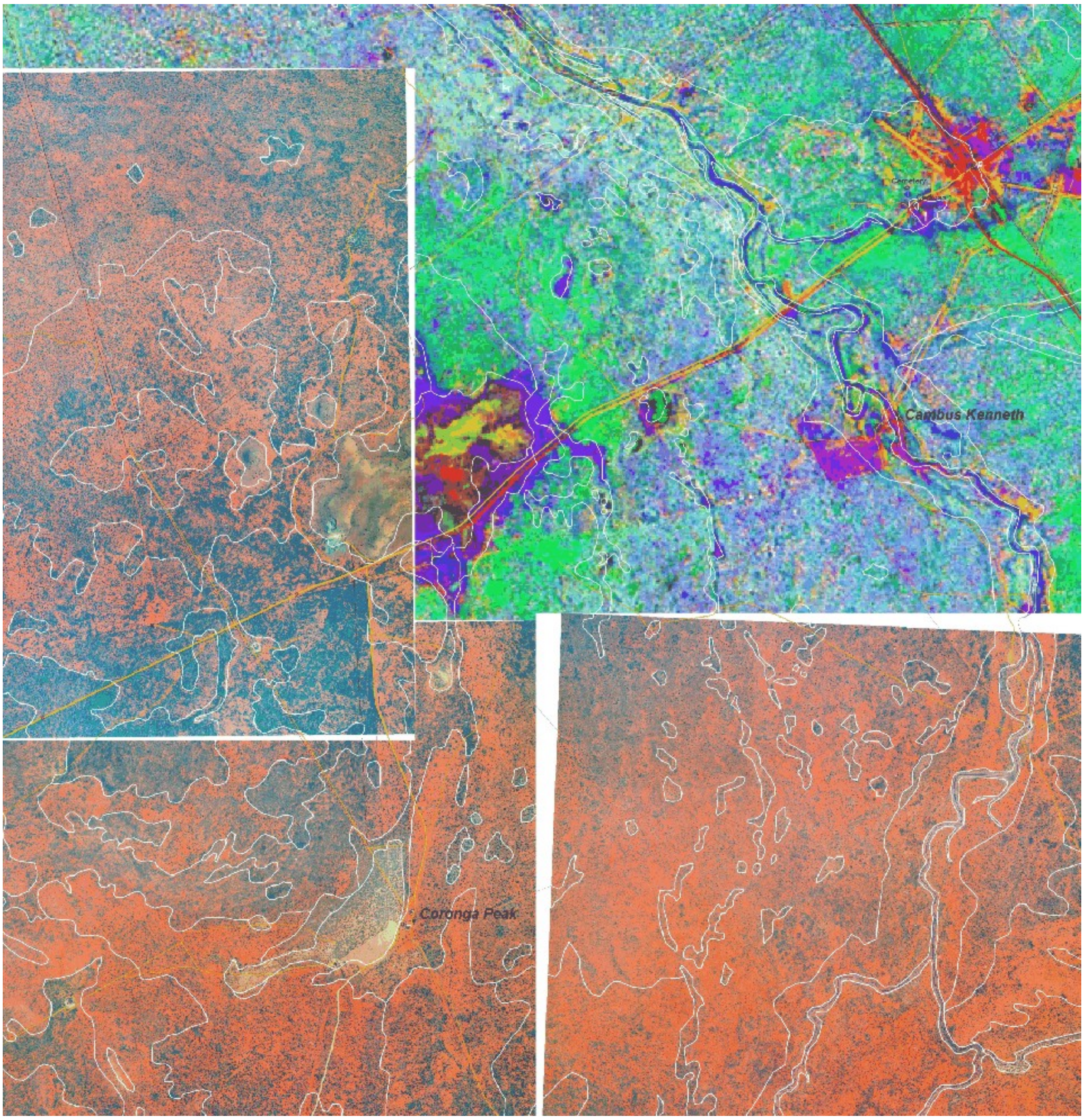

Figure 1. Example of Landsat 7 digital imagery (northeastern corner) with overlayed, air photography (remainder of image). Interpretation of these data was used to produce regolith landform map polygons (white lines). The town of Byrock is visible in the northeastern corner of the image.

MAP SYMBOLOGY

The Byrock 1:100 000 regolith-landform map was constructed using "Regolith-Landform Units" (RLUs). RLUs incorporate both the dominant regolith types and their landscape setting. Regolith and landform types are described using a code system, which has specific letter combinations that convey landform and constituent regolith material type for each RLU. Figure 2 illustrates how landform units are applied.

An example of an RLU letter symbol description is: **Aap1.** The upper case letter/s (A) describe the main regolith type, which in this case is alluvial sediments; The lower case letters (ap) describe the main landform type (ie alluvial plain), and the modifier (1) is added to represent subtle differences within each RLU (such as angular quartz clasts).

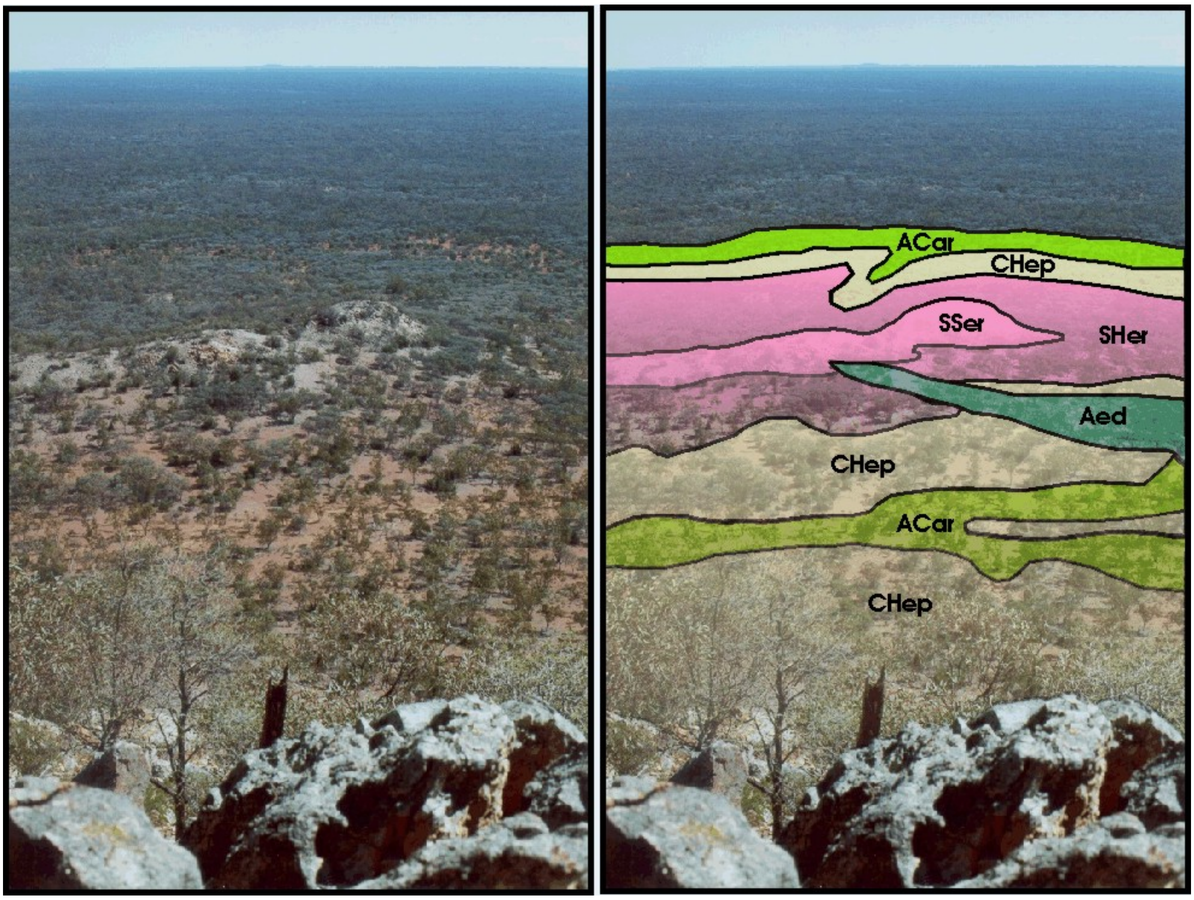

Figure 2. Example of the application of Regolith Landform Units (RLUs) at Coronga peak, within the Byrock study area. The photograph on the right is presented with RLUs applied to landforms visible in the middle distance.

Initial discrimination of regolith-landform units was achieved through the use of aerial photographs (scales of 1:82 000 and 1:50 000), and radiometric, magnetic and DTM data. The methodology differed slightly from that used previously in the project on the Sussex-Coolabah 1:100 000 regolith-landform map, in that 1:50 000 scale air photographs were used and more emphasis was placed on interpreting the radiometric imagery, to aid in the discrimination between regolith-landform units.

INITIAL PRODUCTS AND FINDINGS

The Byrock 1:100 000 scale regolith landform map (Figure 3) and an accompanying GIS project were produced in ArcView 3.2 and ArcMap formats. The results were also incorporated into a basement interpretation (Hicks & Fleming, 2004).

In summary, erosional terrains are generally defined on the map by the colluvial and saprolitic units (yellow and pink of Figure 3) while depositional terrains are defined by alluvial units (shades of green in Figure 3).

A major finding of the study has been the identification of basement faults and the control these faults have on landform development. Closed drainage depressions were identified. These depressions, (darkest green, Figure 3) are coincident with maghemite accumulations and are interpreted to be abandoned meander systems of major drainage channels. When considered en-mass, they assist in defining individual palaeodrainage channels. This palaeodrainage system is significantly different to the modern drainage regime. Figure 4 illustrates both modern (dark blue) and palaeodrainage (light blue). Modern stream systems predominantly drain towards the northwest, while the palaeodrainage system predominantly drains to the northeast and is parallel with the strike direction of basement faults. The faults identified strike northeast and appear to be sub-vertical and have a component of strike-slip movement (red lines Figure 4).

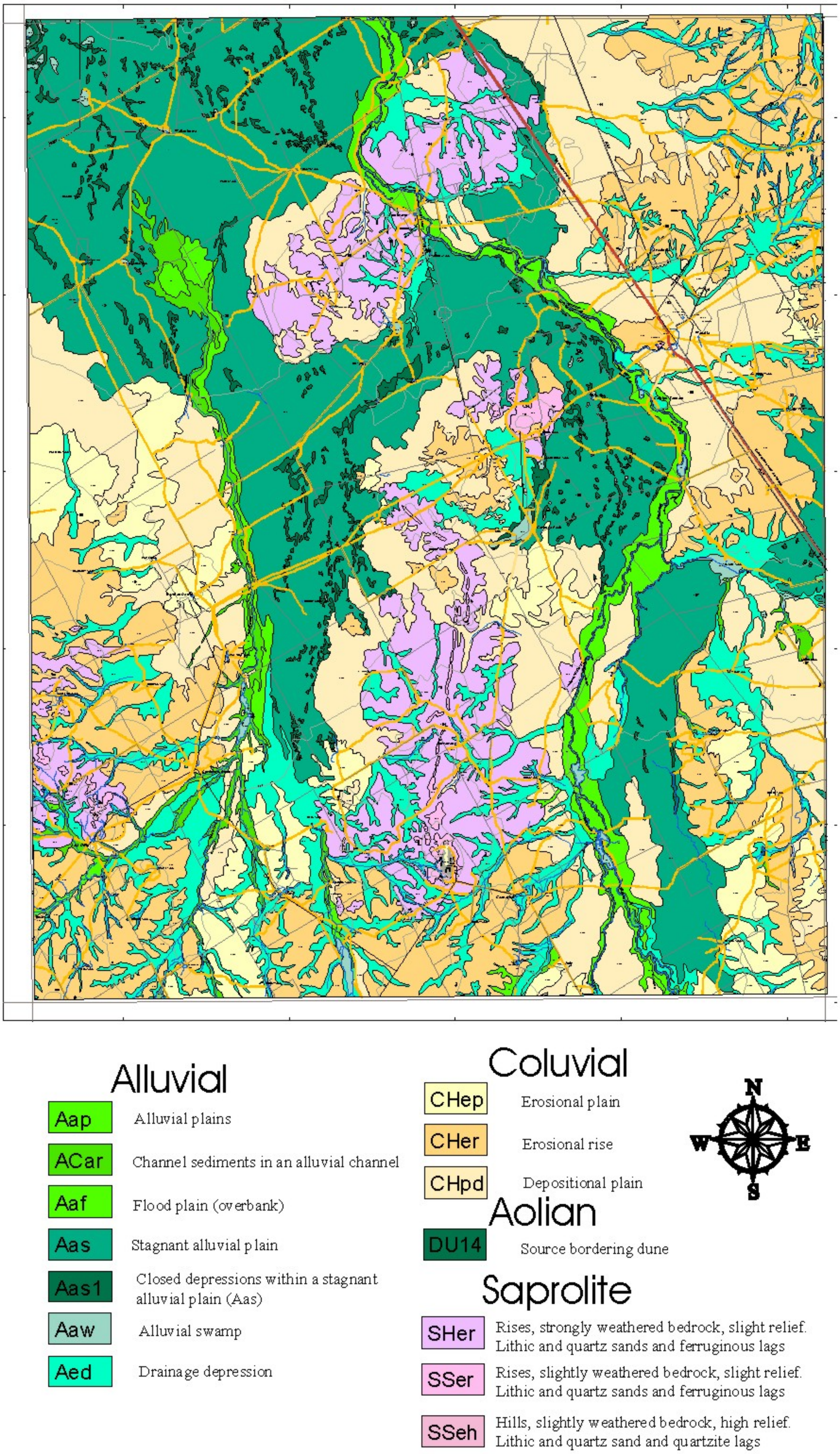

Figure 3. Image of the Byrock 1:100 000 Regolith Landform Map.

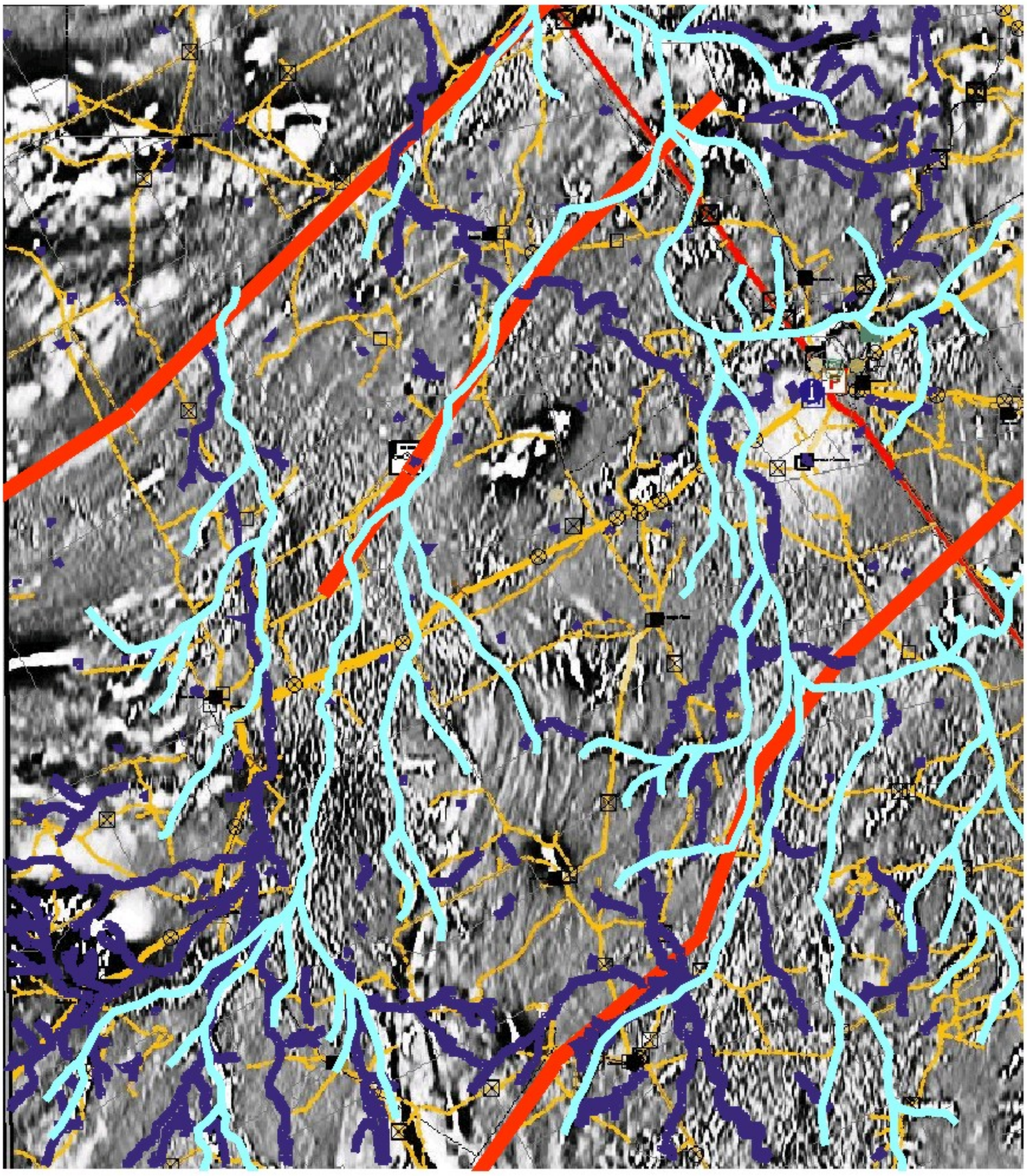

Figure 4. Greyscale image of first vertical derivative of aeromagnetic data, overlayed with interpreted basement faults (red lines), current drainage (dark blue) and interpreted palaeodrainage (light blue).

The identification of fault-controlled change in the sedimentation history has implications for correctly interpreting the results of stream sediment geochemical surveys.

An understanding of regolith landform development of any area can assist with planning new geochemical surveys and may be a fast and cost-effective way of assessing previous geochemical sampling programs. Specifically, an understanding of the history of landform development and sediment flux can show that some surveys would be completely ineffective and many techniques only partially effective.

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A NEW BEDROCK MAPPING PROGRAM FOR THE COBAR-BOURKE REGION

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The Geological Survey of New South Wales (GSNSW) has begun a new program of geological mapping in the Cobar-Bourke region. The work is part of the New South Wales Government's Exploration New South Wales initiative. The principal aim of the project is to highlight the exploration opportunities in this previously underexplored area of the state.

The area of the study includes the Cobar and Bourke 1:250 000 map sheets as well as the eastern parts of the Louth and Barnato 1:250 000 map sheets (Figures 1 and 2). Portions of this area (the Cobar, Wrightville and Canbelego 1:100 000 map sheets), as well as the Nymagee 1:250 000 sheet to the south, have previously been mapped by the GSNSW to a satisfactory standard and a substantial amount of information has been obtained on the geology and mineral occurrences. The remaining area, however, has not been mapped adequately, mainly due to lack of good exposure, and is accordingly not well understood. Good quality geophysical data, acquired through the Discovery 2000 initiative in the 1990s, reveals that the geology of the area is quite complex. Significantly, recent air core drilling by the Department, as well as company work, indicates that areas previously mapped as Ordovician Girilambone Group actually contain Siluro-Devonian Cobar Supergroup rocks. Developing a better understanding of the regional geology will encourage mineral exploration as well as allowing the Department to provide more informed land use advice.

Program activities to date have focussed on gathering drill logs, geological mapping and information on mineralisation from company reports. Drill logs are being compiled and the information incorporated into a basement interpretation of the region using geophysical data. A depth to basement map for the area is also being prepared. Mineralisation data is being used to update the Department's Metmin database and previous geological mapping is being captured spatially for use in a GIS to assist future mapping.

The regional basement interpretation will summarise the degree of understanding of the regional geology and will assist in planning the course of the geological mapping program.

Geological mapping of the Sussex 1:100 000 map sheet will begin in June 2004 and is planned to be completed by June 2005. The initial strategy of the project will be to identify areas which contain rocks of the Cobar Supergroup as this rock package is the most prospective for economic mineralisation. Drilling (air core and possibly other deeper drilling techniques) will be employed and will be targeted so as to assist in understanding the geology in covered areas. Geochemistry, geochronology, isotope studies and regolith mapping will also augment the mapping program.

Initially the mapping team will consist of three geoscientists but it is planned that others will join the project by early 2005. Another 1:100 000 sheet (either Gundabooka or Byrock) will be completed by June 2006 and at least one other by December 2006. Data compilation and report writing will be completed by June 2007. Products will be available digitally and as print-on-demand maps. The future of the project beyond June 2007 will be dependent on further funding.

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Figure 1. Cobar-Bourke project area extent and present mapping status by 1:100 000 map sheet areas

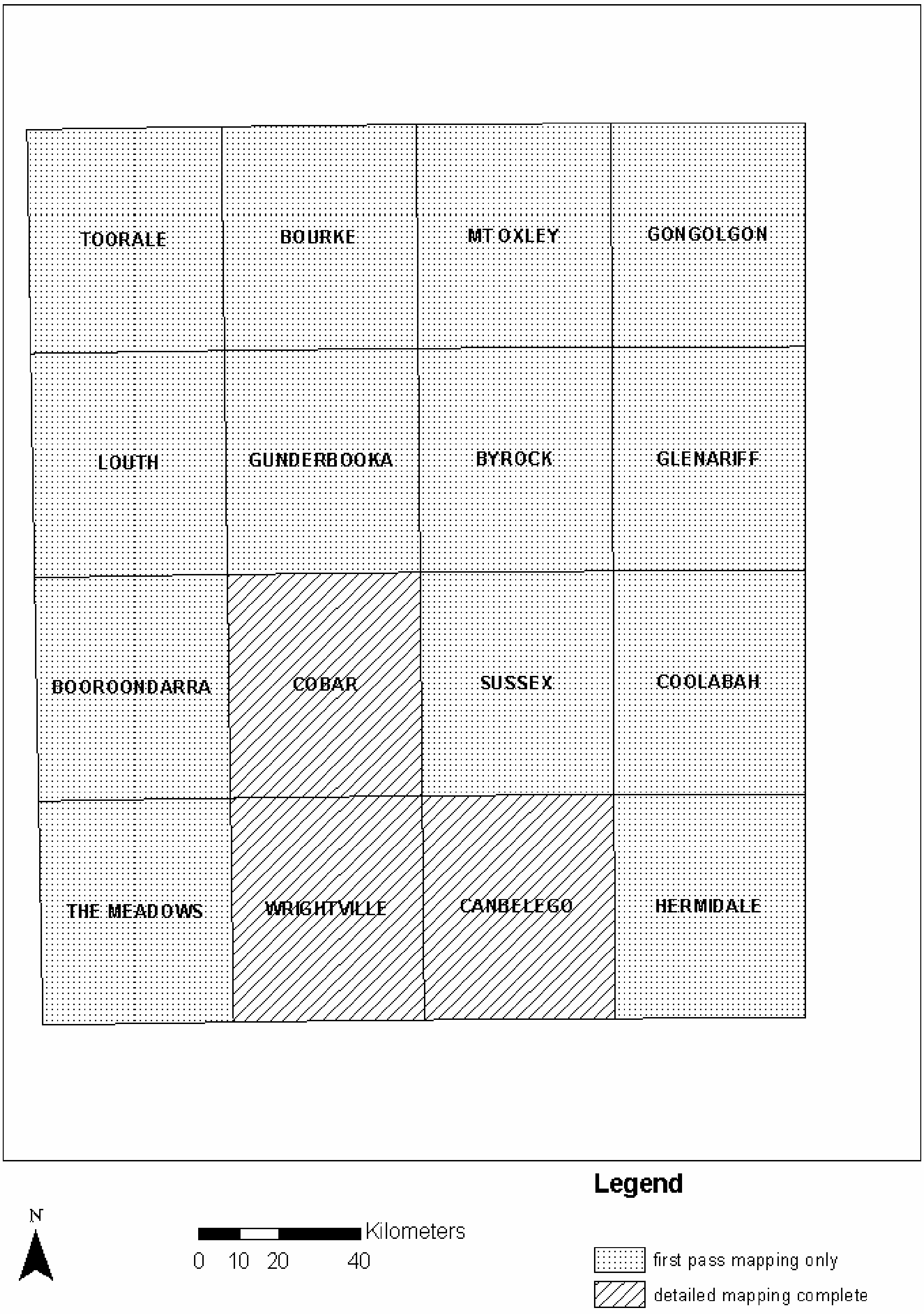
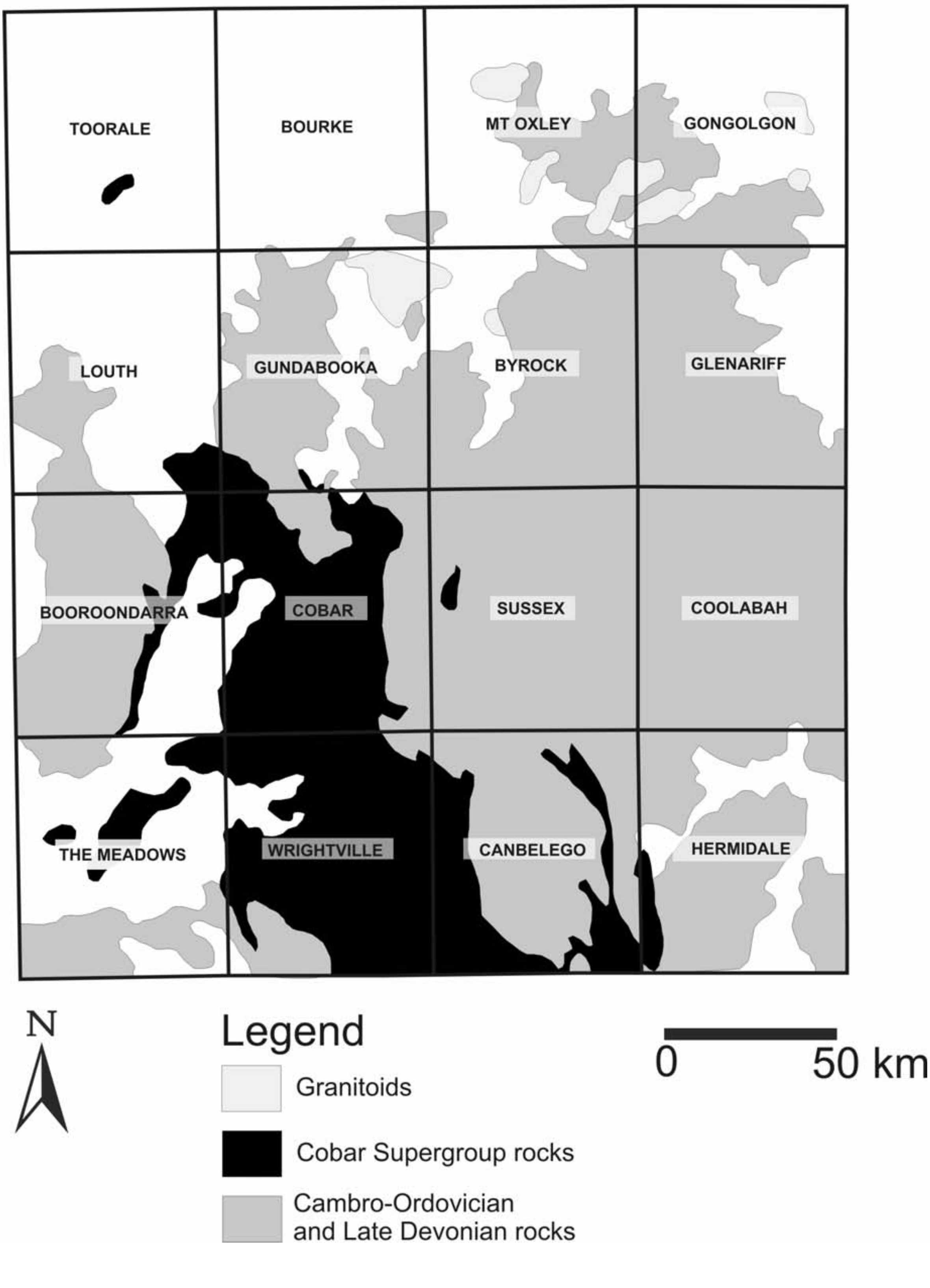


Figure 2. Cobar-Bourke project area geological sketch map



ELECTROMAGNETIC PROFILING OF PALAEOCHANNELS IN THE GIRILAMBONE REGION, NSW

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As a part of larger CRC-LEME funded project, we have conducted time domain electromagnetic (TEM) surveys across two selected palaeochannels near Girilambone, NSW. These TEM transects were carried out to delineate the shallow subsurface resistivity structure and thus demonstrate its effectiveness. Figure 1 shows the survey areas and aeromagnetic data of that region. We used a fast turn-off TEM system called NanoTEM transmitter and a GDP16 receiver system from Zonge Engineering and Research Organisation. with a transmitter(Tx) loop (20x20m) and receiver(Rx) loop (5x5m) configuration.

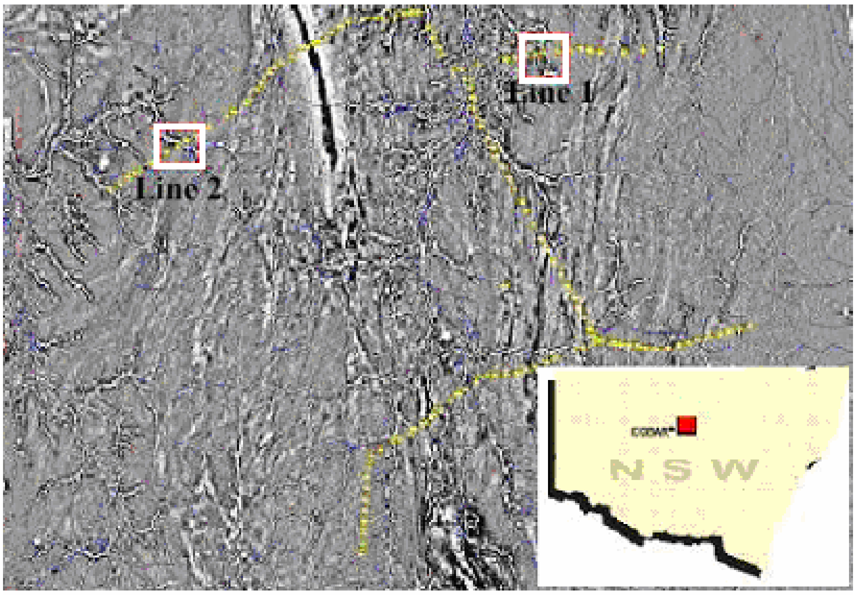

Figure 1. TEM survey areas are marked with white boxes. Lines 1 and 2 were parallel to the drill holes (lighter dots). Background image is the 1.5 derivative of the aeromagnetic data (from Chan et al, 2003).

The 1.5 derivative of the aeromagnetic data and drill hole data (~ 1 km spacing) provided a priori geological information. These constraints were used to select the survey lines. The first line was about 2400 m long and cut across a deep (ca. 20 m) non-magnetic palaeochannel with some more recent magnetic sediments above. The station spacing was 20 m. The second line was also across an area with well-defined, shallow magnetic palaeochannel sediments. Due to some logistic reasons we could do only partial coverage (1560 m i.e., 78 stations) of the planned second profile. For each station three sets of readings were taken and averaged during the data processing to improve the signal-to-noise ratio. Data were inverted using STEMINV (MacInnes et al. 2001), a smooth-model inversion technique to create 2-D depth-resistivity sections.

Figures 2 and 3 show the resistivity sections along Line No.1 and 2 respectively. The X-axis represents the survey length with station numbers indicated and the Y-axis shows the depth. The contour lines and colour shading show the resistivities. Though the sections show resistivities from surface to 70 m depth, the most reliable section is from 2 to 40 m depth, which could be considered as a limitation of the present Tx/Rx combination. One can clearly see the distinct regions of high and low resistivities. For Line No.1, the area between Station No.31 and 73 (820 m) seems to be less resistive (5-25 Ohm-m) up to a depth of 30-35 m. Below this the resistivity increases, probably indicating basement below the palaeochannel. Both sides of this palaeochannel are more resistive (50-100 Ohm-m), which clearly indicates the presence of basement rock at shallow depths. Within the palaeochannel, there are also two distinct zones, one with very low resistivity (between Station No. 33-44), compared to the other (between Station No. 53-73). This indicates some kind of geological median structure separating these two zones. The shallow (0-5m depth) thin high resistivity layer, which blankets the palaeochannel, could be due to the sheet flow of resistive basement materials from both flanks of the palaeochannel.

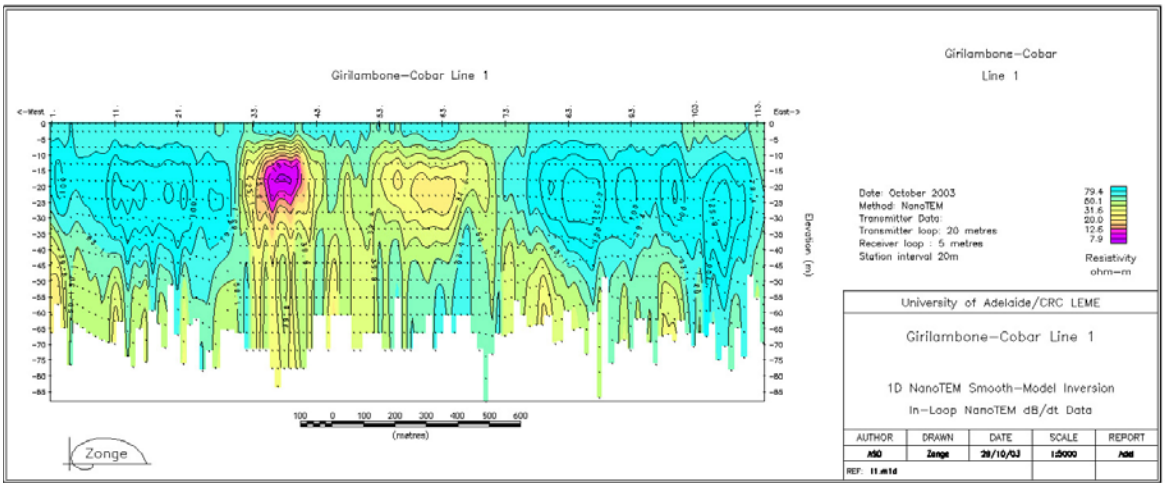

Figure 2. Depth-resistivity profile along Line No.1. Colour legend is also given. (Red/darker=less resistive(5-12 ohn-m); Blue=more resistive(60-100 ohm-m)).

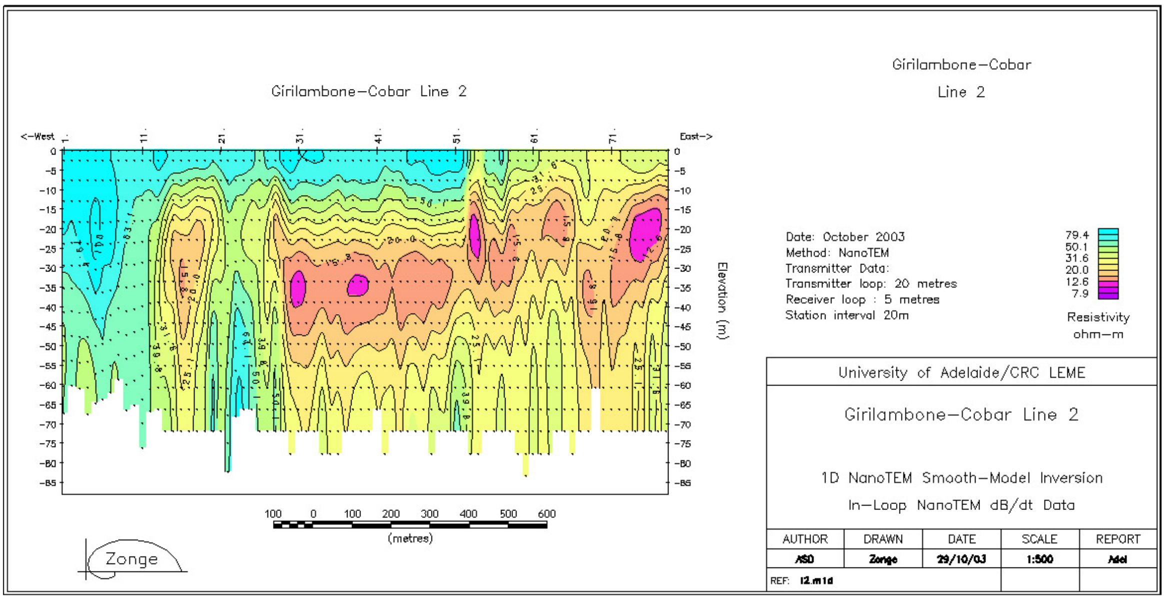

Figure 3. Depth-resistivity profile along Line No.2. Colour legend is also given. (Red/darker=less resistive (5-12 ohn-m); Blue=more resistive (60-100 ohm-m)).

For Line No.2, it is clear that subsurface is highly resistive (50-100 Ohm-m) beneath the first 11 stations. Further east and up to the end of survey line (Station No.78) it is less resistive (5-25 Ohm-m). The low resistive region also appears to extend laterally even further east. This may indicate the presence of a palaeochannel that is wider than the one across Line No.1 or alternatively a channel with low resistivity overlying deeply weathered clay-rich saprolite. The depth-resistivity profiles indicate that the depth to resistive basement beneath the second palaeochannel, could be much deeper (60-70 m) than that for profile No.1. These findings are confirmed by the airborne magnetic and drill hole information. It is also worth noting the presence of a shallow but thicker (~10 m) resistive layer right over the western section (between stations 11 and 52). This could the sheet flow of resistive basement materials from the western flank of the palaeochannel. Abundant maghemite-bearing ferruginous lag was also noted in this area..

Earlier studies (Huang & Fraser, 2000, 2001) showed that the presence of materials with high magnetic susceptibility can influence the results obtained from TEM profiles. It is necessary to carefully address these effects. Probably a joint inversion of magnetic and EM data would provide a better understanding. It should also be remembered that these results are from only two test profiles. It would be useful to conduct a rigorous and fast TEM survey in dynamic mode to obtain a wider coverage. Measurements with a conductivity meter would be another useful option. The latter could highlight shallow conductivity structures (quadrature part) as well magnetic susceptibility (in-phase part) information.

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THE GEOLOGICAL FRAMEWORK OF THE COBAR BASIN

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The Cobar Great Superbasin is located in central western New South Wales about 700 km northwest of Sydney. It lies in the Central Subprovince of the Lachlan Orogen It is one of several intracratonic, half-graben basins developed during Silurian-Devonian time in the Central Lachlan Orogen (Glen, 1995) and (half-)inverted by combined inversion and thin-skinned thrusting (Glen, 1990). The basin underwent deformations during the Late Devonian Tabberaberran and Middle Carboniferous Kanimblan Orogenies (Scheibner, 1989; Glen, 1992).

The Great Cobar Superbasin developed as four deep-water troughs flanked by shallow-water shelves. The northern part of the basin was filled with prograding siliciclastic sediments and locally intruded by felsic rocks. The southern extensions, Mt Hope and Rast Troughs, were filled with sediments, volcaniclastics and volcanics of bimodal character. Along the eastern margins, a large carbonate platform, which broke down during the syn-rift phase of basin evolution, existed in the Early Devonian. The Cobar Basin represents a half-inverted basin characterised by transtensional-transpressional thin-skin tectonics. Locally, on the edges of the deep-water troughs, Silurian granites behaved as tectonic buttresses that governed basin opening and basin inversion. The basin opened as a half-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.

The evolution of the Cobar Basin is defined as a metallogenic epoch that includes syn-rift and basin inversion phases. The syn-rift metallogenic epoch is characterised by development of VMS, intrusion related and Irish-type deposits. The basin inversion metallogenic epoch is characterised by Cobar Style, quartz-vein hosted Au and MVT deposits. The deposits formed during the syn-rift metallogenic epoch underwent greenschist grade metamorphism and the structural overprint of a later basin inversion epoch.

INTRODUCTION

The Cobar Basin is the richest polymetallic basin in the Lachlan Orogen and has a known metal inventory of 198 t Au, 4,597 t Ag, 2.2 Mt Cu, 4.8 Mt Zn and 2.9 Mt Pb valued at more than $A 20 billion. About 70% of the total resources have been mined since the initial discoveries in the 1870's.

The discovery of the Elura deposit in 1974 intensified metallogenic work on the Cobar Basin deposits and resulted in new interpretations of the 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 included the possibility of mechanical remobilisation close to the original place of deposition. Syn-deformational, structurally controlled models were supported by 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) supported a syn-deformational, structurally controlled model for the Elura Zn-Pb deposit. Similar, syn-deformational models were applied to the CSA Cu-Zn-Pb deposit by Brill (1989), and to the Peak Au deposit by Hinman and Scott (1990) and Perkins *et al.* (1994). However, Marshall and Gilligan (1993) supported a polymodal genesis for the Cobar deposits. Jiang (1996), Foster (1997) and Jiang *et al.* (2000) provided detailed fluid inclusion, stable isotopes, lead isotopes and structural studies of the individual deposits in the Cobar Basin. During the 1990's Glen (1995) and Stegman (2001) made significant contributions to understanding the complex relationships between stratigraphy, tectonism and mineral deposits. Under the NSW government *Discovery 2000* project, the Geological Survey of New South Wales, in collaboration with numerous mineral exploration companies, acquired high-quality geophysical coverage of the basin including airborne magnetic and radiometric data on 400 m spaced lines and ground gravity with 1x2 km grid.

In this paper, the approach to understanding the Cobar Basin metallogenesis is based on the lithofacies distribution and deformation styles controlled by basement architecture. The genesis of mineral deposits is related to the tectono-stratigraphic settings in the basin evolution process.

COBAR SUPERBASIN LITHOFACIES

The Great Cobar Superbasin comprises deep-water troughs, as well as flanking and intra-basinal shelves, delineated by major structures and lithofacies changes (Figure 1). The major stratigraphic sedimentary environments that are constrained by lithofacies comprise:

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

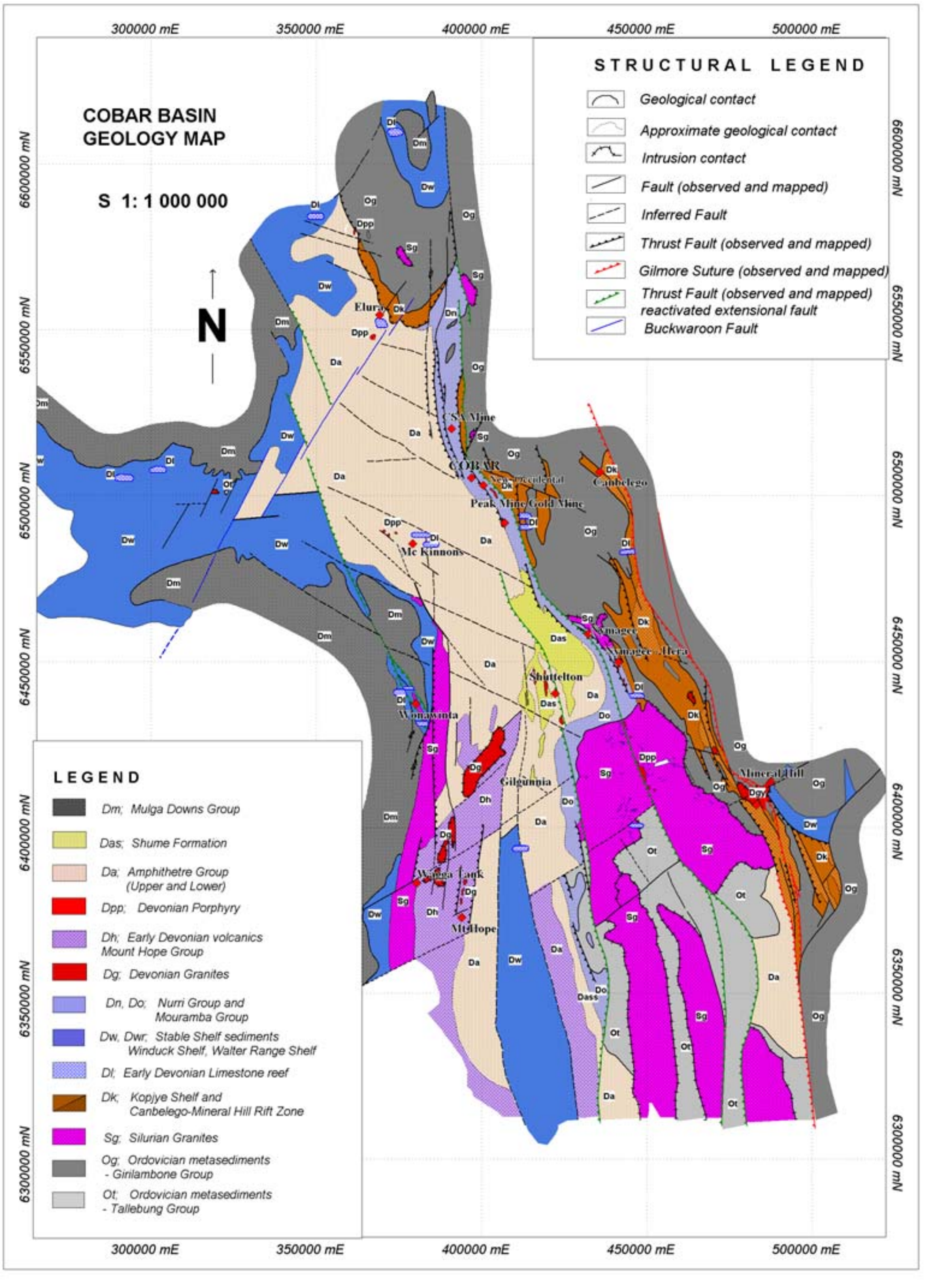

Figure 3. Simplified geology map of the Cobar Basin.

Figure 1. Geological map of the Cobar Basin with major mineral deposits.

Basin evolution commenced in the latest Silurian to Early Devonian with formation of a shallow water shelf to the east (Kopyje Shelf) and deeper water Rast and Mt Hope Troughs to the west, which formed in response to crustal extension. Basin subsidence progressed northwards with transgressive facies deposition and subsequently, to the west on the stable Winduck Shelf, and then east on the Kopyje Shelf. Initial sedimentation was followed by deposition of an upward finning outwash delta facies of arkoses and greywacke. A high-rate of basement subsidence in the Rast and Mt Hope Troughs was followed by a high-thermal gradient that produced bimodal volcanism. Volcanism ranged in composition from rhyolite, rhyodacite and dacite to basaltic and was expressed as submarine intrusions. The initial Mt Kennan Group volcanism was I-type. This was followed S-type volcanism of the Mt Halfway Volcanics. Tectonically, the Mt Hope and Rast Troughs were separated by the Walter Ranges Shelf, which was an area of stable shallow-water sedimentation.

Sedimentation in the syn-rift phase of basin formation commenced with shallow-water sequences (Nurri and Mouramba Groups) that pass rapidly up section into turbidites such as the Chesney Formation and turbidites of the Lower Amphitheatre Group (*e.g.* lower sequence of the CSA Siltstone). In the Cobar Basin, deep-water turbidites comprise the Nurri, lower Amphitheatre and upper Amphitheatre Groups. The relationships between different lithofacies suggest that fans from the east were progressively abandoned, as a result of marine transgression. In general, the thin-bedded, fine-grained turbidite sequences of mudstone, siltstone and fine-grained sandstone intervals (C and D Bouma sequences) together with sedimentary structures and fossiliferous assemblages indicate a basin plain with distal submarine fans at variable depth (Glen, 1994). Progressive rifting and extension is exemplified by relations around the Elura mine, where carbonate facies rocks of the Kopyje Shelf are overlain by turbidities of the CSA Siltstone. At Elura the following facies can be identified from bottom to top:

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

We interpret these relations as reflecting drowning of the carbonate shelf during renewed extension along part of the northern margin of the Cobar Basin. Sag phase deposition in the Great Cobar Superbasin is reflected by reversion to thin-bedded turbidites in the Cobar Basin (Dau) 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 Cobar Basin, where it is reflected by the Winduck Group, and between the Mt Hope and Rast Troughs, where it is reflected by deposition of the Wallets Range Group over ?granite basement. A hiatus marked by disconformity and paraconformity separates the Winduck Group from coarse-grained sandstone, conglomerate and shale of the fluviatile Mulga Downs Group, which probably ranges in age from late Early to Mid Devonian up into Late Devonian, possibly with an internal break.

COBAR BASIN LIMESTONE

Early Devonian limestone is an important indicator of sedimentary environment in the Great Cobar Superbasin. Limestone was deposited in places with low terriginous input and along growth faults. During basin extension and inversion, limestone reefs acted as rigid buttresses (tectonic barriers) creating dilational sites (Figure 1). In addition, limestone was probably an important chemical and physical trap for mineralising fluids. Limestone occurs in a discontinuous N-S trend along the deep-water trough margins of the basin and on the Winduck Shelf. 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 a continuous reef or open carbonate platform during the Lockhovian.

The uniform limestone lithofacies implies the existence of a carbonate platform or carbonate ramp along the growth faults now preserved below the turbidites along the basin margin. Limestone was deposited in the areas of steady basin subsidence and low terrigenous input. Limestone sedimentation ceased with increased subsidence rate and increased input of terrigenous material. Advanced rifting probably broke up the carbonate platforms/ramps and caused collapse of large limestone olistoliths into the deep-water troughs as for the Lerida Limestone (Glen, 1987).

STRUCTURAL HISTORY

During the Early to Late Silurian, left-lateral strike-slip movement occurred on the major regional structures (*e.g*. Gilmore Suture and Kiewa Fault). This resulted in regional transtensional movement localised along NNW-trending listric, syn-sedimentary faults (*e.g*. Jackermarro, Woorara, Rookery and Coonara Faults).

These faults developed perpendicular to the main extensional direction and were inclined at an angle of 40° to 45° to the main transtensional trend. The pre-existing weaknesses and heterogeneities in the basement rocks (granite batholiths) governed the orientations of the listric faults. Furthermore, faults changed orientation synchronously with advanced movement, passive rotation and progressing extension. The variations in the spacing, orientation, geometry and the detachment depth of the normal listric faults were accommodated by NW- and NE-trending strike-slip and/or dip-slip and sub-vertical transform/transfer faults. The Buckwaroon, Plug Tank, Amphitheatre and Nymagee Faults developed as a conjugate set of NW- and NE-trending extensional faults. The basin extension was concomitant with translation and rotation on oblique normal listric faults and transform/transfer faults forming a complex architecture. Movement along basement transform faults created local depocentres and may have localised volcanic activity.

Basin inversion was initiated with open folding and low-angle thrusting and associated development of a N-S trending cleavage (Glen, 1990). There was selective reactivation of normal gently dipping listric faults along the eastern trough margins. The reactivated faults penetrated into basin sediments, forming blind reverse fault systems and resulting in the formation of imbricate fan structures. The irregular reactivation of listric faults, together with fluctuation in fluid overpressure, caused distortion and rotation of structural blocks and the development of tear faults. The tear faults form a NE- and SW-trending *en–echelon* array, with a N-S progressive left-lateral, south block-down movement in the northern part and *vice versa* in the southern part of the basin**.** Initial horizontal tectonic transport changed to a vertical to sub-vertical direction resulting in a clockwise passive rotation. Tight folds and decollement faults progressed eastwards with deformation culminating in reverse lock-up thrust faults. Zones of spaced cleavage overprinted the N-S cleavage. Tectonic barriers, such as basement horsts and Silurian granites, caused clockwise rotation of local stress axes (σ_1) rotated from E-W to WNW-trend) and left-lateral movement along basin bounding faults.

COBAR BASIN MINERAL DEPOSIT

The Cobar Basin hosts eight different mineralisation styles, characterised by differed tectonostratigraphic settings, volcanics activity, host lithology and degree of strain. The styles are described below in the order of abundance.

1. *Cobar-Style mineralisation* includes mesothermal, 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 activity. A significant number of the Cobar Basin deposits (*e.g*., CSA deposit, New Cobar, Great Cobar, New Occidental and Chesney) belong to this group.
2. *Carbonate hosted base metal mineralisation* generally occurs in the open-platform reef limestone at the margin of the deep-water troughs (Elura) and shelf limestone (Wonawinta). This style of mineralisation is characterised by dominant Zn-Pb-Ag metal associations and replacement/cavity fill mineralisation textures.
3. *Metamorphosed VMS mineralisation* is characterised by recrystallised and mechanically remobilised, discontinuous transposed en-echelon sulfide lenses (Sangster, 1979). The deposits are localised in high-strain zones close to the Early Devonian volcanics and porphyritic intrusives. Base metal associations, locally with high-grade Au, dominate the mineralisation. The following deposits and occurrences belong to this group: Peak Gold Mine, Nymagee–Hera, Nymagee Copper deposit, Shuttleton, Queen Bee, May Day.
4. Epithermal gold mineralisation occurs on the Winduck Shelf sediments. Gold is hosted by quartz and sulfide stockwork veins, *e.g*., McKinnons Tank deposit (Bywater *et al.*, 1996; Foster, 1997).
5. *Intrusion-related mineralisation (Tennant Creek Style)* occurs at Mt Allen (Au, Fe) and Double Peak (Au, Cu) in the Mt Hope Trough. Mineralisation is characterised by gold-bearing hematite-magnetite lenses and hematite-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. *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 relative to fold axial planes and deflection along fault jogs.
7. *Porphyry-style mineralisation* was intersected at the Sandy Creek Prospect (20 km north of Gilgunnia) in the diamond drill hole SCDD01 (Skirka & McInnes, 2002). There the 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 in the drillhole KP1 at a depth of 206m (Aberfoyle Exploration, 1980).

GENETIC MODEL OF THE COBAR BASIN MINERALISATION

The Cobar Belt Metallogenic Province was formed by two major metallogenic epochs (Figure 2):

- a Silurian granite related (basement) metallogenic epoch;
- a basin evolution metallogenic epoch.

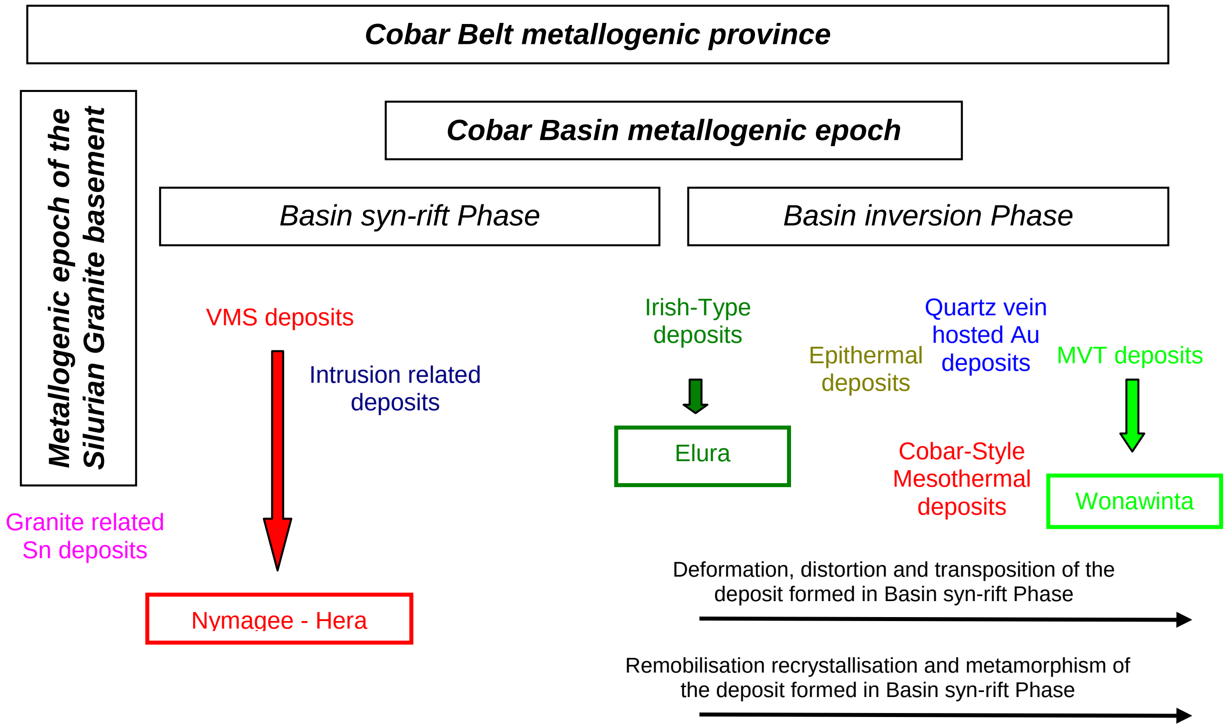

Figure 2. Metallogenic epochs of the Cobar Belt metallogenic province.

Metallogenesis in the basin epoch is observed as a continuum, where deposit formation is associated with northwards spatial progression of basin evolution. Mineral deposit formation can be divided into two metallogenic phases (Figure 2):

- a syn-rift (lower Early Devonian) metallogenic phase; and
- a basin inversion (upper Early Devonian) metallogenic phase.

The majority of mineral deposits in the Cobar Basin formed during the syn-rift metallogenic phase. Deposits are medium to small in size and range from single metal (Au or Cu) to polymetallic (Au, Cu, Pb, Zn and Ag) accumulations. These deposits are overprinted by inversion tectonics and greenschist facies metamorphism. In addition, deposits have undergone recrystallisation and mechanical-chemical remobilisation. The syn-rift metallogenic phase includes the initial inversion phase and is dominated by two genetic types:

- VMS-type and
- Irish-type deposits.

VMS deposits were formed in the eastern Cobar Trough margin and Mt Hope Trough. They formed in proximity to major active structures in the lower syn-rift stratigraphy by subhalative and inhalative processes. Irish-type deposits formed along the major active structures in the presences of carbonate sediments.

Mineral deposits formed in the main basin-inversion metallogenic phase are syn-deformational and epigenetic. These deposits contain Au (Cobar-type, quartz-vein hosted Au-deposits and epithermal deposits) and base metal (MVT deposits). Syn-rift sediments on the eastern basin margin host the Cobar-type deposits, whilst quartz-vein hosted Au-deposits and epithermal deposits are emplaced distal to the trough margins. The Wonawinta MVT deposit is emplaced on the basement high within the reef limestone sequence.

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DRAINAGE EVOLUTION OF THE COBAR REGION

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Understanding the drainage evolution of a region is one of the keys to unlocking the landscape history. The Cobar region has had a long and complex history of drainage evolution reflected in both extensive palaeochannel systems and the more recent drainage. The Cobar region occupies an elevated palaeoplain (Cobar uplands), which has been subjected to weathering, erosion and fluvial-lacustrine deposition since the Mesozoic. It lies in the northwest of the Lachlan Fold Belt at the northwestern end of the Canobolas Divide. This is a major drainage divide between the Murray (south) and Darling (north) River catchments of central NSW (Figure 1). The Cobar region is framed by the Darling River, which arcs around the Cobar upland from the north to the west, the Bogan River, a major north flowing tributary to the Darling River which bounds the region to the east, and the west flowing Lachlan River to the south. The streams that drain radially from the Tarran Hills in the Erimeran Granite south of Nymagee, the highest area in the Cobar uplands region, become tributaries to one of these main drainage systems. Major faults and bedrock strikes define the north-northwest trending physiography of the Cobar region (Figure 2) forming ridges which flank the granite intrusion in the highest part of the region.

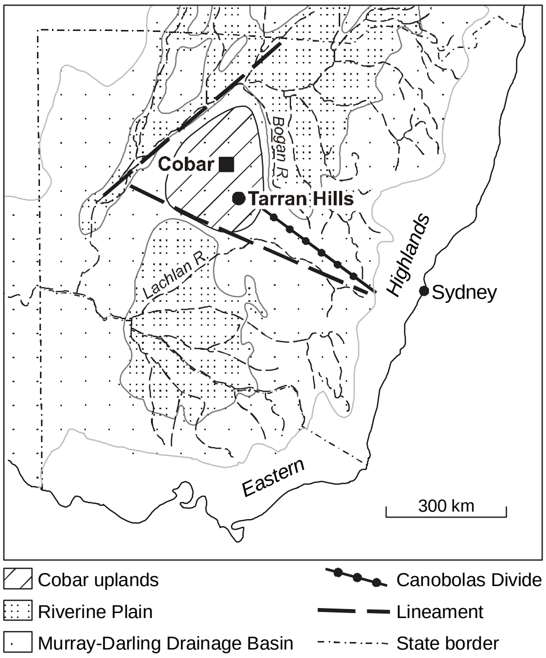

Figure 1. Physiographic setting of the Cobar uplands, modified from of Butler & Hubble (1978).

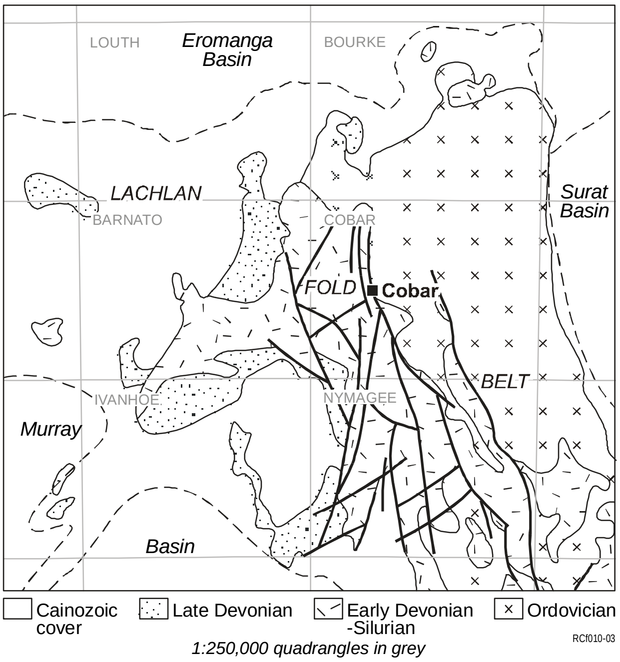

Figure 2. Geology of the Cobar region derived from Geoscience Australia web site and 1:2,500,000 scale Geological Map of New South Wales (1998).

The Cobar uplands are bounded to the northwest by the Darling River Lineament and to the southwest by the Lachlan River Lineament (Figure 1). Ordovician basement predominates in the eastern half of the area and comprises the Girilambone Group turbidite rocks, which have been regionally metamorphosed. The western half of the uplands is underlain by the Early Devonian Cobar Basin, comprising a marine turbidite succession that was deformed and structurally inverted in the Late Devonian to Carboniferous (Figure 2). Fluvial sediments were deposited on these older rocks in the late Early-Late Devonian. Deformation resulted in major folding and faulting with structures trending mostly between north-northwest and north-northeast. Diagonal secondary faults developed between these major structures.

The drainage in general follows the north-trending physiography, but in the western part of the uplands the drainage follows the westerly trending diagonal faults and fractures between the major north-northwest to north-northeast trending faults. The mean elevation of the Ordovician to Early Devonian basement rocks is topographically higher than the mean elevation of Late Devonian and younger rocks, indicating that the region has experienced a minimum average differential uplift of 39 m (the difference between the mean surface elevation of Early and Late Devonian). This differential uplift is reflected in the drainage evolution of the region.

Drainage classification in the Cobar uplands, following Strahler (1952), has indicated an anomaly in the Sandy Creek catchment where a rapid increase in drainage order has occurred to the west of Cobar (Figure 3). The high density of faults and fractures associated with the Early Devonian Cobar Basin between the Rookery Fault to the east and the Jackermaroo Fault to the west (Figures 2, 4) is responsible for this increased drainage density and order. Mineralization in the Cobar uplands is largely structurally controlled, with most known deposits concentrated along the high strain eastern margin of the Early Devonian Cobar Basin (Figure 4). Other deposits are associated with faults within the basin and adjacent to the Early-Late Devonian western boundary of the Cobar Basin. To the east of Cobar deposits are associated with the Ordovician and possibly structurally in-faulted Siluro-Devonian and Early Devonian rocks.

Reconstruction of the drainage evolution of the Cobar uplands from inferred palaeotopography reflects neotectonic activity (Figure 5). The palaeotopography was reconstructed in stages by rebuilding previous relief and elevation, by taking into account the geology and morphology of eroded features and estimating denudation. The evolution of the drainage determined from this reconstruction can be modeled in relation to two major morphotectonic blocks aligned north-south, which converge to the north and fan outwards towards the south. This structure is reflected in the splay of faults in the Cobar Basin converging to the north (Figure 4). These two morphotectonic blocks moved around a pivotal point that lies on the north-south trending Thule Fault just north of its intersection with the Dusty Creek Fault (Glen *et al.* 1996) (Figure 4) on the western edge of the Cobar Basin. Migration of drainage occurred to the south in the eastern block, and to the north in the western block. Migration of drainage in the eastern morphotectonic block is indicative of uplift from north to south while in the western morphotectonic block uplift has been from south to north. Drainage capture and reversal resulted from this tectonic reactivation. Drainage evulsion and redirection towards new base levels occurred as palaeotopography was buried around the margin of the Cobar uplands, due to ongoing erosion.

Ages have not been attributed to the stages of drainage evolution as palynological dating and detrital zircon provenance studies have so far been inconclusive. However, indicative correlations suggest a Late Jurassic to Plio-Pleistocene age range for the six stages of drainage evolution. These correlations are mostly based on sedimentology (palaeoflow directions), provenance of pebble lithology, and dated volcanic events (Figure 5).

Stage 1
The palaeo-Kerrigundi system drains to the north-northwest, following basement structure, from high terrain in the southeast of the Cobar uplands. A remnant outcrop of conglomerates with rounded quartz-quartzite-lithic clasts interbedded with sandstone preserved beneath a silcrete cap on a rise at Belah Trig to the west of Cobar is interpreted as an alluvial fan with dominant imbrication to the north. Another remnant of conglomerates with a similar composition, but with matrix supported rounded and angular clasts, is preserved as a silicified east-west aligned and dipping mesa cap at Tyncin Trig to the northwest of Cobar, and is interpreted as a chaotic flow. These sediments appear similar to Late Jurassic sediments preserved sporadically on the Lachlan Fold Belt (Gibson & Chan, 1999), and co-locate with the palaeo-Kerrigundi system.

Stage 2
The southwestern tributary arm of the palaeo-Kerrigundi system unifies and captures the headwaters of the southeastern tributary arm through accelerated headward erosion, possibly induced by tectonic reactivation along associated fault segments.

Stage 3
Palaeo“A” creek flows to the south-southwest from Late Devonian bedrock headwaters into a fluvio-lacustrine embayment. Drainage diversion by capture of palaeo“C” creek, which previously flowed to the north, towards the west by palaeo“B” creek due to tilting of the eastern Cobar morphotectonic block to south, and exiting into the southwestern embayment. Fluvial foresets and clast imbrication is to the south for dated Cretaceous (Ludbrook, in Rayner, 1969) sediments unconformably overlain by possible ice rafted boulders (Gibson & Chan, 1999) at The Meadows gravel scrape to the west of Cobar. Tectonic reactivation of

Palaeozoic faults on the eastern side of the Cobar uplands may relate to cessation of convergence to the east in the Late Cretaceous and the resulting change in palaeoslope from north to north-west.

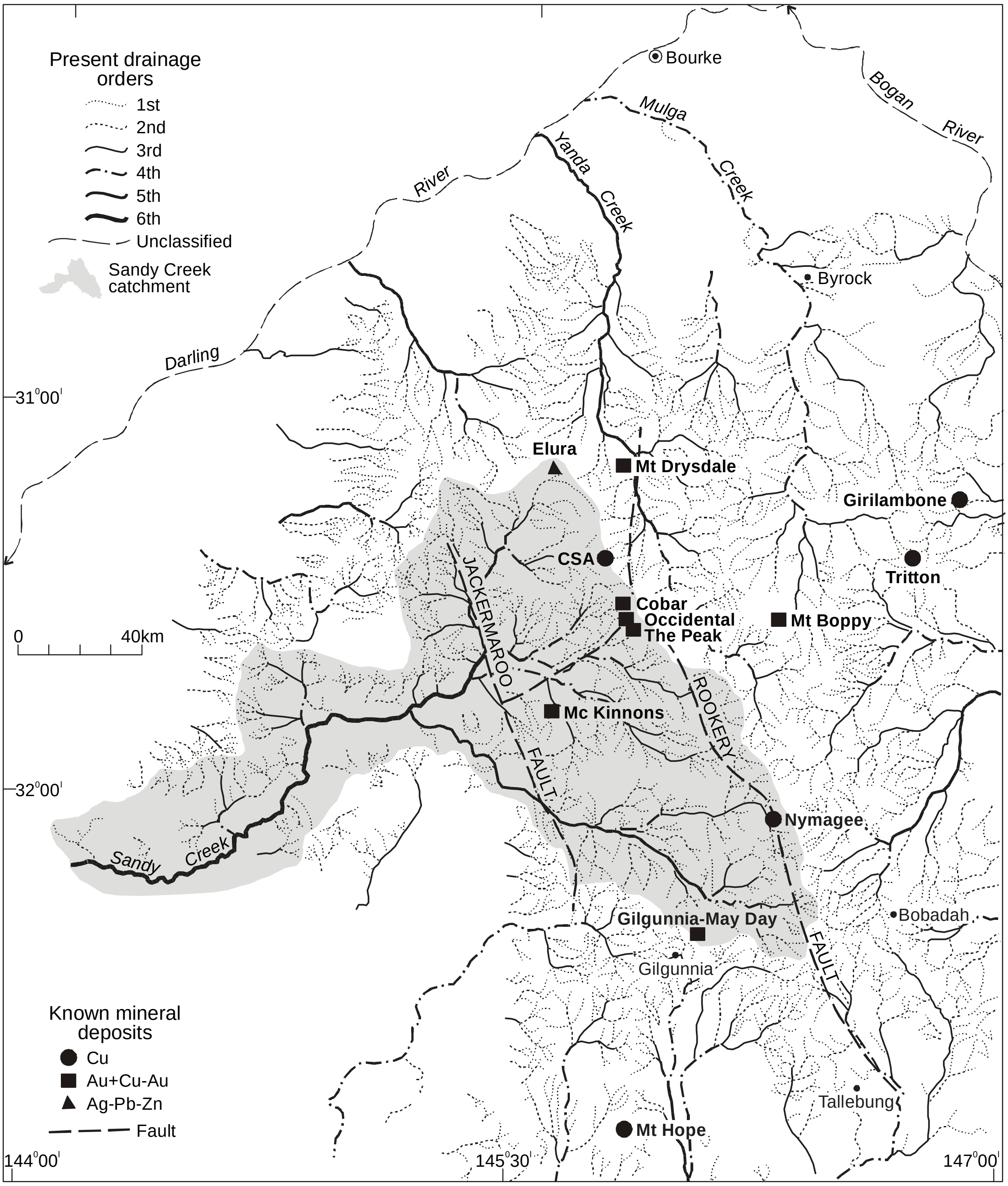

Figure 3. Present drainage orders and anomalous catchment with known mineral deposit locations in the Cobar uplands. Drainage base derived from Geoscience Australia NATMAP 1:250,000 scale topographic maps.

Stage 4.

Palaeo"A" creek captures the west trending headwaters of palaeo"B" creek (via Sandy Creek) further towards the west due to tilting of the western morphotectonic Cobar block to north, and exits into the southwestern embayment. The beheaded palaeo"B" creek continues to flow south into the embayment. Tectonic reactivation of Palaeozoic faults on the western side of the Cobar uplands may relate to formation of the Murray Basin in the Palaeocene.

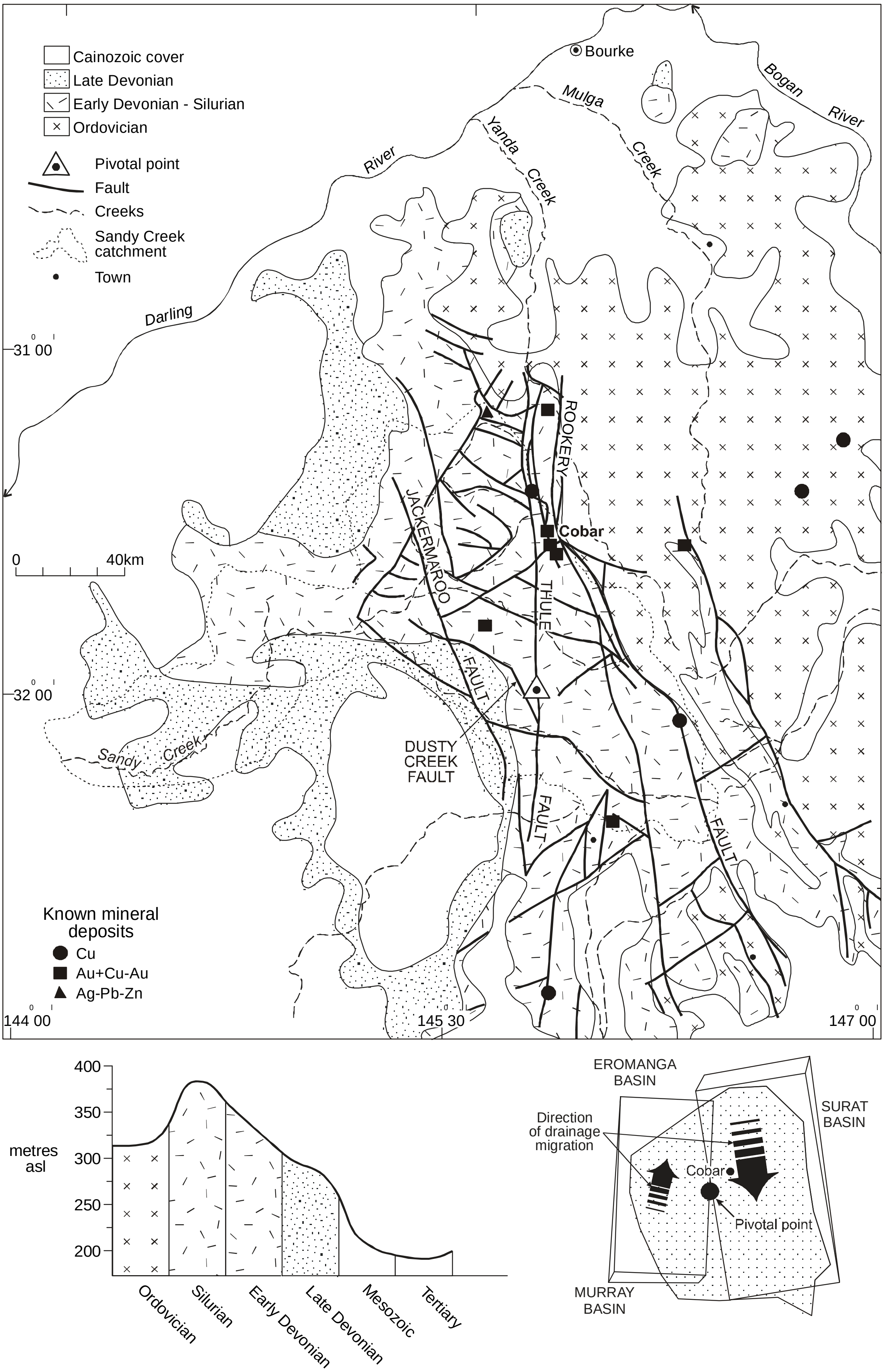

Figure 4. Geology and morphotectonics with known mineral deposits in the Cobar uplands. Faults derived from Glen *et al.* (1996) and 1:2,500,000 scale Geological Map of New South Wales (1998).

Stage 5
Sandy Creek captures the expanded west-trending headwaters of palaeo"A" creek due to headward erosion from a low base level in the Murray Basin and flows west. The beheaded trunk streams of palaeo"A" and palaeo"B" creeks continue to flow south into the embayment. Early to mid Miocene volcanism, such as that burying sediments and saprolite at El Capitan and Wilga Tank to the northeast of Cobar, suggests a period of renewed tectonism, perhaps due to mantle hot spot activity, that may have increased the east-west stream gradient between the Cobar uplands and the Murray Basin at this stage.

Stage 6
Sandy Creek is beheaded of its northwestern tributary arm as it reverses its flow direction towards the north due to continued tilting of the western Cobar morphotectonic block, and is captured by Windara Creek exiting to the west through a gap in the north trending Devonian ridge near Plain Paddock Tank to the west of Cobar. Buried fluvial palaeosediments are preserved at Plain Paddock Tank. With further tilting towards the north this beheaded creek is captured by Tambua Creek and exits to the west at Mount Gap. Palaeosediments exposed at Mount Gap are interpreted as dammed fluvio-lacustrine sediments prior to capture to the west..

The drainage has evolved in an anticlockwise direction in response to the formation of the Eromanga and Murray Basins (Figure 2) and their associated changes in base level. Northerly flowing drainage in the Mesozoic has changed to westerly flowing drainage in the Cainozoic. Palaeozoic faults have been reactivated due to the formation of the surrounding basins, and have significantly impacted on the drainage evolution of the region. Geomorphic evidence indicates that reactivation of this Palaeozoic structural framework continued into the Cainozoic. Apart from some small remnants, such as silcreted inverted relief ?Late Jurassic sediments and fluvial Cretaceous sediments, there is very little record of any Carboniferous to Cretaceous sedimentation, suggesting major erosional stripping or non-deposition. The present day drainage has evolved from a high-density drainage associated with wet climatic conditions, to a drainage characterized by sporadic or intermittent runoff, consistent with drier conditions.

Understanding the drainage evolution of the Cobar uplands has important economic implications. Geochemical exploration for polymetallic deposits in this region is hampered by shallow to thick cover of both *in situ* and transported regolith, particularly in palaeochannels. Knowledge of the palaeochannel systems can assist in the interpretation of transported or displaced geochemical anomalies. It can also be useful in predicting areas of greater erosional stripping of weathering profiles. Progressive, greater stripping of old profiles in the McKinnons area for example (N. Rutherford pers. comm.) can be explained by the neotectonic northward tilting of this area. In the Cobar uplands there is potential for placer deposits of gold and platinum group elements in some of the palaeodrainage systems. Morphometric analysis of each stage of drainage evolution has the potential to highlight anomalous drainage order zones in catchments with fast growth of drainage orders, such as the Sandy Creek catchment in Stage 6. Low order drainage zones can reflect fractured areas, whereas placer deposits may be associated with higher order drainage zones.

Drainage order and lineament analyses can also help in interpretation of basement structures and indicate the presence of additional, potentially mineralized structures. The potential for mineral discovery in the Sandy Creek catchment is high as there is an association of a denser fault network (Figure 4) with the north-northwest trending eastern headwaters of this catchment. Many of the known mineral deposits in the region (Figure 4) are associated with these types of faults. The analysis of drainage evolution is also useful in assessing sediment transport directions, and the net foci of sediment deposition..

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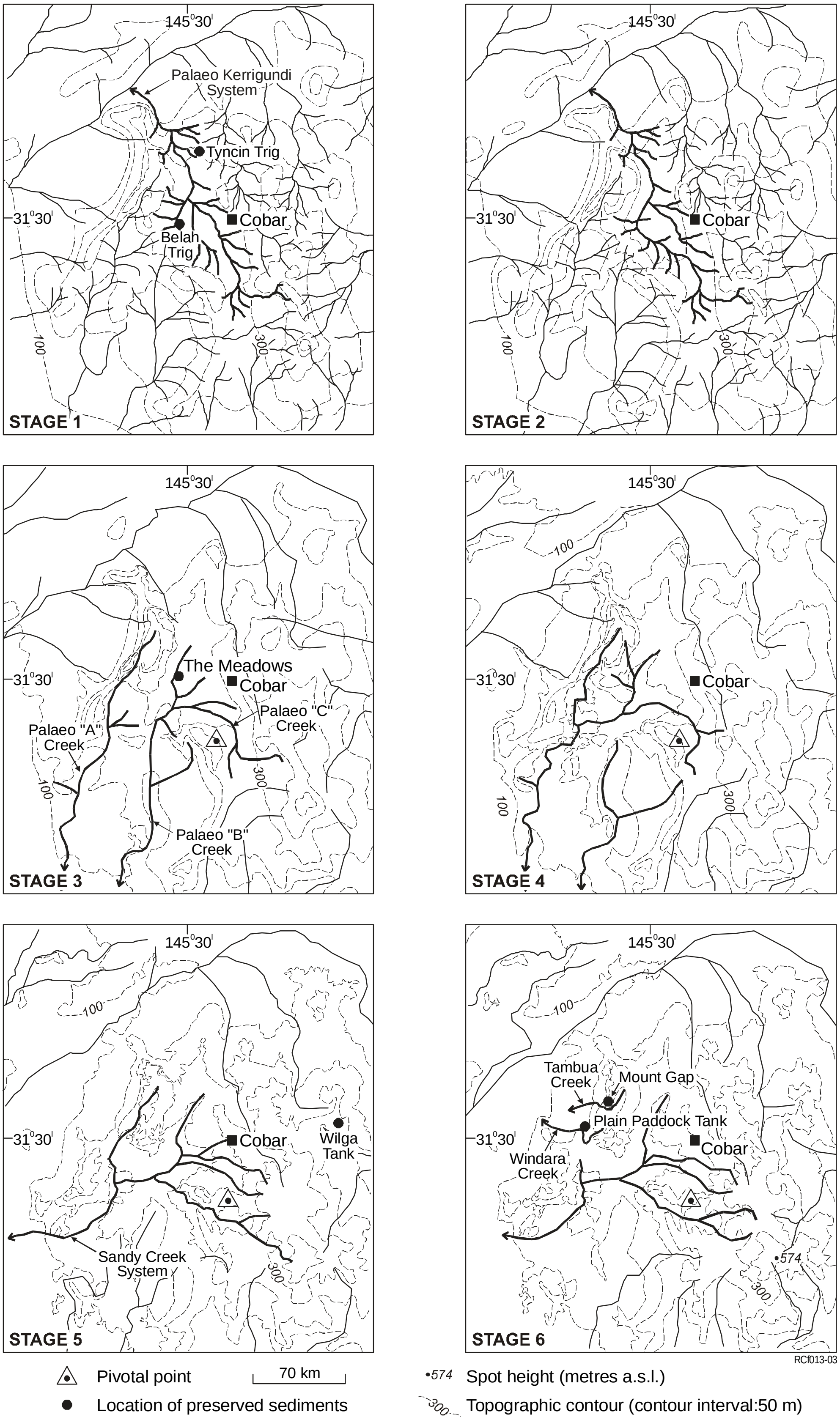

Figure 5. Drainage and topographic evolution stages for the Cobar uplands.

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GIRILAMBONE-COBAR PROJECT: A COLLABORATIVE VENTURE BETWEEN NSW DMR AND CRC LEME

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The Girilambone-Cobar Project is a collaborative venture between the NSW DMR and CRC LEME. The project commenced in June 2000 as part of *Exploration NSW* and is currently focused on the Girilambone Belt to the east of Cobar. It involves the talents of a multi disciplinary team of geologists, geochemists regolith scientists and geophysicists and a key feature of the project is the use of shallow aircore drilling to gain 3D information on the regolith and deeper samples for bedrock interpretation.

The Cobar-Girilambone-Nymagee region is one of the richest mineral provinces in New South Wales. Major deposits occur in the Cobar Basin, around Girilambone and at Canbelego and Nymagee. However, apart from the recent discovery of the Tritton copper deposit, 17 km south of Girilambone, and the re-opening of the Canbelego open-pit gold mine, there has been very little modern exploration activity in the section of the area to the east and northeast of Cobar. Indeed, the DMR's databases show that historically, some parts of this area have never been held under an exploration licence.

The Girilambone-Cobar Project began with three main aims. These were to:

- Gain a better understanding of the basement rocks and regolith within the Girilambone Belt;
- Produce a dataset of regional background geochemical, petrological and other exploration related data;
- Provide a better understanding of the regolith and weathering alteration processes within the area.

Outcrop within the project area is generally highly weathered and poorly exposed, commonly occurring as subcrop within creeks, roadside drains and borrow pits. The oldest outcropping rocks are the Cambro-Ordovician Girilambone Group, which, according to the currently available 1:250 000 Cobar and Bourke Metallogenic maps, covers most of the project area. Siluro-Devonian "Cobar Basin" rocks are shown as occurring in the west. Alluvial sediments and sand plains cover much of the area, making it difficult to accurately map the bedrock of a large part. The advent of *Discovery 2000* and the resulting acquisition of high resolution airborne magnetic data over this region, combined with a belief that highly prospective Siluro-Devonian "Cobar Basin" equivalent rocks may occur within the project area, provided the impetus for the Girilambone-Cobar Project.

Since June 2000, three shallow drilling programs have been completed along approximately east-west orientated roadside traverses in the Sussex-Coolabah, Hermidale and Byrock regions. Hole spacing along these traverses varied from 1–3 km. During the first two programs, drill sites where chosen, where possible, to test sites with varying regolith and to target magnetic features as well as the dominant NNW-trending structures. Prior to undertaking the third drilling program, a 1:100 000 special edition Byrock regolith-landform map (Buckley 2004) was completed. Information from this mapping, combined with data from a first edition magnetic basement interpretation map (Fleming & Hicks 2003) allowed holes to be sited to specifically check proposed geological and regolith units, as well as to target magnetic features.

Figure 1. Air-core drilling rig in action during the Byrock Drilling Program, May-June 2003.

To date, 247 aircore holes have been drilled throughout the Girilambone Belt for a total of 7571 meters. A total of 3364 samples have been collected and geochemically analysed for a large range of elements. This has provided a good understanding of the background geochemical character of the region. Detailed petrographic examination of 323 "core stick" samples collected during the drilling, together with field investigations throughout the project area have led to the realisation that up to 30% of the area is composed of possible Siluro-Devonian sediments. It is likely that distinct north-trending magnetic zones visible on the "overburden filtered" 1VD magnetic data represent "fingers" of imbricate thrust faulted Siluro-Devonian sediments (Fleming & Hicks, 2003). Very highly strained polymictic conglomerates, which outcrop in a northerly belt for over 50 km from Florida station just north of Canbelego through to Druinn Trig on Tara Station show evidence for a Siluro-Devonian depositional age. These conglomerates are currently mapped as Ordovician, however particular pebble lithologies, including radiolarian cherts, crenulated phyllites and siltstones, together with the presence of volcanic quartz within both the matrix and some sandstone pebbles all support a much younger age. Petrographic evidence from pebbles collected from conglomerates at Mount Boppy and Tara suggests a provenance of both Girilambone Beds (θg) and Siluro-Devonian formations (L. Barron pers com., 2004). Pebble lithologies and the presence of volcanic quartz in the matrix suggests a comparison with the less strained Siluro-Devonian Cobar Supergroup conglomerates, which are associated with fault controlled gold mineralisation at Canbelego.

Figure 2. Quartz veining in sandstone bed within Conglomerate unit, Tara Hills. (GDA 430689E – 6563000N).

Figure 3. Polymictic conglomerate, Tara Hills (GDA 430650E – 6553080N).

A preliminary basement interpretation map was completed for the project area in November 2002. However due to time constraints and lack of drilling over much of the area, the interpretation was a "first pass" representation of two dimensional features identifiable in high resolution airborne magnetic data, as well as in gravity and radiometric data. A new, "second addition" Magnetic Basement Interpretation Map is presented here. Definitive age and lithological information has been added from a large amount of project-related drill hole and outcrop data, as well as from open-file exploration drill hole data.

A key tool for interpreting the magnetic data was "overburden filtered" imagery reprocessed by Vector

Research Pty Ltd using the *Discovery 2000* airborne magnetic survey data covering the Bourke, Brewarrina and parts of the Cobar 1:250,000 sheet areas. This filter has the effect of 'removing' surficial noise and revealing magnetic features at depth. Conventional geophysical imagery was used for the remainder of the Cobar 1:250,000 sheet area. Several important features have been highlighted by this interpretation:

- There is far greater structural complexity within the project area then the current geological mapping suggests;
- Major continuous north-trending structures are traceable from south of Canbelego to well into the Bourke 1:250,000 sheet area, a distance of approximately 100 km;
- The area of Early Devonian Kopyje Group or equivalents (north east of Cobar) has been extended by a large degree;
- Continuous northerly-trending 'belts' of distinctly different magnetic signature are identified and interpreted as of likely Siluro-Devonian age.

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A SUPERGENE EXPLORATION MODEL FOR COBAR STYLE DEPOSITS

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Knowledge of the geochemical "signature" of particular mineralisation is a prerequisite for exploration in the supergene environment. Particular elements may be widely dispersed compared to others and it is necessary to have some understanding of the chemical controls that govern this dispersion. With this in mind, it has been adventitious that the oxidised zone of the New Cobar orebody near Cobar, New South Wales, has been recently exposed. Primary mineralisation at New Cobar is of the typical "Cobar" type (Rayner, 1969; Stegman, 2000; Stegman & Pocock, 1996) and consists of arsenopyrite, (FeAsS), pyrite, (FeS_2) marcasite, (FeS_2), chalcopyrite ($CuFeS_2$), galena, (PbS), sphalerite, ZnS, pyrrhotite, ($Fe_{1-x}S$), and magnetite (Fe_3O_4). Cassiterite, (SnO_2), native bismuth, bismuthinite, (Bi_2S_3), and rarer tungsten, molybdenum and selenium minerals are accessories, in common with a number of other deposits in the region. Quartz is the most common gangue mineral and very little primary carbonate mineralisation is present.

In the supergene zone, separate suites of oxidised base metal carbonate and arsenate minerals have been identified; many of the species present are new to the region (Leverett *et al.*, 2003). The more common arsenate suite minerals include agardite, ($Cu_6(REE)(AsO_4)_3(OH)_6.3H_2O$), bayldonite, ($Cu_3Pb(AsO_4)_2(OH)_2$), chenevixite, ($Cu_2Fe_2(AsO_4)_2(OH)_4.H_2O$), duftite, ($CuPbAsO_4(OH)$), gartrellite, ($PbCuFe(AsO_4)_2(OH).H_2O$), mimetite, ($Pb_5(AsO_4)_3Cl$), olivenite, ($Cu_2AsO_4(OH)$), philipsbornite, ($PbAl_3(AsO_4)_2(OH)_5.H_2O$) and segnitite, ($PbFe_3(AsO_4)_2(OH)_5.H_2O$). This assemblage was confined to the lode channel and samples were recovered from quartz-rich stope pillars. Superimposed on this arsenate assemblage is a carbonate suite dominated by azurite, ($Cu_3(CO_3)_2(OH)_2$), and malachite, ($Cu_2CO_3(OH)_2$). This assemblage formed later in the paragenetic sequence and is dispersed more widely through enclosing host rocks. Reconstruction of the chemical environments responsible for the generation of the two oxidised suites provides a ready explanation for the differential geochemical dispersion of Cu and Pb±As in this setting and suggests a strategy for geochemical exploration for Cobar style deposits that have an expression in the intact regolith.

Relationships between the minerals of the arsenate assemblage in the oxidised zone of the New Cobar orebody can be effectively described by an equilibrium approach at ambient temperatures. Minerals taken into account are listed in Table 1 together with data used to derive the phase diagram (Williams, 1990). A value for the free energy of formation (ΔfG^o) of philipsbornite was taken from Schwab *et al.* (1993) with correction to 298.2K using data provided for the analogous phosphate. Other thermodynamic data for these and subsequent calculations were taken from Barner and Scheuerman (1978), Smith and Martell (1976, 1989) and Robie and Hemingway (1995).

Table 1. Thermodynamic data for Cu (II) and Pb(II) arsenate species used in the diagrams below.

Mineral	Formula	ΔfG^o (298.2 K, kJ mol^{-1})
Lammerite	$Cu_3(AsO_4)_2$	-1300.8
Olivenite	$Cu_2AsO_4(OH)$	-846.4
Clinoclase	$Cu_3AsO_4(OH)_3$	-1211.2
Cornwallite	$Cu_5(AsO_4)_2(OH)_4$	-2057.9
Duftite	CuPbAsO4(OH)	-961.1
Bayldonite	$Cu_3Pb(AsO_4)_2(OH)_2$	-1809.8
Mimetite	$Pb_5(AsO_4)_3(OH)$	-2674.3
Philipsbornite	$PbAl_3(AsO_4)_2(OH)_5.H_2O$	-4361.2
Shultenite	$PbHAsO_4$	-809.2

A phase diagram for the minerals relevant to the New Cobar deposit is shown in Figure 1. Knowledge of just which minerals are present in the oxidised zone permits deduction of certain chemical solution characteristics. Pb^{2+} was included in calculations with an activity of 10^{-8}; higher values serve to eliminate olivenite from the diagram at all but very (and unrealistically) high activities of Cu^{2+}. Further calculations

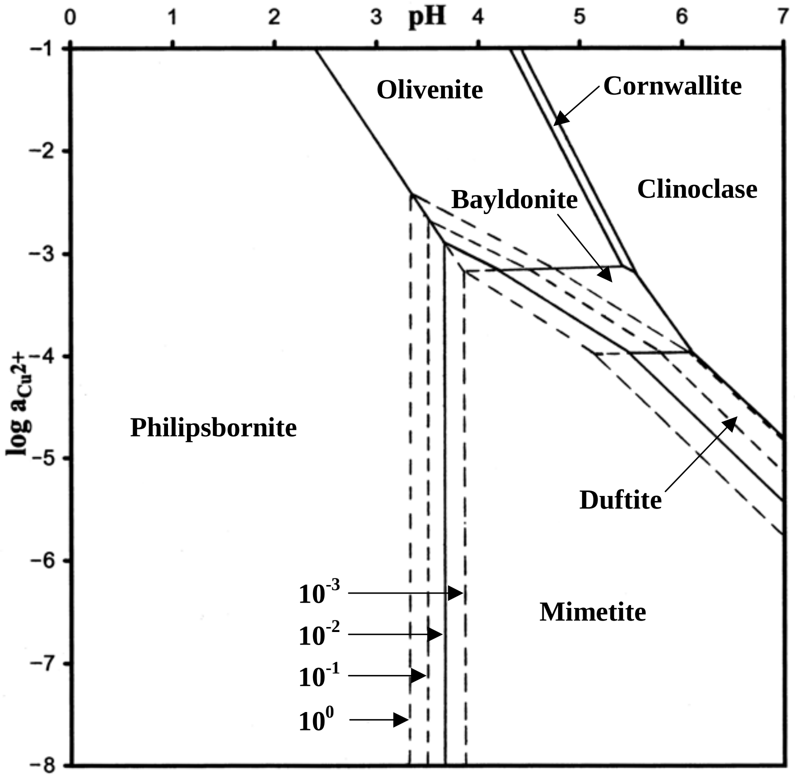

Figure 1. Stability field diagram for Cu(II) and Pb(II) arsenates at 298.2 K in the presence of gibbsite (observed in the oxidised zone at New Cobar), with $a_{Pb^{2+}} = 10^{-8}$ and $a_{Cl^-} = 10^0, 10^{-1}, 10^{-2}$ (bold), and 10^{-3} (as indicated).

show that under conditions of higher Pb^{2+} and reasonable chloride activities, bayldonite and duftite are unlikely to form due to the high Cu^{2+} activities required. Also contoured on Figure 1 are stability fields for mimetite, depending upon prevailing chloride activity. Since no cornwallite or clinoclase was detected in the deposit, inspection of Figure 1 indicates that the Pb-Cu arsenate assemblage formed at a pH of 5 or lower, since philipsbornite is a very frequent associate. With this in mind, and with a judicious choice of other solution parameters, it is possible to reconstruct the chemical nature of the solutions responsible for the development of the Pb-Cu arsenate mineralisation of the New Cobar orebody. Furthermore, it can be shown that these conditions are inappropriate for the formation of other common secondary minerals of Pb(II), such as anglesite, ($PbSO_4$), and cerussite, ($PbCO_3$). With respect to major dissolved constituents, saline ground waters are represented by contributions from sulfate formed during the oxidation of sulfides and sulfosalts, and chloride, this being reflected in the crystallization of large amounts of mimetite in the secondary arsenate suite. In this connection a choice of $a_{Cl^-} = 10^{-2}$ is reasonable, since mimetite can form from bayldonite or duftite at such a value but higher activities (> 10^{-1}) serve to eliminate the fields of the copper-containing species completely. A value of $a_{Cl^-} = 10^{-2}$ is consistent with observations of chloride contents of other ground waters in arid environments, but is well below the chloride concentration of sea water (ca 0.5 M) or other hyper-saline brines. Likewise, a choice of a similar sulfate activity is justified by references to ground water compositions of related deposits (Williams, 1990). Thus a proxy for the bulk ionic composition of the mineralising solutions is an aqueous solution that corresponds to 10^{-2} NaCl plus 10^{-2} Na_2SO_4. With respect to pertinent ionic components of lower activities and the calculation of associated concentration terms, it is necessary to evaluate ionic strength and ionic activity coefficients. For the above bulk solution composition, use of the extended Debye-Hückel relationship $\log \gamma = -Az^2[I^{½}/(1+I^{½}) - 0.3I]$ at T = 298.2 K (the temperature adopted for all model calculations), gives $\gamma = 0.834$ and 0.485 for univalent and divalent ions, respectively. It is then possible to derive Pb(II), Cu(II) and $H_2AsO_4^-$ activities in these solutions when the assemblage of interest was formed. For this purpose, we may consider the formation of bayldonite-duftite assemblages at the equilibrium boundary of the appropriate phase diagram. An activity of Pb(II) ion of as little as 10^{-8} is seen to encroach significantly on the stability fields of the Pb-free copper arsenates and the Cu(II) ion activity at the bayldonite-duftite boundary under these conditions is *ca* 10^{-4}. This Pb(II) activity represents only a few ppb of dissolved lead and is consistent with observations of solution compositions in related oxidised zones

(Williams, 1990). An arsenate activity can then be derived on the basis of the above values by considering the dissolution of duftite at a pH of 5 (see above), as expressed in the following equation.

$$CuPbAsO_4OH(s) + 3H^+(aq) \leftrightarrow Cu^{2+}(aq) + Pb^{2+}(aq) + H_2AsO_4^-(aq) + H_2O(l)$$

At 298.2 K, log K for the reaction equals –1.92. Substitution of values $a_{Pb2+} = 10^{-8}$, $a_{Cu2+} = 10^{-4}$, pH = 5 gives an activity of $H_2AsO_4^-$ of $10^{-4.92}$. It should be noted that at the pH chosen, $H_2AsO_4^-$ is the predominant arsenate species present. It is now a simple matter to evaluate solution *concentrations* of selected species using the activity coefficients given above. Accordingly, $[Pb^{2+}]$, $[Cu^{2+}]$ and $[H_2AsO_4^-]$ equal 2.04 x 10^{-8}, 2.09 x 10^{-4} and 1.45 x 10^{-5} mol dm^{-3}, respectively. This approach can be further refined by consideration of the formation of complex species in solution, from the constituent cations and anions. Values for stability constants for chloride and sulfate complexes were taken from Smith and Martell (1976); those used for $M(II)H_2AsO_4^+$ are set to the value for the analogous phosphate species $CuH_2PO_4^+$. Species included in the calculations are $CuCl^+$, $PbCl^+$, $PbCl_2^o$, $PbCl_3^-$, $PbCl_4^{2-}$, $CuH_2AsO_4^+$, $PbH_2AsO_4^+$, $CuSO_4^o$, $PbSO_4^o$ and $Pb(SO_4)_2^{2-}$. Higher chloride species of Cu(II) were neglected in view of their small association constants, as were contributions of hydrolysed species at the given pH of 5. The species $CuH_2AsO_4^+$, $PbH_2AsO_4^+$, $PbCl_3^-$, $PbCl_4^{2-}$ contribute negligible amounts to total Pb(II) and Cu(II) concentrations. As far as other species of interest, carbonate warrants consideration. It is emphasised that copper carbonates are later in the paragenesis at New Cobar and a separate model for this stage of supergene mineralisation is needed. Otherwise, in terms of the above, a suitable starting point is to fix the CO_2 pressure at atmospheric levels, $10^{-3.5}$, when carbonic acid concentrations are thus fixed. This approach has been explored in detail elsewhere (Williams, 1990). At pH = 5, activities of $HCO_3^-(aq)$ and $CO_3^{2-}(aq)$ are also fixed and calculated values permit an assessment of the significance of the carbonato and bicarbonato complexes $CuCO_3^o$, $Cu(CO_3)_2^{2-}$, $PbCO_3^o$, $Pb(CO_3)_2^{2-}$, $CuHCO_3^-$ and $PbHCO_3^-$, using stability constant data taken from Smith and Martell (1976, 1989) and by putting the stability constant for $PbHCO_3^-$ equal to that of the Cu(II) analogue. Under these conditions, calculated activity of any of the carbonate complexes of Cu(II) and Pb(II) never exceeds $10^{-8.5}$ and $10^{-12.8}$, respectively, and are negligible with respect to total dissolved metal concentrations. A summary of significant dissolved species and total dissolved Cu, Pb and As relevant for the secondary arsenate mineralising event is given in Table 2.

Table 2. Calculated concentrations (mol dm^{-3}) of significant dissolved Cu, Pb and As species at 298.2K, pH 5, $p_{CO2} = 10^{-3.5}$, and $a_{NaCl(aq)} = a_{Na2SO4(aq)} = 10^{-2}$ (see text).

$[Cu^{2+}]$	$10^{-3.68}$	$[Pb^{2+}]$	$10^{-7.68}$	$[H_2AsO_4^-]$	$10^{-4.84}$
$[CuCl^+]$	$10^{-6.32}$	$[PbCl^+]$	$10^{-8.49}$		
$[CuSO_4^o]$	$10^{-3.56}$	$[PbCl_2^o]$	$10^{-10.20}$		
		$[PbSO_4^o]$	$10^{-7.25}$		
		$[Pb(SO_4)_2^{2-}]$	$10^{-9.70}$		
$[Cu_{total}]$	*4.90 x 10^{-4}*				
$[Pb_{total}]$	*7.94 x 10^{-8}*				
$[As_{total}]$	*1.45 x 10^{-5}*				

These results may be contrasted with those calculated for the mineralising event associated with the secondary copper carbonates. An effective model for this stage of mineralisation is conceptually simple. In the New Cobar oxidised zone, malachite and azurite form intimate intergrowths in the oxidised zone and thus the prevailing CO_2 pressure for this to occur must have been close to the equilibrium partial pressure derived for the following transformation.

$$3Cu_2CO_3(OH)_2(s) + CO_2(g) \leftrightarrow 2Cu_3(CO_3)_2(OH)_2(s) + H_2O(l)$$

Thermochemical data were taken from the above sources and an equilibrium pressure equal to $10^{-1.36}$ was calculated at 298.2K This is in accord with estimates of crystallisation temperatures from stable isotope measurements. Iterative calculations lead to a pH of 4.59 and concentrations of other carbonate species follow (Table 3). Further, using stability constants from Smith and Martell (1976, 1989), the activities of carbonato and bicarbonato complexes of Cu(II) and the $Cu^{2+}(aq)$ ion in equilibrium with malachite/azurite can be derived. These calculations alone are valid but the more realistic model adopted here takes into account chloride and sulfate species, the latter being assigned a somewhat lower concentration than was the

Table 3. Calculated activities and concentrations (mol dm^{-3}) of significant dissolved Cu and associated species in equilibrium with azurite and malachite at 298.2K and $p_{CO2} = 10^{-1.36}$, $[Na^+] = 0.012$ M, $[Cl^-] = 0.01$ M, $[SO_4^{2-}] = 0.001$ M (see text).*

Activities			
pH	4.59	Cl^-	$10^{-2.05}$
Cu^{2+}	$10^{-2.15}$	SO_4^{2-}	$10^{-3.19}$
$CuCl^+$	$10^{-3.80}$	$H_2CO_3^o$	$10^{-2.83}$
$CuSO_4^o$	$10^{-2.98}$	HCO_3^-	$10^{-4.59}$
Na^+	$10^{-1.97}$	CO_3^{2-}	$10^{-10.24}$
$CuHCO_3^+$	$10^{-5.75}$	$CuCO_3^o$	$10^{-5.74}$
$Cu(CO_3)_2^{2-}$	$10^{-12.90}$	p_{CO2}	$10^{-1.36}$
Concentrations			
Cu^{2+}	0.011	$CuHCO_3^+$	1.98×10^{-6}
$CuCl^+$	1.76×10^{-4}	$CuCO_3^o$	1.82×10^{-6}
$CuSO_4^o$	1.05×10^{-3}	$Cu(CO_3)_2^{2-}$	1.96×10^{-13}
$[Cu_{total}]$	*1.22×10^{-2}*		

*Activity coefficients of neutral ion pairs taken to be unity.

case above in light of the evolving paragenesis. For the carbonate event, solution parameters are summarised in Table 4.8. With total chloride and sulfate concentrations fixed at 10^{-2} and 10^{-3}, respectively, and with sodium as the counter ion, the ionic strength is calculated as 0.013 and $\gamma_{\pm} = 0.90$, $\gamma_{2\pm} = 0.64$.

The startling conclusion to be drawn from the data of Tables 2 and 3 is that total dissolved copper is nearly two orders of magnitude greater in solutions associated with the carbonate mineralising event, as compared with the arsenate-mineralising event.

In turn, this provides a rationale for the differential dispersion of copper versus lead during the development of the oxidised zone of the New Cobar orebody and the results may be applied to geochemical exploration techniques for base metal-associated gold deposits in the Cobar Basin. This notion is reinforced by the similarities observed for secondary mineral occurrences in oxidised zones found across the Basin and ranging from the north at Elura, through the cental Cobar mining field, to the south as far as Wagga Tank and Mineral Hill. The only significant difference between the several deposits that have been studied by various workers appears to be the presence (sometimes in large amounts) of cerussite and anglesite in some of them. These normal Pb(II) salts also are quite insoluble species and the difference in mobility of lead and copper in the oxidised zones remains a prominent geochemical feature of the region.

The implications of the above are straightforward; the Pb(II)-Cu(II) arsenate suite in the New Cobar orebody is restricted to the central mineralised zone; a direct effect of the relatively limited solubilities of minerals of this type. When sufficient arsenic is present in the oxidised zone to fix Pb(II) and Cu(II), dispersion of these elements will be limited. It appears that in the New Cobar orebody enough arsenic was present to fix essentially all of the lead but was not sufficient to fix the large quantities of copper released in the oxidised zone. Conversely, the Cu(II) hydroxycarbonates malachite and azurite are found in significant quantities in the deposit many metres from the central mineralised zone. This is directly related to the solubilities of malachite and azurite in carbonated groundwaters, which are considerably higher than those of related Cu(II) arsenates (Williams, 1990). As noted above, the activity of copper in solutions associated with the arsenate assemblage is almost two orders of magnitude lower than for solutions associated with the copper carbonate assemblage. Anomalous levels of copper are thus anticipated in dispersion trains of greater extent than would be the case for lead and arsenic. As many of the other gold and base metal deposits in the Cobar Basin have a comparable primary mineralogy, the geochemical model developed for the oxidised zone at New Cobar may be extended to exploration for other deposits in the area. In simple terms, a broad copper anomaly would be expected to form a relatively large halo surrounding an oxidised deposit; Pb and As anomalies would be expected to have significantly more limited expressions, closer to primary sources, and could be used to pinpoint deposits in terms of drill targets. While this conclusion is broadly in line with long held and generally accepted views concerning the relative mobilities of base metals in the supergene environment, the present study has provided a rational mineralogical and geochemical model for the phenomenon for Cobar style deposits.

Limited studies undertaken in the area with respect to geochemical exploration and observations concerning a number of other prospects and deposits lend support to the model. Lead arsenate/phosphate mineralisation associated with the oxidised zone of the Spotted Leopard deposit is a case in point. It is noted that this style of secondary mineralisation was completely overlooked by earlier workers, although it did receive passing mention by Rayner (1969). Similarly, anglesite and Pb-bearing members of the alunite-jarosite supergroup (particularly plumbogummite, hinsdalite and beudantite) have been noted by various workers at a number of deposits and prospects in the region, including the McKinnons gold deposit, the Wagga Tank prospect, and the No. 4 Tank prospect. Tight arsenic anomalies are associated with the first of these and the Mrangelli prospect. Recently, both duftite and mimetite were identified by powder X-ray diffraction for the first time in oxidised ore from the Mineral Hill mine. Broad copper anomalies surrounding narrow, linear, north-south trending Pb and As anomalies are known from elsewhere in the region (Stockton, pers. comm., 2003). Special mention should be made of the Elura deposit. Although considerable amounts of cerussite and anglesite, together with minor lanarkite, (Pb_2OSO_4), occur in the oxidised zone of the deposit, secondary lead mineralisation is dominated by beudantite, ($PbFe_3(AsO_4)(SO_4)(OH)_6$) hidalgoite, ($PbAl_3(AsO_4)(SO_4)(OH)_6$), and, especially, mimetite. Broad, low-contrast Cu and Zn anomalies are associated with residual soils but highly anomalous Pb and As anomalies are associated with *in situ* and solution-deposited gossans.

Finally, other characteristic mineralogy of Cobar-style may be useful to further prioritise geochemical anomalies. Small but significant quantities of the resistate mineral cassiterite, (SnO_2), are present at all levels of the oxidised zone of the New Cobar orebody. The presence of tin is in fact a feature of Cobar-style mineralisation (Rayner, 1969; Stegman, 2001;). Rayner (1969) reported elevated levels of tin (up to 0.3%) in chalcopyrite from the Great Cobar, Gladstone, New Cobar, Chesney and Shuttleton deposits. He tentatively assumed that the tin was present as stannite, (Cu_2FeSnS_4), but observations at New Cobar suggest that cassiterite was responsible. This is born out by more recent studies of primary mineralisation at the Peak and New Occidental orebodies, which identified an early cassiterite-wolframite-scheelite depositional event (Stegman, 2001). In addition, elevated concentrations of tin as cassiterite have been noted to occur in the Elura gossan. Significant cassiterite is also present in primary and oxidised zones of the Mount Boppy orebody, some 40 km to the east of Cobar (although this deposit is hosted by sediments of the Girilambone Group). Since the regolith in the Cobar region is highly weathered, leaching of base metals, especially near the surface, renders geochemical exploration difficult. However, the immobility of tin in cassiterite might prove useful since any tin anomaly would be very localised. This suggestion remains to be tested, but may form a useful geochemical exploration adjunct to the methods suggested by patterns of Pb and Cu mineralisation, the models for which would benefit from further refinement and validation over known mineralisation.

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THE NATURE, ORIGIN AND EXPLORATION SIGNIFICANCE OF THE REGOLITH, GIRILAMBONE-COBAR REGION

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INTRODUCTION

The Girilambone-Cobar region has been a surficial or near surficial environment since at least the Mesozoic. The region is now an elevated palaeoplain straddling the Canobolas Divide between the Lachlan and Darling Rivers (Figure. 1). It is flanked by the Mesozoic-Cainozoic Eromanga, Surat and Murray Basins and much of the history of erosion and deposition across the block has been controlled by events in these basins, particularly the timing of basin initiation and subsequent changes in base level.

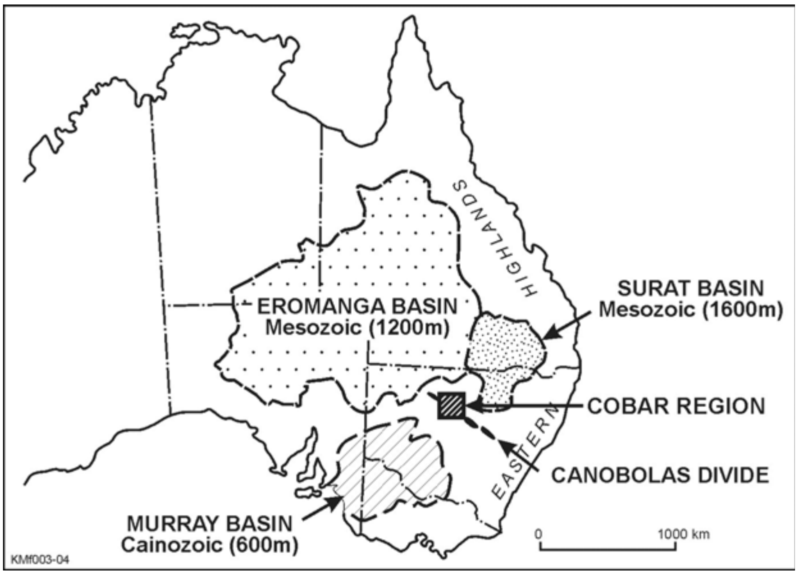

Figure 1. Location and regional geomorphic setting of the Girilambone-Cobar region. The approximate maximum thickness of preserved sediments in the basins is shown (in parentheses).

There has been a long and complex history of weathering and regolith development in the region. Preserved weathering profiles show great variability (<3 m to >100 m thick). This variability has resulted from a combination through time of variable depth of weathering, controlled by the interplay of lithological variation, permeability and availability of water, and variable erosion, reflecting differential tectonic uplift and incision. Older profiles are preserved beneath resistant cretes, palaeochannel sediments and leucitite lava flows. Some of these older profiles are inverted in the present landscape.

Detailed regolith-landform mapping of key sites, combined with apatite fission track and palaeomagnetic dating, now provides a better knowledge and understanding of the regolith and a temporal framework for regolith evolution. This has important implications for understanding geochemical dispersion and for applying geochemical exploration methods.

COVER THICKNESS

The exposed bedrocks of interest for mineral exploration in the Girilambone-Cobar region include: Early Devonian turbidites and shelf facies sediments; Devonian and possibly some Silurian felsic volcanic rocks; Ordovician metasediments, mafic volcanics and Alaskan-type mafic intrusions; and Silurian and Devonian granitoids. The oldest preserved cover rocks of any great thickness on these units are late Early to Late Devonian fluviatile sediments of the Mulga Downs Group. Thin (<30 m) remnants of mostly fluviatile, lacustrine and possibly shallow marine sediments of younger age (Cretaceous-Early Tertiary) are preserved at different levels in the present landscape. There is also extensive cover by younger transported regolith, particularly in palaeochannel systems (up to 60 m deep), colluvial fans and plains and modern drainages. Much of the post-Miocene cover is backfilling older more deeply incised palaeovalleys. The geological evidence suggests a continuously evolving landscape with concomitant erosion, deposition and recycling of surficial materials through changing landscape levels.

Apatite fission track dating (Donelick & O'Sullivan, 2002) at five sites across the region indicates cooling ages (<110º C) greater than 180 Ma and possibly up to >280 Ma. Time-temperature modelling of the ages and track length distributions suggests initial rapid cooling and very limited or unchanging temperatures (<50º C) for the past 160 Ma. These data are consistent with minimal cover (<1 km) over the area since about the Jurassic.

WEATHERING HISTORY

The weathering history of the Girilambone-Cobar region has been strongly influenced by major climatic variations through the Cainozoic. In general terms this has resulted in deep chemical weathering under predominantly warm humid conditions in the Early-Mid Tertiary and superimposed drier chemical weathering under increasingly arid conditions from the Late Tertiary. In detail the picture is more complex with fluctuations to at least two cooler-dry episodes prior to the Oligocene (McGowran & Li, 1997).

Early Miocene land surfaces are preserved beneath leucitite lavas in the El Capitan-Wilga Tank area northeast of Cobar. These sites provide evidence of the pre-Miocene weathering conditions. At Wilga Tank, a deep weathering profile characterised by a ferruginous mottled zone and underlying bleached saprolite is exposed beneath a dissected flow. An adjacent volcanic plug has been radiometrically dated at ca. 17 Ma. This buried profile is similar to many exposed profiles throughout the region, suggesting that much of the deep, chemical weathering predates the Early Miocene. Weathering profiles on the leucitites are extremely thin without significant ferruginisation, consistent with very limited chemical weathering since their eruption in the Early Miocene.

Palaeomagnetic dating has been conducted on ferruginous weathering profiles at Elura (43 km NNW of Cobar), McKinnons (35 km SW of Cobar), just east of Cobar (5 km), at Wilga Tank (40 km NE of Cobar) and at New Cobar (2.5 km S of Cobar, Figure. 2, McQueen *et al*., 2002). At the first two sites, results indicate two widespread periods of stable iron oxide fixation in the Latest Cretaceous to Early Palaeocene (60±10 Ma) and in the Middle Miocene (12±3 Ma). The early period is also preserved in a road cutting just east of Cobar. At Wilga Tank the Mid Miocene ferruginisation is preserved. These results show that intense chemical weathering and ferruginisation extended into the Mid-Miocene and that an older, Early Palaeocene

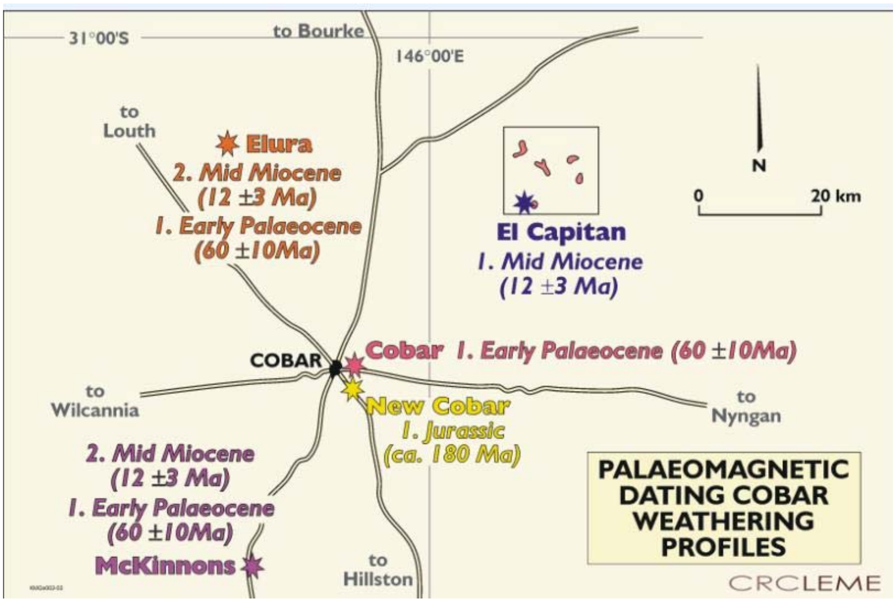

Figure 2. Location and results of palaeomagnetic dating of weathering profiles in the Cobar area. The Wilga Tank locality occurs in the southweatern area of the El Capitan volcanic field.

ferruginisation has been preserved at some sites. The period just prior to the Middle Miocene (16 Ma) was characterised by hot climatic conditions, high global sea levels and a major marine incursion in the adjacent Murray Basin. This would have promoted profile development, particularly as conditions were characterised by high perennial rainfall and high watertable levels. From the Middle Miocene, conditions became drier and falling watertables allowed oxidation and dehydration of the profiles, precipitating stable iron oxides. This is consistent with the Middle Miocene age for ferruginous materials in most of the profiles. Deep weathering was restricted after the Middle Miocene, as indicated by the limited profiles on the leucitites of this age. The Early Palaeocene ferruginisation reflects oxidation of deep weathering profiles developed through the Late Cretaceous. At the New Cobar open pit, dating of oxidised saprolite (after Early Devonian shales and siltstones) has yielded a Jurassic age (ca. 180 Ma). This indicates oxidation of the ore and hematite fixation at this time and suggests that a weathering profile has been preserved close to the surface since this time without much detectable modification or erosion. It is possible, that oxidation of the sulfide-rich deposit extended significantly deeper than weathering in the surrounding rocks. Alternatively this profile was buried and re-exposed much later. A model incorporating the current age data for cover thickness and hematite fixation is presented in Figure 3.

REGOLITH MATERIALS

The regolith of the region can be conveniently divided into *in situ*, transported, indurated and lag materials.

- *In situ* materials can be subdivided on the basis of landform setting and degree of weathering. Preserved weathering profiles vary with lithology and geomorphic setting. Weathering is generally very extensive on the Girilambone Group rocks, except for some prominent quartzite units. The Lower Devonian turbidites of the Cobar Basin are moderately to deeply weathered, but the more siliceous units, including equivalents outside the basin, are less weathered. Regolith thickness is generally less in a belt from Hermidale to Cobar, along the present divide (Cobar spur). This reflects greater erosional stripping of this zone in the later Cainozoic. Well-developed weathering profiles show considerable ferruginisation in the upper parts and ferruginous mottling and veining in the saprolite zone. However, they cannot be described as classical "laterite" profiles. This may be due to the relatively low iron content of the common lithologies (siliclastic sediments) and greater erosional modification during profile development. In many profiles it can be difficult to pick the boundary between fresh rock and saprolite (e.g. in drill cuttings) because the abundant primary minerals (quartz-muscovite-clays) are stable into the weathered zone. The breakdown of muscovite, and colour changes related to oxidation are the best guides.
- Transported materials include alluvial, lacustrine, colluvial and aeolian components. Alluvial materials are probably the most abundant and occur at all levels of the landscape. Old inverted palaeochannels contain quartz-rich sands and gravels and some cobble-boulder conglomerates. Clay-rich sediments with sand and minor gravel lenses are preserved in deeply incised palaeochannels that developed through the Tertiary. Pisoidal, ferruginous clasts are abundant in some of these palaeochannel sediments. This ferruginous component contains maghemite, resulting in a strong expression of the host palaeochannels in aeromagnetic imagery (a problem when conducting magnetic surveys for basement features). Currently active alluvial systems are dominated by sandy loams (largely sourced by sheetwash from recent soil and aeolian deposits) with minor channel gravels. Clays, silts and fine sands are common in alluvial swamp and lake deposits that developed as a result of drainage disruptions. Marginal lunettes contain coarser, well-rounded sediments. Colluvial materials are widespread in generally thin, bedrock-masking deposits. These are typically coarse and angular on upper slopes and decrease in grainsize downslope. The colluvium is generally dominated by lithic clasts in a silty loam matrix. Colluvial regolith occupies depositional and erosional plains, slope deposits on rises and less commonly colluvial fans adjacent to rangefronts and higher relief landforms. Aeolian materials mainly occur as a silt-sized component in the red silty-loam soils of the region. They also include well-rounded and sorted sands and silts in stabilised longitudinal dunes on the western edge of the area and in some source-bordering dunes adjacent to lakes and the modern drainage system.
- Indurated materials have formed during the weathering history of the region by the introduction and precipitation of silica, iron oxides and carbonates. This has occurred in bedrock, transported regolith and soils. The indurated materials are generally more resistant to further weathering and erosion and commonly become inverted in the landscape. Silicified gravels (silcretes) originally formed in channels, now occur as cappings on hills. These silcretes appear to be early to mid Tertiary in age. Silicification of more porous (typically already highly siliceous) bedrock is also a feature of the region. Ferricretes ("ironstones") occur in thick, horizontal caps and linear masses, and probably also formed low in the landscape along drainage channels or groundwater seeps. Regolith carbonate (calcrete) is common throughout the region occurring mainly as nodules in the lower part of the soil, as more massive, in some cases laminated, hardpans at the soil-bedrock/saprolite interface and as coatings and veinings on bedrock. Calcrete occurs within palaeochannels but does not appear to be present in the active, modern drainage systems The carbonate includes calcite, dolomite, and rarely magnesite. The calcretes have formed under arid climatic conditions (probably during the last 1 Ma).

- Surface lag is widespread in the present landscape and has been derived from the full range of underlying regolith materials. Thus it may reflect the immediately underling bedrock (in areas of outcrop), a local source (in some colluvium) or a distant source (underlying alluvial regolith). Lag is dominated by chemically and physically resistate minerals and rocks. It includes a macroscopic component of quartz, lithic fragments, ferruginous lithic fragments and highly ferruginous materials. The latter includes residual and surface deposited-cementing iron oxides (predominantly hematite with some maghemite). There is also a micro-lag component of resistate minerals including zircon, rutile and other heavy minerals (probably including gold), which has concentrated at the surface by the winnowing effects of wind and sheetwash.

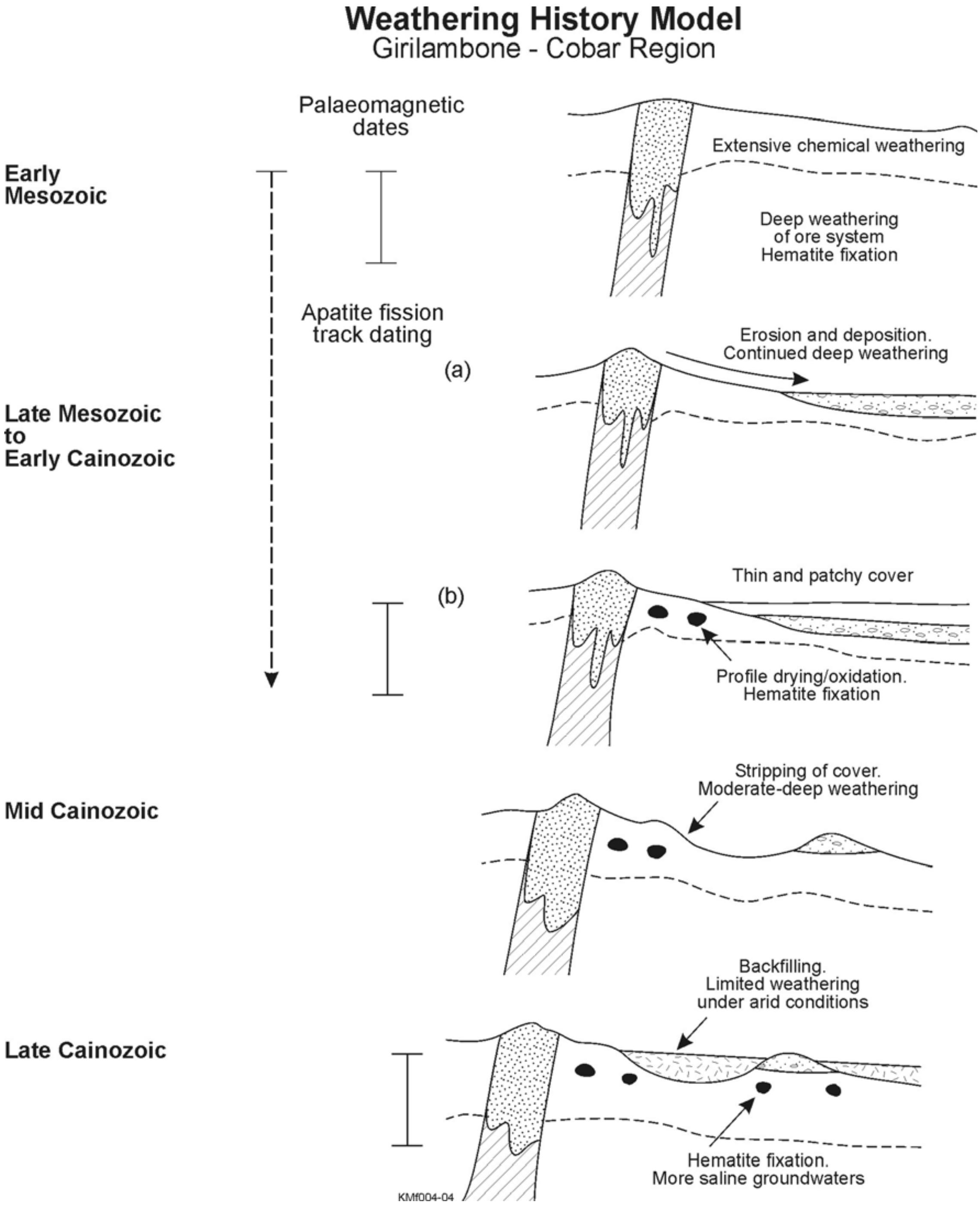

Figure 3. Weathering history model for the Girilambone-Cobar region incorporating new palaeomagnetic and apatite fission track dating data.

REGOLITH-RELATED ELEMENT ASSOCIATIONS
Geochemical investigation of regolith materials from background/baseline sites across the Girilambone-Cobar region has identified important regolith-related associations of elements. Some of these give rise to highly variable background levels for ore and pathfinder elements in different parts of the regolith, which may be confused with ore-related anomalies. The main associations are:

- an "evaporitic" association of Ca-Mg±Au, in some cases with Ba-Sr, related to regolith carbonate and barite accumulation in the near-surface regolith and at the base of palaeochannels and transported regolith;
- an association of Mn-Co-Zn±Ni-Cu±Au developed in redox boundary accumulations of manganese oxides/oxyhyroxides (particularly lithiophorite), commonly at around 20-30 m and at the present, deeper water table;
- an association of Fe-Cu-Zn with goethitic accumulations in the regolith;
- an association of Fe-As-Pb±Sb±Bi with hematite, particularly in ferruginous lag, paleochannel sediments containing ferruginous lag and in hematite rich mottles in the upper saprolite.

In mineralised environments there is a weathering-related fractionation of most target and pathfinder elements to different host minerals in different parts of the regolith profile (McQueen & Munro 2003; Levrett *et al;* 2004).

IMPLICATIONS FOR MINERAL EXPLORATION
Almost all surface-based mineral exploration and much sub-surface exploration is in the regolith. Better knowledge of this layer can significantly improve exploration strategies and success. Mapping the 3D distribution of different regolith materials is a first step for unravelling the regolith puzzle (Figure 4). A simple subdivision into *in situ*, shallow transported and deep transported regolith is commonly sufficient to dramatically improve sampling and data interpretation strategies. It is not "rocket science". More control can be obtained by understanding the degree of chemical leaching, chemical enrichment, source and direction of transport of different regolith materials. Understanding the landscape (and paleo-landscape) setting of regolith materials can help in determining their nature and history, and hence their local suitability as sampling media.

Work in the Girilambone-Cobar region has demonstrated an approach for producing reliable regolith-landform maps (suitable for application by the State Geological Survey). Methods have also been developed to build derivative maps or "go" maps, which highlight particular regolith attributes (e.g. *in situ* vs. transported origin; thickness of transported cover). These can be included in a GIS available for explorers. Geochemical data from unmineralised regional sites has established a number of element associations related to regolith-forming processes. These can help account for some of the background variation encountered when sampling the regolith of the region. This work is also establishing the important regolith host minerals and traps for dispersed pathfinder and target elements. With this knowledge it is possible to target the most appropriate sampling media for a given area and apply appropriate normalisation procedures to the data. It should also be possible to develop a series of geochemical templates for different regolith materials that identify trends in multi-element relationships reflecting mineralised environments as distinct from normal background regolith concentrations and variations. Work is underway to further develop this approach.

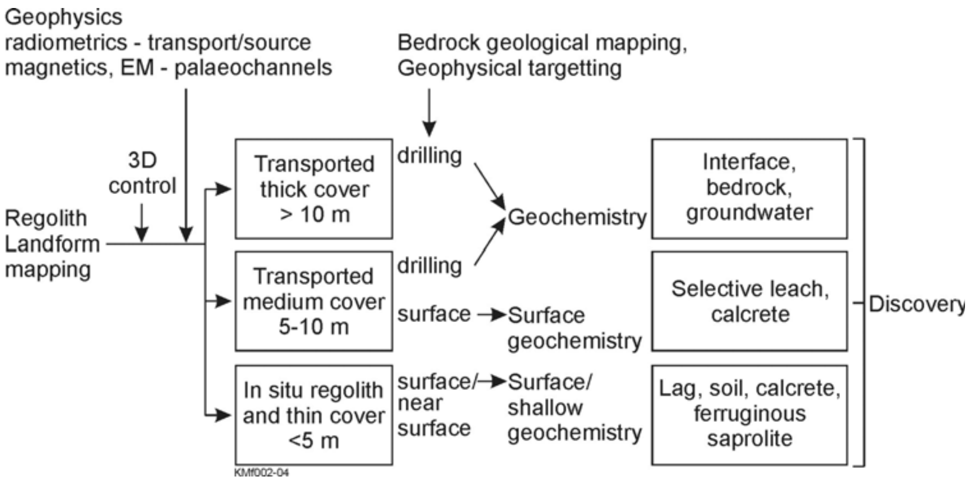

Figure 4. The role of regolith-landform mapping in assisting mineral exploration.

CONCLUSIONS

Recent work in the Girilambone-Cobar region has established a temporal framework for the landscape evolution and the weathering history. It has produced a better understanding of the regolith-forming processes, including the deep weathering and chemical leaching, and the variable preservation of weathering profiles related to differential erosion. This work has also revealed the importance of transported cover, preserved at different levels of the present landscape, particularly in widespread palaeochannel systems. Regolith-landform mapping is an important new tool to determine the spatial distribution of different regolith materials and their landform setting and origin. This information, combined with data from drilling and geophysics can also be used to determine the three dimensional nature of the regolith. Better knowledge of cover thickness, regolith type and likely element dispersion pathways and traps can greatly assist mineral explorers in planning and interpreting geochemical and drilling surveys.

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FACTORING IN WEATHERING-CONTROLLED CHEMICAL FRACTIONATION IN SURFACE SAMPLING MEDIA

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INTRODUCTION

Polymetallic sulfide ores in the Cobar gold field (Figure 1) have undergone prolonged weathering where they have been exposed at the surface or intersected by the water table. This has led to oxidation, chemical leaching and element dispersion, variable supergene enrichment and eventual mechanical dispersal of the weathering products across an evolving landscape. In addition to predominant Au and Cu, the ores have associated Zn, Pb, Ag, Bi, As, Sb and W, which provide useful pathfinders for geochemical exploration. Understanding how these different ore and pathfinder elements behave during formation of the ore weathering profile and its subsequent dispersal is important for developing appropriate and robust geochemical exploration models in the region.

The regolith mineralogy and mineral distribution of major, minor and trace elements through the weathering profile have been investigated at three mineralised sites in the Cobar gold field. This has been linked with a study of residual and transported lag at these sites and an area down-catchment of the gold field.

AN IN SITU PROFILE

Mineralogical and geochemical trends at the New Cobar Au-Cu deposit indicate a progressive change in mineral hosts from primary sulfide and specific secondary minerals in the lower part of the weathering profile to more generic Fe- and Mn-oxides/ oxyhydroxides towards the top (Figure 2). Goethite is an important host for Zn, Cu, As and to a lesser extent Pb, Bi and Sb. Hematite, where predominant, is an important host for Cu, Pb and Sb (Figure 3). Cryptomelane and alunite-jarosite group minerals are important hosts for Pb and As and lithiophorite for Co, Cu and Ni (Scott & McQueen, 2000; 2001, McQueen *et al*. 2001). Geochemical data on bulk samples from the lower part of the oxidised zone show very poor correlation of ore and pathfinder elements with Fe because they are hosted by a range of secondary minerals and not just the iron oxides/oxyhydroxides (Figure 3). Closer to the surface, where most of the intermediate secondary minerals have been broken down, goethite and hematite are more important host minerals and a stronger correlation between these elements and Fe is evident in the bulk geochemical data (Figure 4).

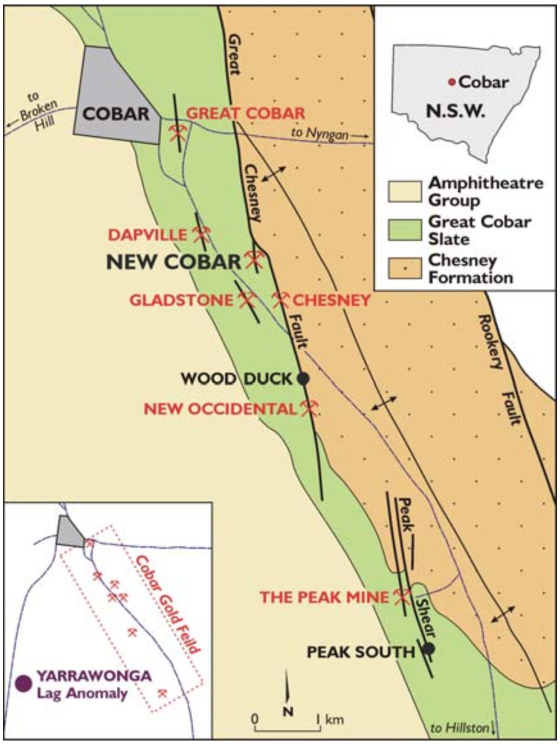

Figure 1. Location and geology of the Cobar gold field also showing known ore deposits and sites examined in this study. Insert shows the location of the Yarrawonga lag anomaly.

NEAR-SURFACE PROFILES

At the Wood Duck and Peak South prospects (Figure 1) detailed mineralogical and geochemical investigation of the upper 15 m of the weathering profile indicates that there has been significant leaching of metals and sequestering of the remnant geochemical signal in goethite and hematite (Cairns *et al*. 2001). Bulk samples from near-surface RAB drilling at the Wood Duck prospect contain less than 450 ppm Cu, 100 ppm Zn, 150 ppm Pb, 10 ppm As and generally less than 20 ppb Au (with up to 180 ppb in several samples near the very top of the profile). Primary mineralisation contains 1.75% Cu and 2.23 g/t Au, with trace Pb and Zn. Marked positive correlation between Cu and Fe in the near surface oxidised zone is consistent with concentration of Cu in abundant hematite within the profile. Lead and Zn contents are not significantly correlated with Fe (Figure 4). Similar sampling at the Peak South prospect indicates less than 100 ppm Cu, 250 ppm Zn, 100 ppm Pb, 300 ppm As and less than 100 ppb Au. Primary mineralisation here contains

4.24% Zn, 1.72% Pb, <0.02% Cu and 0.4 g/t Au. Goethite is the predominant Fe phase in the weathering profile and there is marked positive correlation of Zn and As with Fe. Copper is low in abundance and does not show significant correlation with Fe. There is no apparent correlation between Pb and Fe contents (Figure 4). Ferruginous lag immediately overlying the mineralisation at these sites contains variable mixtures of hematite and goethite and anomalous concentrations of Cu, As, Zn and in some cases Au and Ag. These concentrations are significantly greater than in the underlying regolith. Sequential leaching analysis of these lag samples indicates that these elements are largely bound within the crystalline component of the iron oxide/oxyhydroxides (Cairns *et al*. 2001).

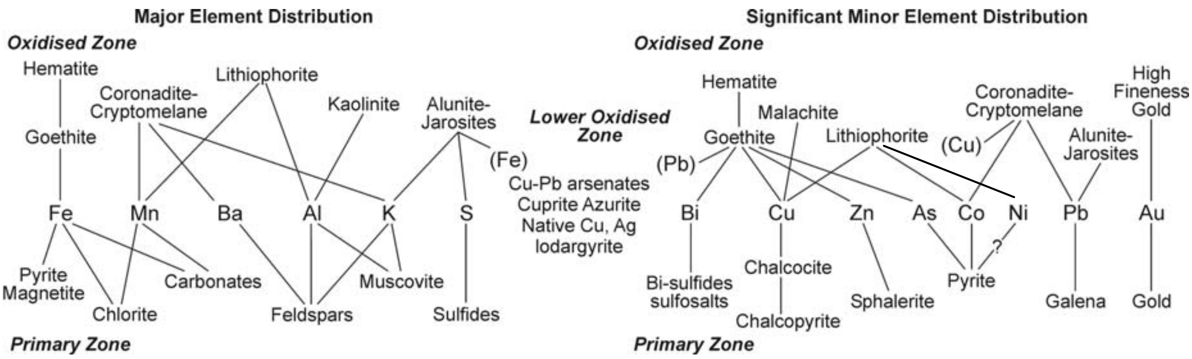

Figure 2. Connectagrams showing the mineral host pathways for major and minor elements through the primary and oxidised zones at the New Cobar deposit.

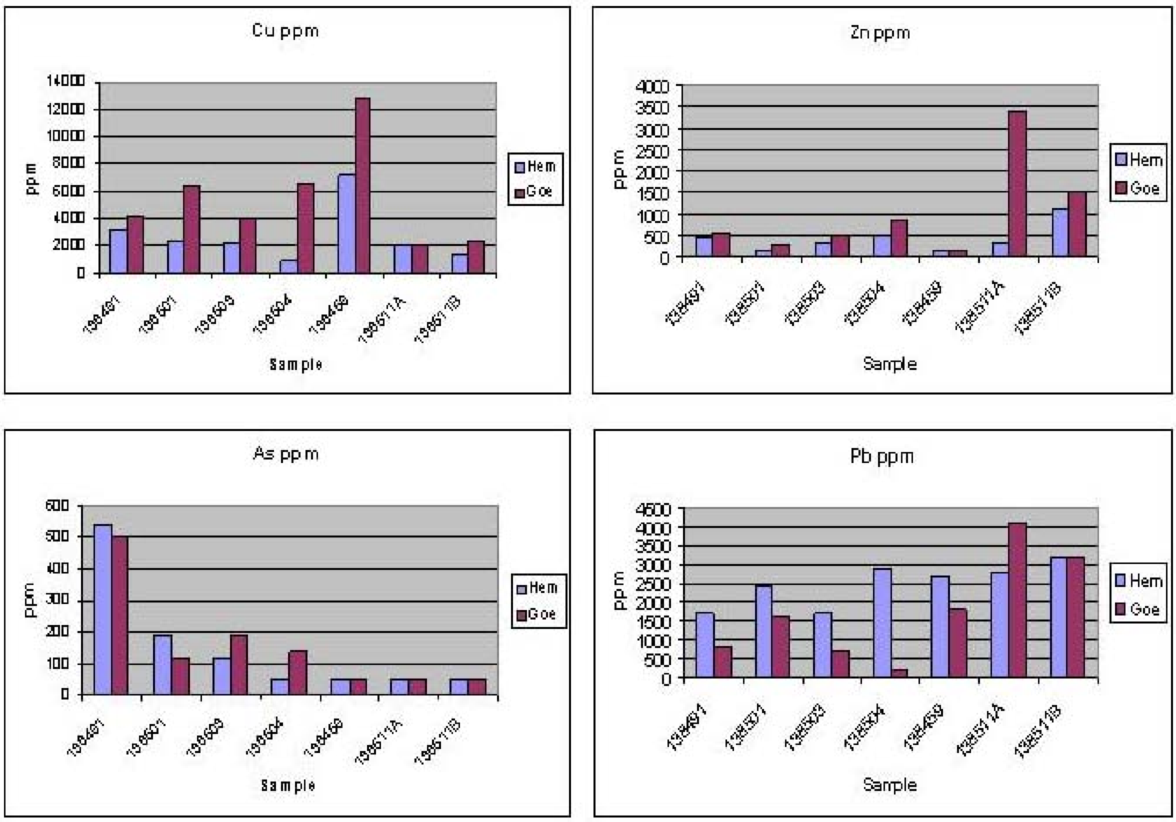

Figure 3. Electron microprobe analyses of hematite (blue) and goethite (red) from samples in the upper part of the weathering profile at the New Cobar deposit (Analysts K. Scott and K. McQueen).

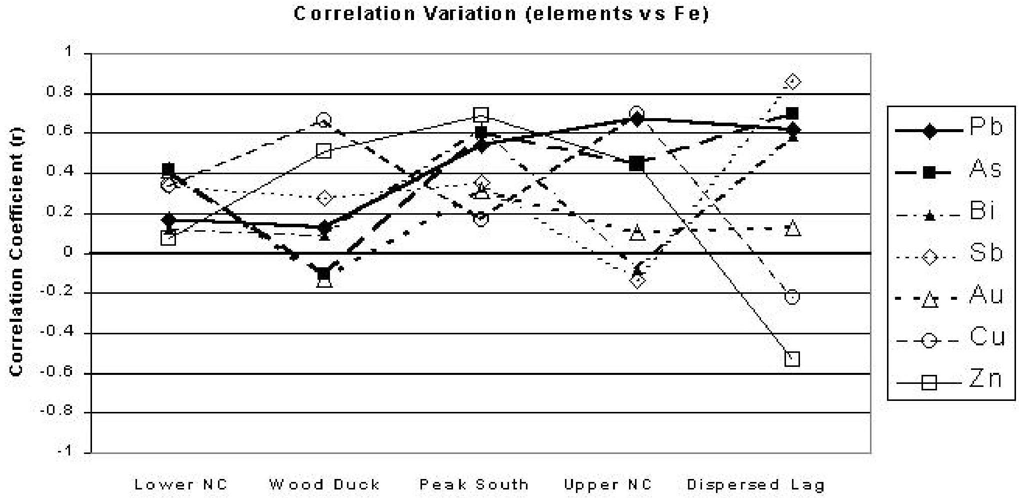

Figure 4. Correlation variation diagram showing correlation coefficients for Fe with pathfinder elements in the lower part of the New Cobar (NC) profile, the Wood Duck profile, the Peak South profile, upper part of the New Cobar profile and for dispersed lag at the Yarrawonga anomaly and up catchment. Geochemical analysis was by INAA and ICP OES.

DISTRIBUTED LAG

A detailed study was made of lag from the Yarrawonga anomaly located down-catchment of the Cobar gold field (Figure 1). Lag collected from 8 sites was subdivided into different fractions including: a micro lag component (< 120 μm), quartz lag, lithic lag, ferruginous lag and magnetic ferruginous lag. The last three categories were further subdivided into angular and rounded categories as an approximate means of separating the less reworked lag from the more reworked or transported lag. Geochemical trends (Figure 5) in the lag indicate progressive increase in Fe content with rounding and presumably exposure and transport/reworking. Some other elements including As, Pb, Sb, Bi and Ba show a similar increase suggesting that these elements are being stably fixed in the more Fe-rich lag and their relative abundance increased as the non Fe oxide components of the lag are leached and removed. This represents a type of weathering fractionation of these particular trace elements driven by chemical leaching and mechanical reworking. A good marker for this process is the Th versus Fe fractionation trend (Figure 5). The rounded (more reworked) ferruginous lag can contain up to twice the levels of Pb, As, Sb and Th found in the less Fe-rich angular fraction. This suggests that lag geochemical data should be normalised to Fe content for these elements during interpretation.

Quantitative XRD analysis of representative lag samples from the Yarrawonga sites indicates that hematite (19-64 wt. %), quartz (16-54 wt. %) and muscovite (3-14 wt. %) are the dominant mineral constituents. The magnetic lag contains up to 15 wt. % maghemite, which is generally more abundant in the rounded fraction. Amorphous (poorly crystalline) components comprise 5-17 wt. % and lesser kaolinite up to 6.5 wt. %. Goethite comprises less than 2 wt. % in this lag.

DISCUSSION

Due to their overall abundance and ability to incorporate trace elements and trace element mineral inclusions, iron oxides/oxyhydroxides are major hosts for ore and pathfinder elements in the upper part of the regolith. As primary and intermediate oxide minerals weather and break down a proportion of the released elements are fixed in goethite and hematite. Trends in the correlation variation for Fe with pathfinder elements (Figure 4) are consistent with the increasing importance of iron oxides/oxyhdroxides as major host phases up the weathering profile. Interestingly, Au is not well correlated with Fe or other elements and rather than being chemically linked to the iron phases it is probably present as dispersed elemental particles.

Progressive conversion of goethite-hematite assemblages in the weathering profile to dominant hematite ± maghemite near surface and in lag, also has an important influence on the element dispersion pattern. Hematite selectively incorporates elements such as Pb, As, Sb, Bi, Ba, Cr and Th. With surface exposure, mechanical degradation, chemical leaching and additional precipitation of iron oxide, surface lag is enriched in Fe and these pathfinder elements (Figure 4). Mineralogical analysis indicates that this increased Fe content of the geochemically mature lag is essentially due to increased hematite content (Figure 5). Strong positive correlation between hematite content and the strongly Fe-correlated elements is consistent with hematite being the main host mineral for these elements in the mature and dispersed lag. This contrasts with the pattern for largely *in situ* lag at the Wood Duck and Peak South sites (Figure 5). Maghemite abundance is not significantly correlated with Fe content.

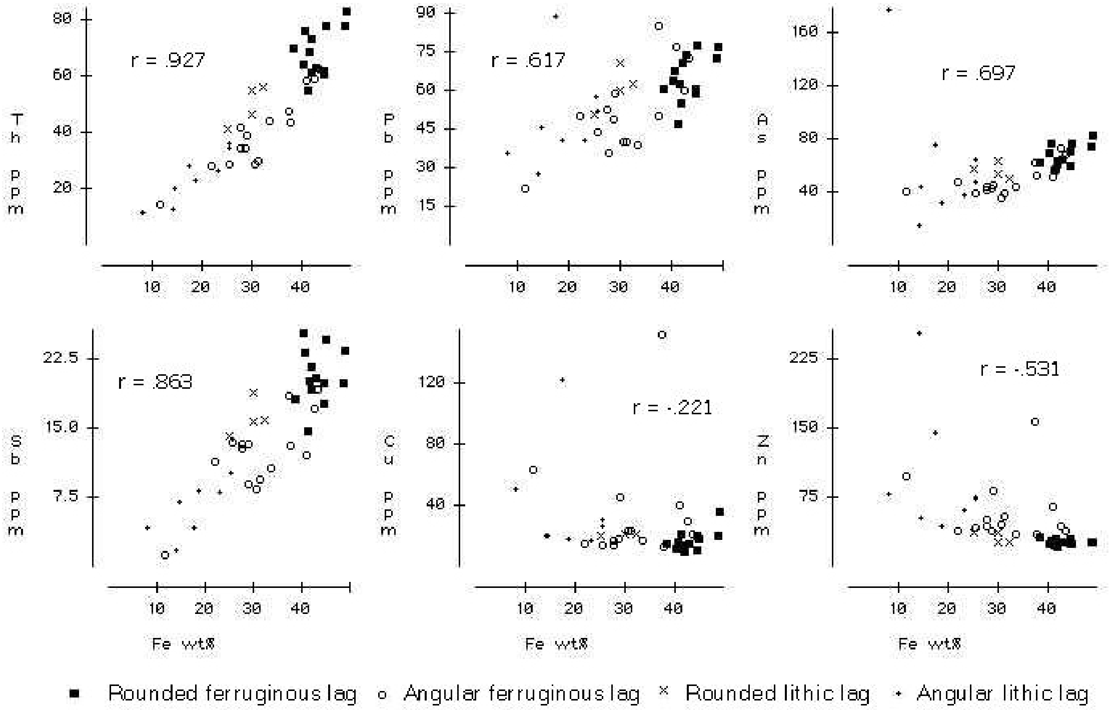

Figure 5. Bivariate plots of Fe versus pathfinder elements for lag samples from the Yarrawonga area. Each lag type has been subdivided into angular and rounded variants (r = correlation coefficient). Geochemical analysis was by INAA and ICP OES.

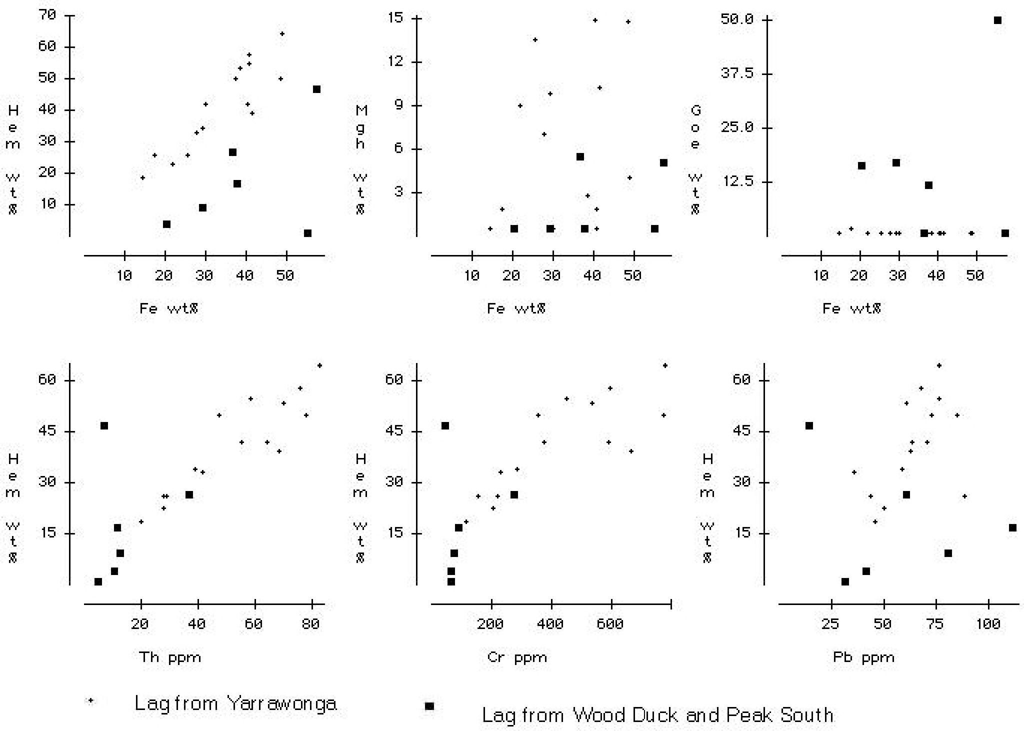

Figure 6. Bivariate plots of iron oxide/oxyhydroxide mineral contents with element abundance in lag from the Wood Duck, Peak South and Yarrawonga sites (Hem = hematite, Mgh = maghemite, Goe = Goethite). Mineralogical analysis by quantitative X-ray diffraction (SIROQUANT) and geochemical analysis by INAA.

CONCLUSIONS

To understand the behaviour of pathfinder elements in intensely weathered terrains it is important to identify their host minerals and understand how geochemical dispersion and weathering fractionation have affected the development of these minerals in different components of the regolith. The story can be complex. For example, in the Cobar gold field, Pb and As within deposit profiles show limited chemical mobility, but once fixed in goethite/hematite near-surface can become mechanically widely dispersed. The Cu and Zn signatures are typically broader around the deposit due to leaching and chemical dispersion, but become more strongly correlated with Fe closer to the surface where goethite-hematite assemblages take up these metals. Prolonged surface exposure of ferruginous materials leads to progressive conversion to hematite±maghemite, increase in overall Fe content and retention and relative concentration of Pb, As, Sb, Bi and Ba. This represents the end stages of a weathering fractionation of trace elements driven by chemical leaching and mechanical reworking. The process is indicated by a marked Th vs Fe fractionation trend. Interpretation of lag geochemistry should take into account the tendency for As, Pb, Bi and Sb in particular, to be relatively concentrated in the ferruginous component during surface exposure and transport. The overall weathering-controlled fractionation process is summarised schematically in Figure 7. Analysis of both near surface *in situ* and hematite-rich transported lag indicates that most of the trace elements of interest are strongly bound in the crystalline phases with virtually none in weakly adsorbed sites.

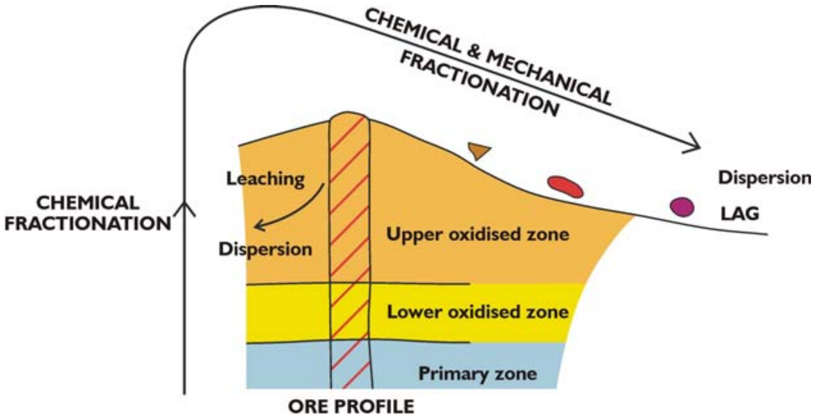

Figure 7 Schematic model summarising the weathering fractionation process.

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Acknowledgments: This study was encouraged and supported by Peak Gold Mines Pty Ltd. Our special thanks to Rex Berthelsen, Peter Leah and Craig Roberts from the company. Geochemical analyses were performed by Becquerel Laboratories, Lucas Heights and Analabs (Perth). Quantitative XRD analyses were provided by Ulrike Ttoitzsch, Department of Earth and Marine Sciences, The Australian National University. Keith Scott provided constructive comments and assisted with collecting data for the New Cobar deposit.

EXPLORING THE ELURA SYSTEM

Geoff Reed

Consolidated Broken Hill Endeavor Mine, Cobar, NSW 2835.

LOCATION

The Elura Deposit, Endeavor Ag-Pb-Zn mine is located 43km NNW of Cobar at 31.16 ° S and 145.65 ° E. It is in the northern part of the Cobar Basin within the Lachlan Fold Belt, central western New South Wales.

DISCOVERY HISTORY (after Davis, 1980)

In 1971, the Electrolytic Zinc Co. of Australasia (EZ) applied for two Exploration Licences in the area to the NW of Cobar. An aeromagnetic survey of the area commenced on the premise that the rocks of the Cobar Group that host the CSA Mine, continued to the N and possibly NW under soil cover. Previous exploration campaigns had assumed that the Cobar Group continued to the NE of the CSA Mine, to Mt Drysdale.

On the aeromagnetic survey, the Elura Deposit appeared as a discrete bulls eye anomaly and, although it was thought to be sited in unprospective stratigraphy, it was earmarked for further work on the basis of its discrete nature. Ground magnetometry showed the anomaly to have a deep source. An auger sampling program commenced with a sample spacing of 5-10 m on lines 50 m apart and samples taken at 1.8 m depth. A Pb anomaly over a strike length of 1200 m was defined. Delays in processing exploration tenements allowed gravity and EM surveys to be completed but the initial drilling programme had been planned on the magnetic and auger data. The diamond hole E1 intersected gossan at 102 m on the 12th February 1974 and sulfide mineralisation at 133.5 m on the 16th February 1974.

In retrospect, the most efficient way to have found the deposit would have been to accurately locate the aeromagnetic anomaly on the ground and to have drilled at a high angle to the magnetic field into the "guts"of the anomaly. If the pyrrhotite at the Elura Deposit was not magnetic (non-magnetic pyrrhotite is found extensively at the Hera prospect near Nymagee and has been reported at the CSA mine), the best strategy would have been to sample lag at 500 m intervals on 1-2 km spaced lines and follow up Pb assays of greater than 60 ppm with infill sampling (Lorrigan, 2003).

THE DEPOSIT

The Elura Deposit, Endeavor Mine consists of 6 elliptical, zoned massive sulfide pods that are subvertical in plunge. They consist of the Main Lode (composed of 2 elliptical pods that merge together around the 10000 mRL) and the Northern Zone. The Northern Zone consists of 5 elliptical pods that trend to the NNW (at 343º N) for a strike length of 650 m and dip at approximately 80º to the west. At depth, mineralisation breaks into a series of steep westerly dipping lenses. The Main Lode extends 900 m from surface. The five Northern Zone pods, to the northwest, extend to the same depth from 450 m below surface (Figure 1; Leevers, 2000; David, 2004).

Production by the Electrolytic Zinc Company commenced in 1982 at a rate of 80,000 tonnes per annum. Mining in the Northern Zone Pods commenced in August 1997. Production for the life of the mine to 31st March 2003 was 21.5 Mt. The combined Measured and Indicated Resource of the Elura Deposit, Endeavor Mine Resource at the 31st March 2003 was 15.2 Mt at 8.7% Zn, 5.3% Pb and 65 g/t Ag of which 3.35 Mt is Proven and Probable Reserve.

The Resource estimation has been done using ordinary kriging with domain constraints for the grade interpolation. Drill spacing is variable due the lack of suitable sites for sectional drilling , therefore less than 10 mE x 10 mN x 10m RL in heavy drilled areas, to greater than 40 mE x 40 mN x 80 mRL (Grove *et al.*, 2003).

GEOLOGICAL SETTING

The Elura Deposit, Endeavor Mine is close to the northwest boundary of the Cobar Basin, one of several intra-continental basins in the central part of the Lachlan Fold Belt.

In the northern part of the basin (Cobar Trough) sedimentation progressively advanced from basal conglomerates through sandstone and siltstone into deep water turbidite sequences. In the vicinity of the

Elura deposit the stratigraphy passes from limestone, mudstone and sandstones, through to the CSA Siltstone of Schmidt (1980).

The deposit occurs within the CSA Siltstone, 200 m vertically above the NNW-trending Elura Limestone. Re-activation of basin-parallel (NNW-trending) syn-sedimentary structures during the D1 and D2 of Glen (1985) appears to have resulted in the development of splayed, fan structures, deflected against the limestone barrier and terminating in anticlines at the fault leading edges. The Elura Deposit occurs within these anticlines. The ore lenses are blind, terminating against folded CSA Siltstone. Very few veins or fractures appear to penetrate far above the top of the lodes although an iron oxide bearing vein, extending from the gossan developed above Main Lode, forms the surface expression of the deposit.

HOST ROCKS

The Elura Deposit is hosted within the CSA Siltstone, a turbiditic sequence of siltstone, fine-grained sandstone and shales of the Amphitheatre Group. Mapping in the upper areas of the Northern Zone Pods and along the Southern margins of the Main Lode indicates that the CSA Siltstone is discordant to the mineralisation, with bedding draping and wrapping around the Northern Zone Pods and Main Lode. Strong chloritisation, folding and faulting exists within the CSA Siltstone immediately surrounding ore. Folds are typically synclinal and anticlinal, of short extent with quartz veining and brecciation often occurring along ore margins. Localised shears commonly ramp between fold limbs of synclines and anticlines. The folding and faulting becomes less intense further away from ore, with folds developing into NNW trending anticlines and synclines parallel to the Lodes. These folds are generally symmetric on the eastern side of the orebody and asymmetric on the western side (fold hinges dip towards the west). A well-developed pressure cleavage is the most consistent structure throughout the mine and generally dips 70º towards 240º. Siderite spotting is a common alteration feature of the CSA Siltstone surrounding the mineralised zone (locally known as Altered CSA Siltstone), with spots often oblate and parallel to the pressure cleavage.

Underlying the Elura Deposit are sediments of the Kopyje Group. These consist of a sequence of shallow water, reef and back reef sediments that grade into shallow marine sands to the east of the deposit. The dominant feature of these sediments is the reef complex that lies directly underneath the Elura Deposit. The reef is an interbedded calcarenite packstone (Carolan, 1999), common fossils include bryzoans, crinoids and rugose corals. Stylolites are also common. Drilling around the reef suggests that it was a basement high with silicified CSA siltstone being intersected to the west and the east of the reef complex at depths greater than the top of the reef. These intersections grade into slope facies (matrix supported reef blocks with fine carbonate mud matrix) then into the interbedded packstone with no evidence for faulting. Coarse pyrrhotite and sphalerite veins with only minor galena of limited extent are hosted within the reef complex. The reef facies and its surrounds have been interpreted as representing part of the Brookong Formation (Carolan, 1999).

ORE TYPES

Zonation of sulfides within the cores of the individual pods is gradational, with the central core being pyrrhotite-dominant (PO) and grading to pyrite-dominant (PY) on the outer areas. The classification of both of these ore types is dependent upon which iron sulfide is dominant. Surrounding the massive zone are massive sulfide veins with strong silicification *i.e.,* siliceous pyrite (SIPY) and siliceous pyrrhotitic ore (SIPO: again classification is dependent upon the dominant iron sulfide). Detailed logging and mapping of underground exposures indicates a strong degree of mobilisation, with more mobile pyrrhotite, galena and sphalerite forming a strong banded texture that anastomose around fractured and fragmented pyrite clots. There is also zonation of grade within the pods, with Zn and Pb grades being highest within the pyrrhotitic core and decreasing in grade towards the siliceous margins of the pods. This variation ranges from approximately 9% Zn and 6% Pb at the core of the pods to 7% Zn and 3% Pb at the margins. The thin zone (between 1 m and 5 m in thickness) of lower grade mineralisation existing along the margins of the siliceous ore is classified as Vein Ore (VEIN).

The six main ore types within the Elura Deposit are described in more detail below;

1. *Pyritic Mineralisation (PY)* – Pyritic Mineralisation consists of massive sulfide with no siltstone inclusions. The dominant mineralogy is pyrite, sphalerite and galena and usually occurs on the outer margins of massive mineralisation.

2. *Pyrrhotitic Mineralisation (PO)* – Pyrrhotitic Mineralisation forms the core of all the pods and is the dominant sulfide below the 9600mRL. Pyrrhotitic Mineralisation consists of massive sulfide with no siltstone inclusions, the dominant mineralogy is pyrrhotite, sphalerite and galena.

3. *Siliceous Pyrrhotitic Ore (SIPO)* – Siliceous Pyrrhotitic Ore consists of a dense stockwork of pyrrhotite-dominated sulfide veins and develops at the contact between wall rock and massive sulfide mineralisation. The mineralogy of Siliceous Pyrrhotitic Ore is pyrrhotite, pyrite, sphalerite and galena with varying percentages of rounded silicified clasts of CSA Siltstone and occasional white breccia type quartz veins.

4. *Siliceous Pyritic Ore (SIPY)* – Siliceous Pyritic Ore consists of a dense stockwork of pyrite-dominated sulfide veins at the contact between massive sulfide mineralisation and wall rock. The dominant mineralogy of Siliceous Pyritic Ore is pyrite, pyrrhotite, sphalerite and galena with varying percentages of rounded silicified clasts of CSA Siltstone and occasional white breccia type quartz veins.

5. *Vein Ore (VEIN)* - Vein mineralisation is a broad classification of sub-economic mineralisation that forms the interface between massive ore and wall rock. The classification between Vein Ore and Siliceous Pyrite/Pyrrhotite Ore is accepted to be a cutoff value of less than 10% Pb+Zn for vein mineralisation.

6. *Mineralised Altered CSA (MINA)* – Mineralised Altered CSA consists of varying concentrations of pyrite, pyrrhotite, sphalerite and galena within siderite altered CSA Siltstone at the extremities of ore or as internal waste within the Northern Zone.

REGOLITH

The base of partial weathering in the siltstones is encountered at 80-120 m, with grey, fresh rock first appearing at an average depth of 60 m. Within the ore the base of oxidation is at 80 m, though oxidised sulfides in cavities are observed at depths of > 800 m.

Pisoliths of magnetic lag accumulate within or above a surface layer of red soil, up to 1.5 m thick. This passes down into a zone of mottled weathering characterised by soft, bleached bedrock with iron oxide developed on fractures and within discrete, elongate "mottles" up to 0.2 m in diameter. In places substantial calcrete development is observed within this zone, down to 6 m. The profile then grades into harder, white to tan-coloured bedrock, with iron oxide developed along some bedding planes and on fractures and veins.

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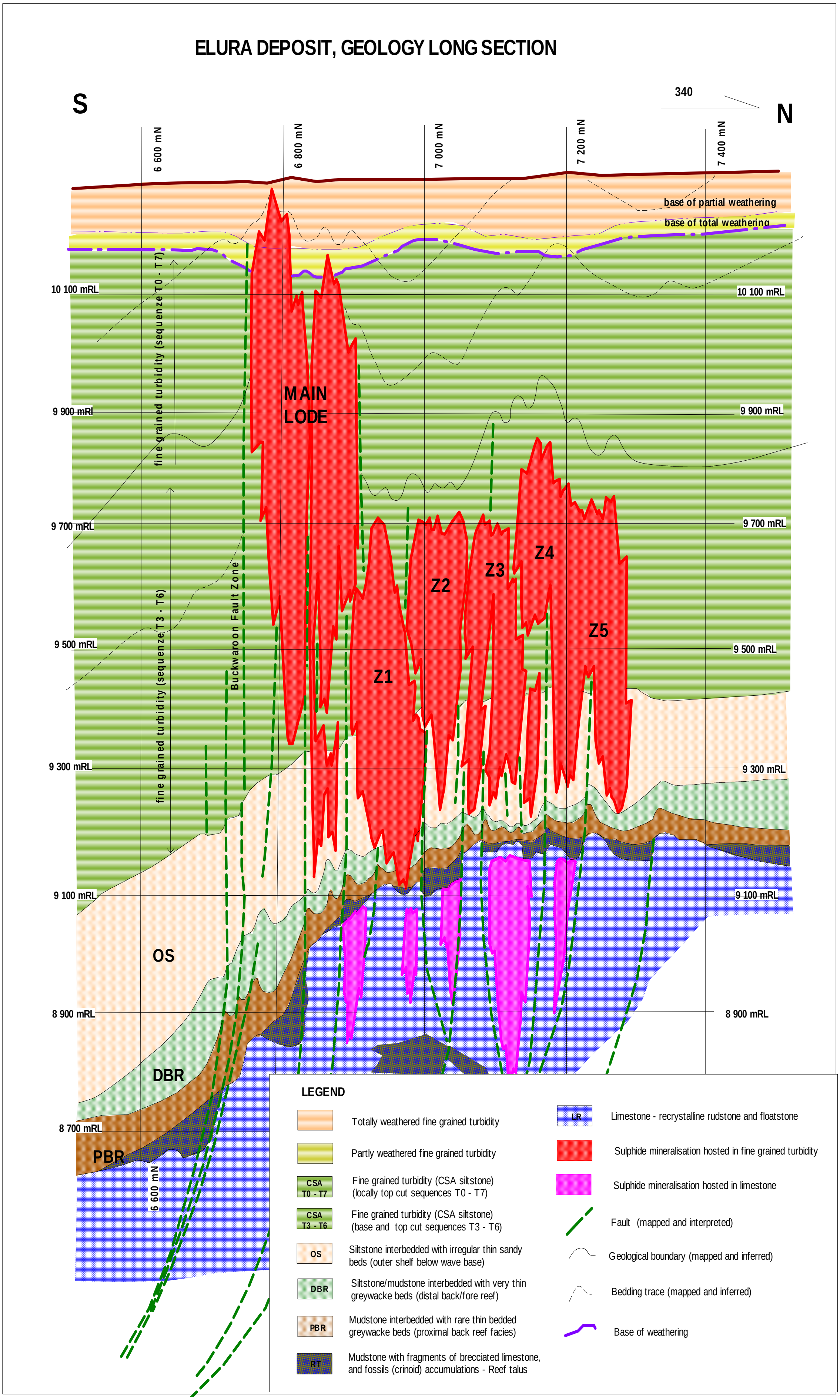
ELURA DEPOSIT, GEOLOGY LONG SECTION
S
N
340
6 600 mN
6 800 mN
7 000 mN
7 200 mN
7 400 mN
base of partial weathering
base of total weathering
10 100 mRL
9 900 mRL
9 700 mRL
9 500 mRL
9 300 mRL
9 100 mRL
8 900 mRL
8 700 mRL
fine grained turbidity (sequenze T0 - T7)
fine grained turbidity (sequenze T3 - T6)
Buckwaroon Fault Zone
MAIN LODE
Z1
Z2
Z3
Z4
Z5
OS
DBR
PBR
LEGEND
Totally weathered fine grained turbidity
Partly weathered fine grained turbidity
CSA T0 - T7
Fine grained turbidity (CSA siltstone) (locally top cut sequences T0 - T7)
CSA T3 - T6
Fine grained turbidity (CSA siltstone) (base and top cut sequences T3 - T6)
OS
Siltstone interbedded with irregular thin sandy beds (outer shelf below wave base)
DBR
Siltstone/mudstone interbedded with very thin greywacke beds (distal back/fore reef)
PBR
Mudstone interbedded with rare thin bedded greywacke beds (proximal back reef facies)
RT
Mudstone with fragments of brecciated limestone, and fossils (crinoid) accumulations - Reef talus
LR
Limestone - recrystalline rudstone and floatstone
Sulphide mineralisation hosted in fine grained turbidity
Sulphide mineralisation hosted in limestone
Fault (mapped and interpreted)
Geological boundary (mapped and inferred)
Bedding trace (mapped and inferred)
Base of weathering

THE X-Y-Z OF GEOCHEMICAL DISPERSION FROM MINERALISATION IN THE COBAR TERRAIN

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ABSTRACT

There are many instances in exploration using geochemistry in the Cobar region where failure to consider the implications of weathering, erosion, transport and deposition of material in the landscape have wasted significant exploration budgets. Analytical information might be spurious and misleading if these factors are not considered. Geochemical sampling methods and strategies need to be modified across the region to accommodate changes in the geochemical and physical landscape.

Geochemical dispersion is a three dimensional process. Different media disperse or concentrate anomalism from the same source in different ways and to differing extents. We generally treat geochemical anomalism as a two dimensional (X-Y) entity in routine surface exploration, only adding the third (Z) dimension when we drill. Sometimes we only consider the "Z"-dimension by undertaking drill programs to avoid the near surface rocks. In many instances the practice of not considering all three together in their relation to the *geochemical landscape* can result in failure to delineate source targets and to only focus on widely dispersed secondary geochemical anomalism remote from source.

The physical landscape (and in particular the regolith) is only one part of a geochemical landscape. A geochemical landscape also considers the influence of Eh and pH, groundwater hydrology both above and below the ground, time constraints, chemical speciation and a range of similar factors. Some primary anomalies may be subtle, short-lived and mobile while related secondary anomalies may be strong, persistent and fixed. Primary anomalies of this type require sensitive analytical techniques to define them, most techniques will find the secondary one perhaps hundreds or thousands of metres away from source.

Three examples are presented to illustrate the dispersion of geochemistry in the Cobar terrain, Anomaly P4 a quartz-pyrite alteration system, Anomaly LP3, Pb-Zn mineralisation hosted in carbonate and Mafeesh, quartz-Au-As-pyrite mineralisation.

Cobar Landscape

Tertiary and Quaternary erosion has produced a variably incised landscape that shows markedly different outcrop expressions of the Late Cretaceous-Early Tertiary deeply weathered profile that dominates much of the Cobar region. We see remnants of a mature lateritic terrain away from the Cobar Trough boundaries and main drainage lines. In some areas, particularly along the Cobar Trough margins, the profile has been completely eroded. Elsewhere it is partially stripped, for example, about McKinnons Gold Mine. There are sites where an immature profile is re-developing over eroded elements of the old. Regionally red earths, locally calcareous, derived from sheet-wash erosion of the laterite profile and wind blown materials dominate at the surface. Redox fronts were established at different depths in the landscape in response to rising and falling water tables. Active redox fronts now lie between about 40-60 metres depth and occur close to the base of weathering. Much of the old terrain relief is infilled and covered with the eroded components of the weathered landscape. A significant depth (~0.5 m) of sheetwash erosion has occurred in the last 100 years or so in some areas following land clearing and introduction of stock resulting in loss of original A-horizon soils (Leah, 1996; Cohen et al, 1996).

This gives rise to a range of sample settings and media, both at the surface and at depth. Figure 1 models some of the laterite zone characteristics of mature (upper) and immature (lower) terrains observable in the Cobar region. This complexity needs to be taken into consideration in sampling and in interpretation of geochemical data, especially for surface materials such as soil or stream sediment and shallow drill samples. It requires good field records of sample site attributes in terms of their regolithic and geochemical setting with particular emphasis as to erosional level exposed to interpret the data. This is generally lacking for most sampling undertaken in the Cobar District.

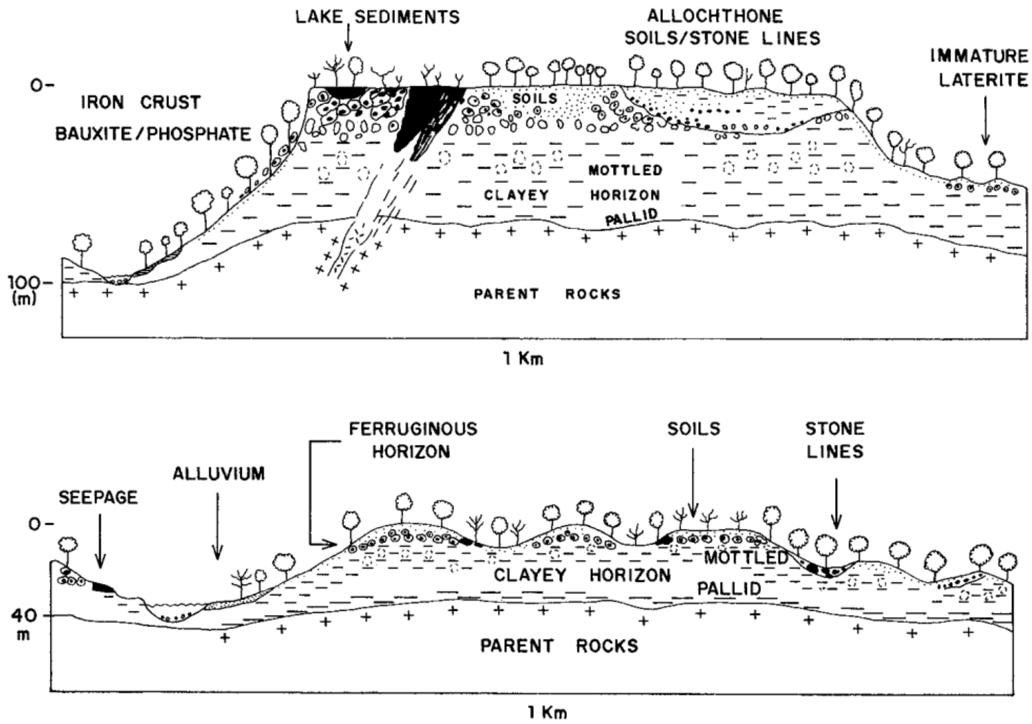
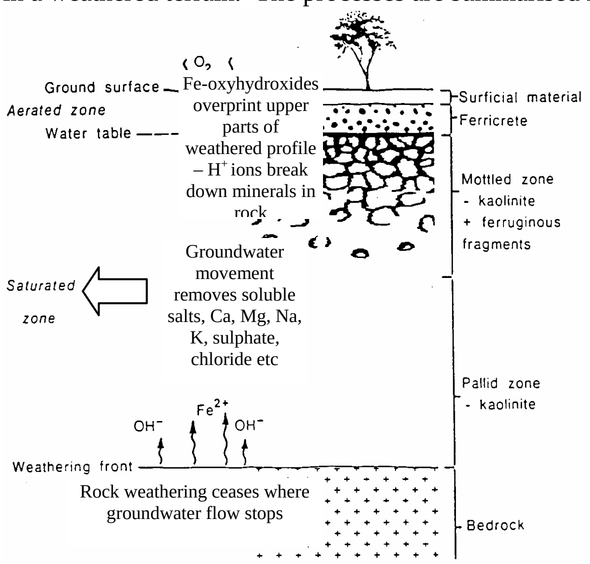


Figure 1. Examples of characteristics of mature (upper) and immature (lower) lateritic terrains. Elements of both occur in the Cobar region. **(**Da Costa, M.L., 1993).

Weathering Processes and Weathered Profile Geochemistry

Interpretation of analytical data is directly influenced by the geochemical processes that produced the deeply weathered lateritic terrain and continue to modify it. By understanding the way in which elements are redistributed through a profile during its formation and subsequently it is possible to determine where you are in a weathered terrain. The processes are summarised in Figure 2.



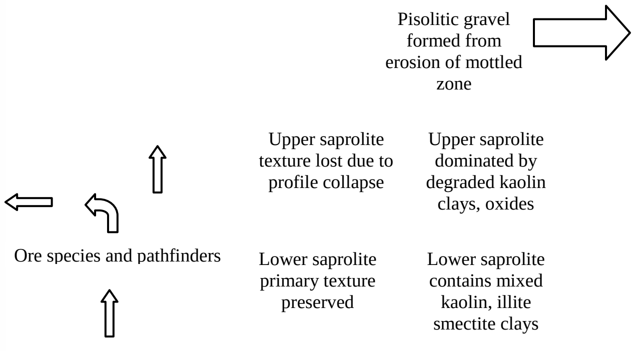
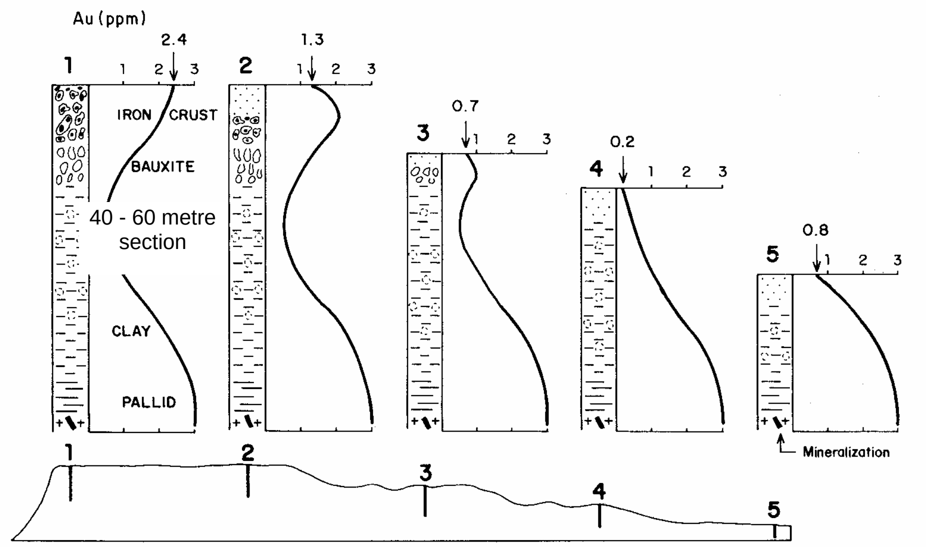


Figure 2. Elements of geochemistry in a weathered profile (after Mann, 1991)

Figure 3. Element pathways through a weathering profile.

Figure 3 illustrates the "classic" form of a geochemical profile for both major silicate cations and trace metals through a weathered zone from surface to fresh bedrock. It shows the effect of strong leaching in the profile coincident with the upper saprolite. Element values increase to depth as weathering intensity declines (lower saprolite and saprock). It may not be possible therefore to recognise primary lithologies from major element geochemistry alone in weathered bedrock. This will be dependant upon other observations such as rock texture, mineralogy from logging or trace elements associated with resistate minerals in the primary rock. Figure 3 also illustrates how geochemical profiles might appear in drill sections at sites near mineralisation but eroded to different depths. The changes in surface values are of particular note in regard to stream or soil programs. This is one of the dilemmas we face in the Cobar region - where are we in the profile?



Surface values vary significantly depending on depth of erosion of weathered profile – a low value might be just as significant as a high one!!

Figure 4. Variation in the geochemistry of gold through a weathered profile. The relationship of profile (curve) form to erosion level is important to recognise and understand. In Cobar most profiles are eroded to 3, 4 or 5, rarely are they 2 or 1. The Cobar profiles are often capped by recent post-erosion fluvial gravel, sand and silt. These sections do not illustrate the sharp peak frequently seen corresponding to a redox front. (Da Costa, 1993).

Sampling in Weathered Profiles

The recognition of position in a weathered profile is relatively simple with clues seen in airborne magnetic and radiometric data, in outcrop and position within the Cobar Trough. The colour of drill cuttings or rock exposure in a trench or pit also provides a useful clue as to depth for sampling. This is normally supported by textural evidence (log cuttings dry). The most important colour changes to recognise in drilling from a geochemical perspective are those that occur near the base of the weathered bedrock, the transition zone corresponding to the saprock (partially weathered bedrock) and fresh bedrock.

The colour changes from pale browns, buff, yellows and orange-yellows to green to green-grey to dark green-grey to grey. This is generally obvious and easy to log. This change frequently corresponds to the active redox position in the profile. About Cobar this is at about 40-60 metres depth but it can vary depending upon local hydrology and extent of erosion. Elsewhere, such as along deeply incised drainage lines saprock may be capped by more recent fluvial sediments.

Sampling the active redox front should be one of the objectives in geochemical exploration in deeply weathered terrains. The reason for this is two-fold. Firstly, geochemical responses are likely to be significantly higher at the redox interface for many ore related elements if present and thus they will be easier to detect. Secondly, as this also generally closely corresponds to the groundwater interface and we are likely to get significant lateral dispersion by groundwater producing a broader anomaly halo. The dispersion of Fe-oxide colloidal precipitates from the redox front is of note in this regard. These have a high adsorption capacity for many ore pathfinder elements and dispersion of them accounts for much of a geochemical halo (along with species such as alunite-jarosite).

We should also try to sample fresh bedrock and should drill until we get dark grey or green-grey material, normally within a metre or two of the change from light pallid colours to dark colours. From this we can reliably log bedrock geology, alteration and mineralisation. Where rocks are altered or of a favourable lithotype we might analyse the chips to assess whether they contain low order halo signatures to build up a picture of regional geochemical zonation for areas under cover.

The relationship of colour variation and distribution of Fe-oxides through a weathered profile is often confusing. Iron, the fourth most abundant crustal element, produces coloured compounds. The colour changes seen in weathered profiles often only reflect changes in the chemical and mineralogical state of Fe-oxides (or other Fe-bearing minerals). The Fe-oxides change colour in response to changes in their hydration and crystallinity and variation in the local pH conditions through a weathered profile.

The primary form of Fe-oxide that results from oxidation of Fe^{2+} under the low pH conditions that prevail at the redox front is goethite (or perhaps similar species such as feroxyhyte at slightly higher pH). It is usually a distinctive yellow to orange colour. Where kaolinite or other clays are also abundant its colour is subdued by them to give buff to light straw-yellow colours. It is this material that we should sample as our redox sample. It frequently occurs in the first metre or so of pallid coloured material above the transition from green and grey colours. Sample a composite of the first two metres of buff to light straw yellow-brown colours above the colour transition. Yellow orange zones may occur more than once in a single hole. These frequently correspond to palaeo-redox positions. It is the lowermost that is generally of most interest as this will be the current active redox front, although this depends on the depth at which the water table is intersected.

Anomalism, Thresholds and Backgrounds in Weathered Rocks

What should be clear is that there is no single "anomalous" or "threshold" value, calculated or assumed, for a particular element that might indicate mineralisation or alteration is represented by a particular analysis value. This is particularly so with geochemical data from surface samples and those taken from the saprolite zone. The *qualitative* spatial distribution of major and trace "pathfinder" species characteristic of an ore, alteration or rock type are more important than their *absolute* values.

High ore values are always important but subtle near background values, where these are co-anomalous with other "pathfinder" elements, are often overlooked by using thresholds to define anomalism or background. Co-anomalism may be indicative of blind mineralisation, reflect dispersion remote from source mineralisation, or be related to an anomalous halo about a mineralised vein in an alteration zone and be more important than a high analysis value. Depletion or enrichment halos are often completely missed by making assumptions about thresholds or backgrounds as these are often relative (proximal-distal, stronger-weaker source) and the scale at which they occur difficult to define.

Correlation matrices and factor analysis can assist in definition of co-anomalism or depletion relationships and this should be applied to data from different geological and geochemical settings. Factor analysis can often highlight subtle relationships that can be lost in processing large suites of elements particularly when the volume of analytical data is large. Plotting of spatial relationship of factors, "multi-element enrichment" or "alteration depletion" ratios or stacked line profiles is generally more definitive than using single element plots as these take into consideration the inter-relationship of co-anomalism and relative dispersion as well as spatial distribution.

Analytical Strategy for Geochemical Samples

Levels of many useful pathfinder elements associated with mineralised systems are low. Their dispersed geochemical halo therefore normally falls below the limits of detection of routine "total" ICP-AES (ppm level) analytical methods. Consequently low detection ICP-MS (ppb level) analytical methods should be utilised in field geochemical studies in intensely weathered rocks (Cohen et al., 1998).

ICP-MS analysis can measure values to the low ppb range in rocks and soils. In waters it can measure into the ppt range. It can only do this however, where ionic solution strengths resulting from sample digestion are low, otherwise the ICP-MS detectors are overwhelmed by signal and sensitivity declines. This makes ICP-MS an ideal analytical tool for partial leach extractions as they produce solutions with relatively low ionic solution strengths that are suitable for determination of trace analytes to the ppb level. This is the prime reason for using partial leach methods in exploration geochemistry.

An example of an ICP-MS based partial leach method designed to exploit this situation in weathered samples is Regoleach, (ALS Chemex method ME-MS08). It uses a combination of ICP-MS for trace species to achieve very low levels of detection of ore-related pathfinder elements and ICP-AES for major species to determine lithology and alteration.

By limiting geochemical analyses to a limited number of discrete intervals in drill holes the cost of undertaking multi-element ICP-MS geochemistry is low. There is no need to analyse whole holes but rather a few selected holes at the start of a program to determine the local character of the geochemical profile then sample only the intervals of interest. The significant enhancement in detection limit of ICP-MS over ICP-AES permits a much greater range of pathfinder analytes to be reliably determined.

Examples of Geochemical Dispersion – Anomalies P4, LP3 and Mafeesh

Host lithologies in the local geological setting are bedded siltstones, fine to medium-grained sandstones, mudstone, minor limestone (Lerida Limestone) and various calcareous, fossiliferous units of the Devonian Amphitheatre Group along the western margin of the Cobar Trough. Folding occurs along the NNW trending Nullawarra Anticline with its axis approximately 1 km E of Anomaly P4 and similarly to the west of LP3. Deep-seated shears parallel this anticline and the tectonic margin of the Cobar Trough and are likely the pathway for regional mineralization, such as at the McKinnons deposit and the anomalies discussed.

Regionally, partial leach geochemical anomalies are controlled by lithology, regolith and proximity to structures. Elements such as Cu, Tl, Sb and Zn, for example, concentrate in and along margins of the Quaternary drainage system in association with recent ferricretes. Quartz float broadly defines faults and shears in areas with sheet-wash cover.

Anomaly P4 is a Au-Ag-As-Bi-Cu-Hg-Mo-Pb-Sb-Tl-Zn anomaly found by partial leaching of a composite of two 100m spaced soil samples (<75μ fraction) collected from 250-300 mm depth along 400 m spaced traverse lines. Regional pisolith sampling shows a local low order anomaly from the vicinity of the Anomaly P4 site with low base metals but elevated As and Sb compared with pisoliths from surrounding catchments; this is consistent with patterns in the soil data. Low numbers of pisoliths indicate the upper parts of the laterite profile (mottled zone) have been removed by erosion.

Grey vein quartz with abundant pyrite occurs below the redox front enclosed by a siliceous, pyritic envelope, in excess of 50 m in width. As with the McKinnons Au deposit nearby the mineralization is hosted within a shear zone. It probably also occupies a local, but now buried, topographic high within the pre-Quaternary landscape. The present redox and weathering front is at approximately 45-46 m depth over the anomaly and is sharp, with a 10-30 mm transition from completely weathered to fresh sulphide. The weathering front is deeper, away from mineralization, particularly to the east.

Anomaly P4 does not appear to contain an economic resource. (Johnston, 1996; Salt et al., 1996). Maximum concentrations in RAB drilling are 0.3 g/t Au, 200 ppm Cu, 940 ppm Pb, 1000 ppm Zn, 2.4 ppm Ag, 2250 ppm As, 380 ppm Sb.

There has been dispersion of soluble Cu, Zn, Tl and Sb for some 1000 m down catchment, detectable at the ppb level. This highlights the need to assess geochemistry on a catchment-by-catchment basis to define dispersion patterns for different elements. Where low pH results from oxidation of pyrite a target zone may have abnormally low abundances for many elements in the weathered profile, as soluble elements (eg Cu, Zn, As, Sb) may have been totally leached and redistributed down catchment (Figure 4). Elements that form insoluble salts (eg Pb as plumbo-jarosite) or Au (as the metal) precipitate and become enriched in the vicinity of the ore zone and at palaeo-redox fronts and show limited dispersion. This is readily apparent in drill cross sections and points to the folly of only taking shallow bottom-of-hole samples in RAB programs in such terrains and of not drilling to below the base of oxidation to assess the geochemistry of the whole weathered profile (Figure 5, Rutherford, 2000).

Near mineralisation the saprolite is intensely leached and generally grey, light grey, beige-pink or white. Just above the redox front, goethite has stained the rocks orange to medium-brown. Elsewhere it is generally yellowish, mustard, light brown or medium brown, or near surface, pinkish red-brown, due to hematite (Figure 5). PIMA analysis indicates increasing kaolinite content in the saprolite away from the mineralization both vertically and laterally, in a similar manner to the nearby McKinnons gold mine (Marshall & Scott, 1999). Silicification occurs toward the top of the saprolite over the centre of the anomaly, beneath the transported overburden. This is attributed to precipitation of silica leached from bedrock and the alteration halo under a low pH generated by oxidation of pyrite at the redox front.

Anomaly LP3 occurs within the same structural corridor as the McKinnons Gold Mine and along strike of low grade base metal mineralization at that mine site. RAB drilling suggests mineralization is fault-hosted within and at the margins of fault bound blocks of massive Lerida Limestone units of the Amphitheatre Group that extends from just north of McKinnons for at least 2 km north. Although speculative, the irregular depth of intersection of the upper surface of the limestone unit and presence of abundant Fe-Mn oxides at the contact could suggest development of a karst surface during the Tertiary, prior to burial by 10-40 m of gravels and silt during the Late Tertiary and Quaternary although faulting could also account for the variation.

Erosion of the weathered profile left thick saprolite zones in some areas while, a short distance away, it is thin or missing. This indicates strongly dissected terrain prior to infill during the Late Tertiary and Quaternary. Boundaries between soil, transported cover and weathered bedrock are difficult to distinguish in RAB cuttings due to high clay contents, but the presence of quartz gravels defines base of alluvial cover. Calcrete is frequent at a depth of 5-8 m and is considered to reflect the presence of the limestone beneath (Salt & Donnelly, 1996; Johnston, 1996).

Immediately above the limestone unit and extending away from the fault-bounded blocks is a dark brown-black Fe-Mn-rich horizon that is typically enriched in Zn. Lead is enriched immediately adjacent to the limestone contact and within the limestone unit. Lead, Zn and Au are also locally enriched at distinctive brown coloured redox boundaries in the saprock.

RAB drilling did not reach primary mineralization. It is however, considered to be similar to that in the McKinnons pit where minor galena, sphalerite, with a trace of chalcopyrite, arsenopyrite and gold occur within a broad silicified shear. Shear-hosted disseminated pyrite causes a well-defined IP anomaly beneath the McKinnons gold mineralization and extends NNW toward LP3 where pyrite is the only sulphide observed in saprock. There are at least three, possibly four, mineralized fault or shear zones, two along the boundaries of the limestone blocks and one or more within faulted limestone within a 600 m wide interval over 1000 m strike length. Mineralization beneath the limestone unit is untested.

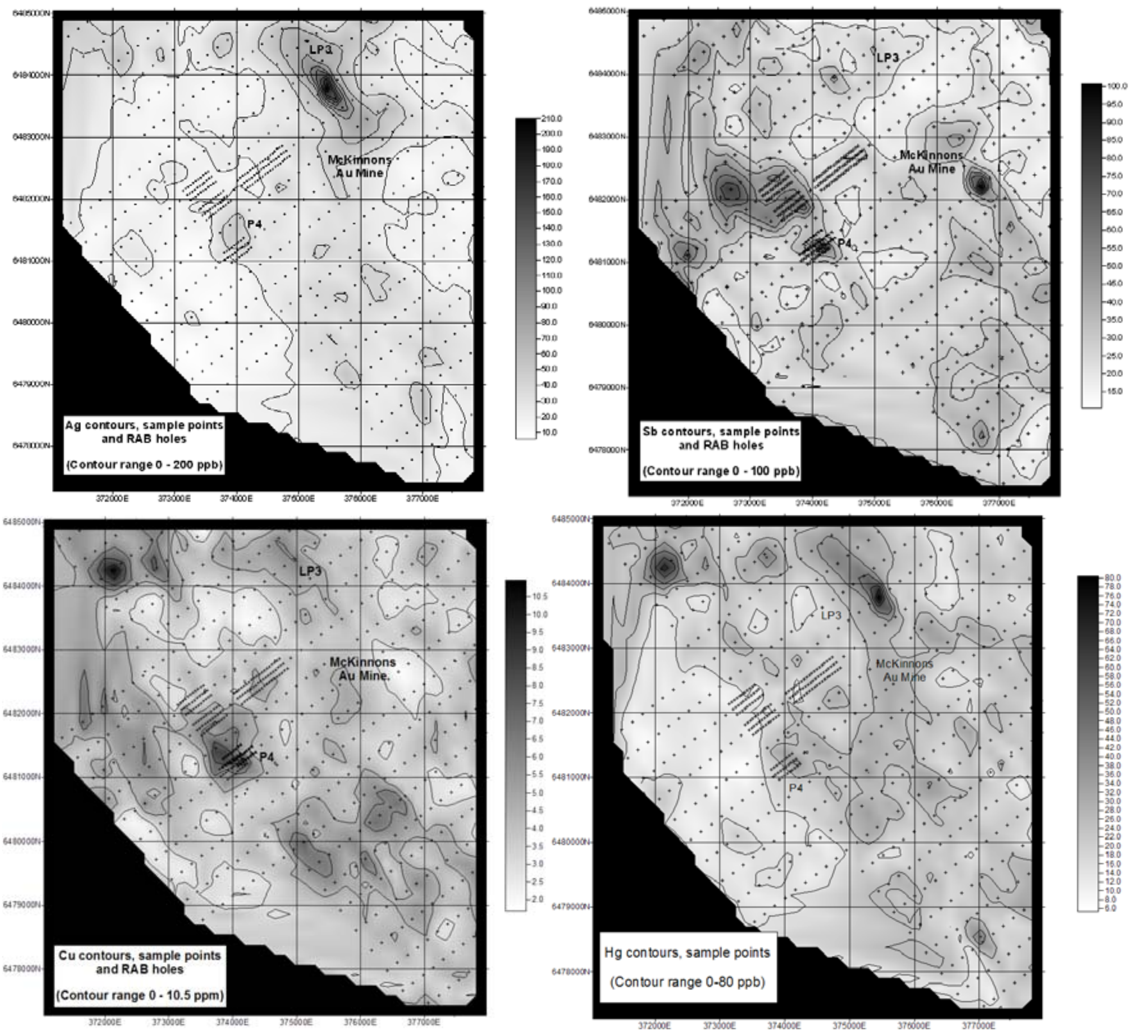
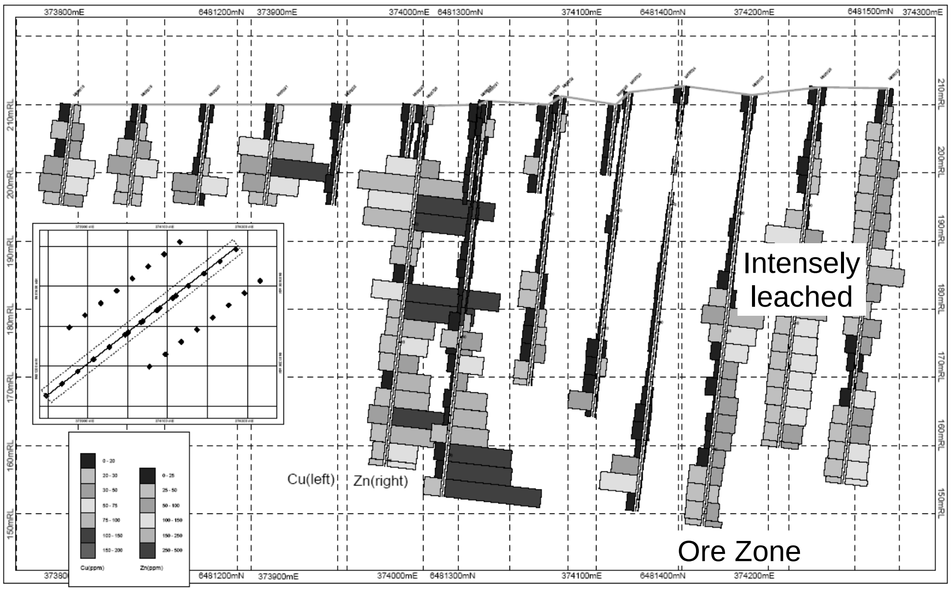


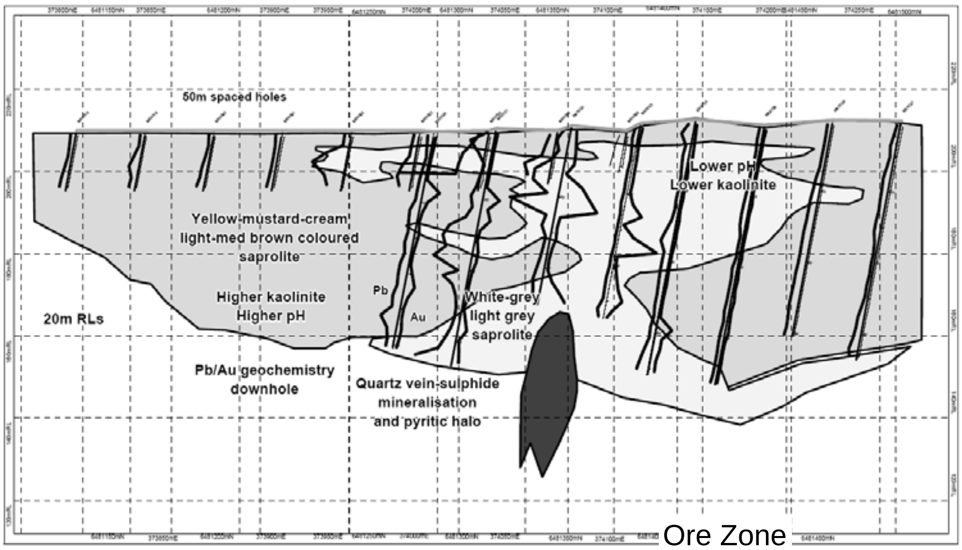
Figure 5. Geochemical expression of P4 and LP3 from partial leach soil results.

Anomaly LP3 is best defined by soil partial leach Ag geochemistry. Silver forms a broad 2000 m long anomaly, trending NNW from the McKinnon's deposit, with a maximum of 230 ppb. Mercury, Mn and to a lesser extent, Co, Mo, Cu and Zn also show anomalism (Figure 4). The strong Ag anomaly was originally thought by Burdekin Resources to be derived from the McKinnon's deposit (Bywater et al., 1996). Although

Ag itself is near continuous from McKinnons due to continuity of mineralized host structures into Anomaly LP3 the dispersion of base metals, e.g. Zn into the cover sequence has been strongly inhibited by the high pH alkaline environment developed about the limestones and calcareous sandstones in the sequence. Elements such as Ag, Hg, Mo, (and possibly also locally Co, Mn, Bi, Au) may by quite soluble in this environments as thio-complexes (after oxidation of pyrite, Mann, 1984, 1998) hydroxy-species or oxyanions and disperse through the profile (Thornber, 1992). Thus metals like Ag, Hg and Mo become the target species for exploration geochemistry in high pH environments rather than relying on base metals whose dispersion can be very low. Levels of these trace elements in the soils are very low hence ICP-MS analysis of partial leachates is the best tool for their detection (Cohen et al., 1998; Rutherford, 2000). Most concentrations are well below the detection limits for routine "total" analysis. Pisoliths are rare or absent over most of the anomaly area and none have been analysed.



Anomaly P4 - Central RAB Line
Cu (ppm)-Zn (ppm) values
(3 metre composites)



Anomaly P4 - Colour of Saprolite Bedrock
Pb/Au Geochemistry

Figure 6. Distribution of elements around ore zone at P4. Immediately above ore there is a "geochemical hole".

Mafeesh is a quartz-Au-As-Sb-pyrite shear sediment-hosted occurrence that provides a useful example of anomaly dispersion by sheetwash erosion of soil and pisoliths (Schmidt, 1991). It highlights the need to treat dispersed geochemistry on a catchment basis. In this case outcropping mineralisation has provided a source for widespread anomalism extending for several kilometres down catchment in both media.

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GEOCHEMICAL DISPERSION IN THE REGOLITH, GIRILAMBONE BELT REGION

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INTRODUCTION

The drilling of 247 air core holes over the poorly exposed Ordovician sediments of the Girilambone Group within an area approximately 160 x100 km, 600 km northwest of Sydney, provided an opportunity to integrate geological, geomorphological, geochemical and mineralogical studies to better understand weathering processes within the region. This improved understanding could greatly assist mineral exploration. In particular, the application of infra-red spectrometry (PIMA) to systematically define mineralogical variations in the profiles (provided by the drilling) when coupled with geochemical information provides a much better basis for interpreting geochemical dispersion in regolith materials than simply relying on bottom of the hole information.

METHODS

A total of 7553 m of air core drilling (247 holes) were completed by the NSW Department of Mineral Resources (DMR) and CRC LEME during 3 phases of investigation of the nature of the regolith in the Girilambone Belt region. Using information about the known geochemical associations in regolith at the Girilambone Cu deposit and other mineralisation in the Cobar region, a standard suite of elements (Au, Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sr, Ti, V, W, Zn and Zr) has been determined routinely on samples from the regolith profiles. Specifically every metre to 9 m and then 4-6 m composites at selected intervals to the bottom of the hole have been sampled and analysed. More detailed infill sampling has subsequently been undertaken where appropriate.

As indicated by Chan *et al*. (2002), the geochemical information must be used carefully because elements such as Ba, Cr, Ti and Zr may not be fully dissolved during the 4 acid digestion prior to analysis by ICP/ICPMS. For this reason high precision XRF analyses have been done on the freshest samples from each hole (bottom of hole samples) to facilitate lithological discrimination (e.g.Ti/Zr ratio).

A PIMA II spectrometer was used to determine the mineralogy of material from all holes drilled during the study. The PIMA instrument records the Short Wavelength Infrared (SWIR) reflectance spectrum (1300-2500 nm) of samples. In this spectral region, discrete wavelengths of light are absorbed due to the bending and stretching of molecular bonds. The types of mineral groups which display absorption features within the PIMA range include phyllosilicates, hydroxylated silicates, carbonates, sulphates and ammonium-bearing minerals, plus Al-OH, Fe-OH, Mg-OH. Absorption features may overlap, *e.g.,* kandite minerals (kaolinite, dickite and nacrite) all have very similar Al-OH features and are difficult to distinguish spectrally. However, in most cases, experience allows the distinction to be made (see Chan *et al.*, 2001 for further details of PIMA methodology).

The methods for both the chemical and mineralogical determinations were designed to give rapid, broad information, with the knowledge that more detailed study would be needed to fully evaluate some features.

RESULTS AND DISCUSSION

The geochemical suite utilised provides substantial information both on the lithology of the basement rocks and the weathering processes affecting the rocks, especially when the geochemical information is used in conjunction with mineralogy determined by PIMA's TSA algorithm. Four specific examples of the use of this approach are outlined:

Identification of mafic rocks in profiles

Mafic rocks, commonly dykes within Ordovician rocks, are widely distributed throughout the Girilambone Belt Region and have been encountered in 20 of the drill holes of this study. In weathered profiles they contain elevated Fe, Mn, Ti, Cr and V. However, as indicated previously, Ti and Cr contents can appear low due to incomplete dissolution of resistate Ti- and Cr-bearing phases and the absence of these elements does not necessarily discount elevated Ti and Cr in samples. Thus, the fact that the PIMA spectra of weathered mafic material reveal either one (Fe-bearing kaolinite) or no phyllosilicates in their spectra is very useful in rapidly confirming their mafic nature. Some mineralisation is commonly associated with or adjacent to these dykes. For example, in drill hole CBAC16 (17 km north of Canbelego), Ba up to 8800 ppm and S up to 4200 ppm (but not directly correlated with Ba) occur in the mafic material. The Ba and S are suspected to be in both barite and an alunite–jarosite mineral (Chan *et al*., 2001). Furthermore, drill hole CBAC198 (south of the Mt Dijou-Bald Hills deposits) contains mafic material (from 48-51 m) characterised by elevated Fe, Mg, Mn, Ni, P, Sr, Ti, V and Ti/Zr = 91 *plus* no phyllosilicates indicated in the PIMA spectra for that interval (Figure 1). Mineralisation in the hole varies from Zn (averaging 180 ppm between 1-5m) and anomalous Pb (>100ppm from 3-18 m, especially between 6-15 m where Pb is commonly >1000 ppm) but no other associated pathfinder elements, although 20 ppb Au occurs between 14 and 18 m. Mineralisation in the hole varies upwards from Au to Pb to Zn with distance from the mafic material.

Anomalous Au
A thick sequence with anomalous Au (40 m @ 40 ppb) occurs between 27 and 66 m in CBAC 238 (Figure 2). This is within a probable shear zone in the Lord Carrington Hill area, 20 km northeast of Byrock. Three meters of transported material occurs in this hole with calcrete developed at about the unconformity. The Au content of the calcrete-bearing samples is slightly elevated (4 ppb) relative to non-calcareous material above and below (2 ppb). The phyllosilicates of the residual saprolite are kaolinite and phengite, but magnetite, feldspars, quartz and hematite are also present with chlorite present at depth (Chan *et al.*, 2004). High Ca and P contents between 33-47 m reflect apatite (also detected by XRD). Although Zn varies from >100 ppm below the unconformity to 15 m and >150 ppm below that, no other chalcophile elements are present in the Au-rich interval (Figure 2).

Further south, in the Hermidale area, Au occurs associated with elevated As, Sb and Zn in hole CBAC142, 6 km along strike from the Muriel Tank Goldfield. Between 29-48 m up to 21 ppb Au is present and As contents are generally >20 ppm. Below 29 m other geochemical data, particularly Fe, but also Al, Cu, Ti and Zn are elevated. From 39 m downwards, Zn tends to be further elevated relative to abundances higher in the profile. The PIMA spectra also suggest a decrease in the kaolinite crystallinity and an increase in the abundance of mica at about 29 m. Only 1 m of transported material occurs in this profile and dolomite, reflected by elevated Ca, Mg and Sr contents is strongly developed at the top of the residual saprolite (especially between 1-3m). There may be some enrichment of Au associated with the carbonate in that interval.

In the central and southern portions of the Girilambone Belt Region, the common association of As with low level Au anomalies in regolith materials appears useful as an indicator of derivation from a Au-pyrite association. In the northern (Byrock) area Au anomalies are generally bereft of pathfinder elements. The association of some Au with Ca in calcrete confirms previous findings that calcrete can be used as a sampling medium provided the cover is not too deep (McQueen *et al*, 1999).

Significant base metal contents in the saprolite
Substantial As, Sb, Cu, Mo, W and Zn contents occur through the length of CBAC167 through the Babinda Volcanics (30 km northeast of Nymagee), with isolated anomalous Au also present at the top and bottom of the hole. Zinc contents are particularly high (1400 ppm) toward the end of the hole at 21 m and maintain abundances >700 ppm up to 7 m. PIMA spectra also show a change from dominant illite to kaolinite above this level, and indicates that the decrease in Zn content reflects dispersion of mobile elements with intense weathering. Some carbonate is developed at the transported/saprolite interface, with the increased Ca below 15 m reflecting the presence of residual plagioclase in lower saprolite/saprock. Dump material from an old shaft, 30 m away from this hole, contains 1.8% Pb *plus* anomalous Au, As, Cu, Mo, Sb, W and Zn (M. Hicks, pers. comm., 2002) and hence this hole must be regarded as representing the edge of a mineralised zone.

Significant Zn (>100 ppm) is present below 11 m in CBAC176 (26 km east of Nymagee). Zinc abundances increase down the profile, reflecting normal dispersion of Zn during weathering, although the highest Zn content is associated with Co, Mn, Ti, Fe and P with a mafic dyke. PIMA spectra indicate a change from muscovite/phengite- to kaolinite- rich assemblages above 7 m (*i.e.*, close to where the Zn anomalism stops). This coincidence again suggests that Zn is depleted as weathering intensity increases. In fact, because muscovite (and phengite) may contain hundreds of ppm Zn (*e.g.*, Scott, 1988) but kaolinite does not, the destruction of its host may be responsible for its depletion higher in the profile. Carbonate is present at the transported/residual saprolite interface in this hole. The presence of intermittent anomalous Bi and/or W with the elevated Zn in this hole indicates that this region within and about the Babinda Volcanics (including hole CBAC167 which has been seen to be weakly mineralised) in the extreme south west of the Girilambone Belt Regions deserves further investigation for it mineral potential.

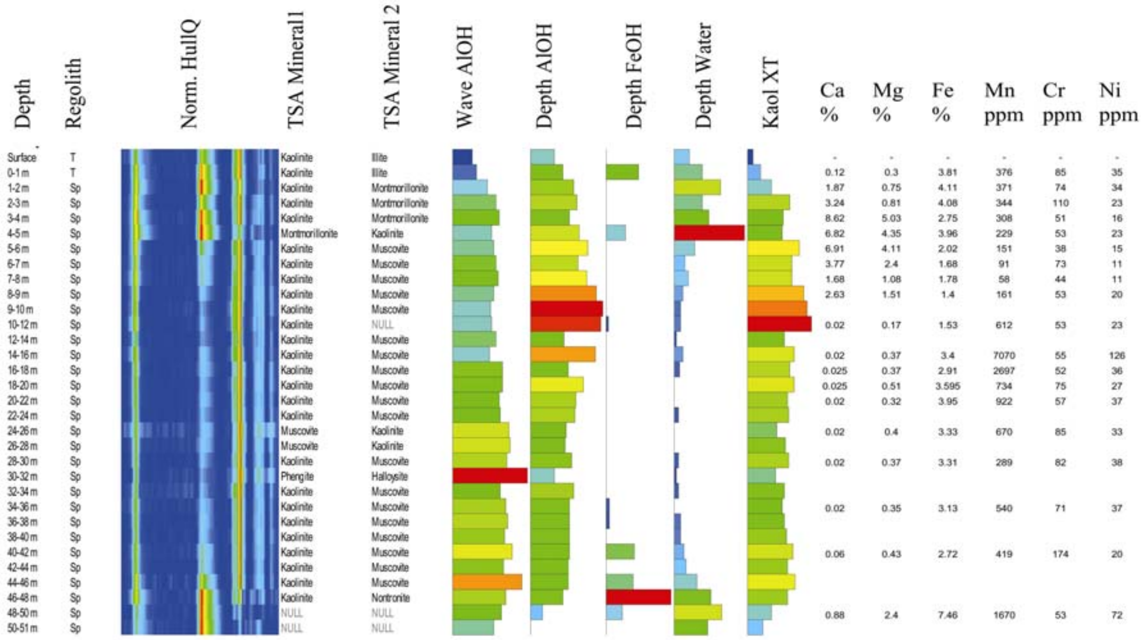

Figure 1. PIMA analysis and selected geochemical data of the regolith profile of drill hole CBAC198.
-: Not determined

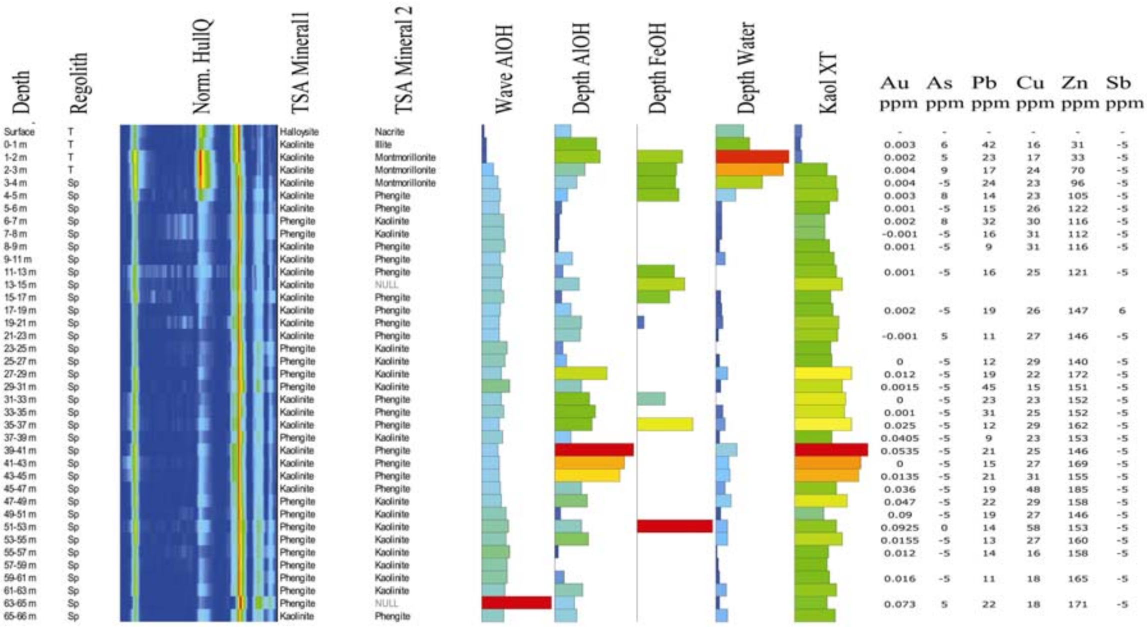

Figure 2. PIMA analysis and selected geochemical data of the regolith profile of drill hole CBAC238.
-: Not determined

However in CBAC201, south of the Mt Dijou-Bald Hills deposits, Zn and Co occur associated with Mn between 15-72 m. Although this association reflects the presence of mafic material from 51-72 m, the strong association between 15-33 m and the low abundance of pathfinders like Pb and As suggests that the anomalous upper zone may represent incorporation of Zn and Co into Mn oxides at a former water table (*cf.* McQueen, 2004).

Anomalism in transported material

Drill hole CBAC80 has As and Sb associated with anomalous Pb from 0-12 m. Such an association of pathfinders with the Pb adds confidence in regarding the anomaly as significant. However PIMA results clearly indicate that this interval is within transported material. Nevertheless, because of the retention of the pathfinder elements with the Pb, it is likely the anomaly consists of transported gossanous fragments and that their source is not too far distant.

CONCLUSIONS AND IMPLICATIONS FOR EXPLORATION

The following comments can be made about the geochemical and mineralogical data collected during the Girilambone Belt Project:

- Because of the methods used for analysis, the geochemical results should be interpreted cautiously (*e.g.*, high Cr identifies mafic dykes but the absence of Cr does not preclude material from being mafic). Specifically, Ba, Cr, Ti and Zr values determined by ICP analysis should be regarded as minimum values only because of the possibility of incomplete dissolution.
- Mafic rocks (dykes) within the Ordovician rocks of the region are commonly mineralised.
- PIMA shows changes down profiles and when integrated with geochemical data can help interpret position in the regolith profile during drilling. Samples for which the TSA algorithm suggests no or only one mineral phase should be specifically checked to determine whether such material is mafic. In other profiles the coincidence of the mineralogical change from dominant mica to kaolinite coincides with loss of mobile elements like Zn.
- Anomalous Zn occurs in the Babinda Volcanics regionally (Fleming & Hicks, 2002). This study indicates that other mineralisation-associated elements may be present in such Zn-rich profiles and in these cases an analogy may be drawn with the Mt Windsor Volcanics (in which stratiform mineralisation generally occurs at a particular level in acid to intermediate volcanic sequences: Berry *et al.*, 1992).
- Weak but extensive zones of Au-anomalism in the Byrock region (*e.g.*, CBAC238) deserve further investigation.
- Weak Au-As mineralisation occurs in CBAC142, along strike from the Muriel Tank mineralisation.
- Au is elevated in some surface and near surface samples and there is a high probability that such Au is associated with secondary carbonate, "calcrete". Thus calcrete sampling may be an appropriate sampling medium in the region, provided the cover is not too deep.
- Weak As-Sb-Mo-W-Zn-)-(Cu)-(Au) mineralisation occurs in CBAC167 and probably reflects the edge of more Pb-rich mineralisation (as found in nearby dump material).
- It is critical to identify whether anomalism occurs within transported or *in situ* material in order to determine how further exploration should be conducted.

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THE DISCOVERY AND REGOLITH EXPRESSION OF THE HERA AU-CU-ZN-PB-AG DEPOSIT

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DISCOVERY HISTORY

The Hera prospect, located 5 km SE of Nymagee, was initially identified by Buka Minerals in 1974 following a Barringer Input Survey. CRAE drilled the first hole into the mineralised horizon in 1984, intersecting sub-economic mineralisation. During 2000, Pasminco intersected ore grade mineralisation along strike from the CRAE drilling, beneath a Pb soil anomaly. In 2003, Triako Resources Limited acquired the prospect and, with additional drilling, has confirmed the continuity of high grade Au mineralisation and extended it to the north. The presence of coarse-grained Au in drill core from Hera prompted Triako to commence a program of screen-fire Au assaying, resulting in a large upgrade in Au tenor over the width of the most significant mineralised zones. To date, high-grade mineralisation has only been intersected at depths greater than 250 m below the surface. The surface expression of the mineralisation is as rare, weakly gossanous float on a colluvial slope adjacent to a siliceous hill – The Peak. Historic prospecting is evident with a shallow shaft sunk into The Peak, 250 m east of the surface projection of the Hera mineralisation.

GEOLOGICAL SETTING

The Hera prospect is located proximal to the eastern margin of the Palaeozoic Cobar Basin, near the contact between shelf facies sediments of the Mouramba Group and turbiditic sediments of the Amphitheatre Group. The mineralisation is hosted within a tightly folded sequence of steeply dipping siltstone and fine-grained sandstones with a strong, near vertical cleavage. The sediments have been metamorphosed to low to middle greenschist facies.

REGOLITH

The Hera prospect lies beneath a thin veneer (<1 m) of colluvial sediments and talus material on a slope adjacent to a prominent low silicified hill known as The Peak. The colluvial slope extends to the north, west and south approximately 300 m from The Peak and gives way to a broad erosional plane underlying a thin veneer of residual and colluvial sediments (Figure 1). A series of low hills comprised of slightly to moderately weathered Palaeozoic bedrock occur to the east and southeast of The Peak.

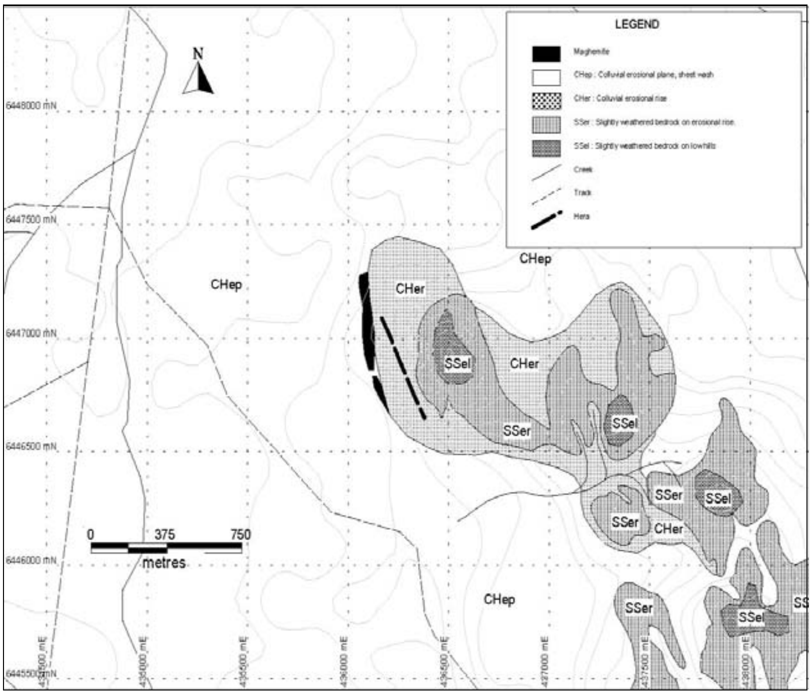


Figure 1. Local regolith geology of the area surrounding the Hera prospect showing the relative topography, dominant landform features and the distribution of colluvial material and weathered bedrock. Hera is shown as a bold. dashed line.

Colluvium material is comprised of locally derived, poorly sorted, subangular to angular fragments of weathered bedrock and ferruginous silty clay. The colluvial layer is generally less than one metre in thickness and is underlain by weakly to moderately weathered bedrock.

At the break between the colluvial slope and the erosional plane to the west of Hera lies an accumulation of maghemite lag which forms a narrow (<50 m) band. This maghemite accumulation is also broadly coincident with an anomalous magnetic and EM response, which was initially interpreted as a palaeochannel however subsequent drilling indicates a band of kaolinitic saprolite.

MINERALISATION

Mineralisation at Hera consists of several parallel narrow lenses of intense vein-type mineralisation comprised of pyrrhotite, sphalerite, galena, pyrite ± chalcopyrite and gold. Host sandstones and siltstones are pervasively silicified, with varying degrees of green chlorite alteration and commonly contain disseminated, non-magnetic pyrrhotite, typically aligned parallel to cleavage. Quartz veining is common and several zones of barren buck quartz veins, up to 1 m thick, are spatially associated with sulfide mineralisation.

Geometrically, the sulfide lenses appear to strike approximately 340º N and dip steeply to the east (>80º). Based on drilling to date and EM modelling, the top of the sulfide package occurs approximately 250 m below surface in the southern part of the prospect and appears to plunge shallowly to the south, extending along strike at least 800 m. There is some indication that the EM source may continue a further 400 m to the north. However, interpretation is difficult due to the interference from an interpreted palaeochannel response.

There is insufficient drilling at present to estimate the true grade of the mineralisation or to interpret any zonation of metals. The best Main Lens intersections to date have been (Figures 2 and 3):

- 8.6 m @ 26.6 g/t Au, 19.0% Pb+Zn and 1.8% Cu from 371.4 m in PNDD2 (Simpson *et al.*, 2001). Later screen-fire gold assays by Triako indicate 38.6 g/t Au.
- 5.0 m @ 2.8 g/t Au, 14.1% Pb+Zn and 33 g/t Ag from 514.0 m in TNY002
- 13.5 m @ 8.1 g/t Au, 0.5% Cu, 3.5% Pb+Zn and 13g/t Ag from 374.7 m in TNY004
- 8.0 m @ 1.5 g/t Au, 14.7% Pb+Zn and 29 g/t Ag from 341.0 m in TNY007

A number of Au-only drill intersections have been returned from Hera, demonstrating that significant Au-only mineralisation exists within the Hera mineralised system, *e.g.*,

- 2 m @ 8.2 g/t Au from 400 m in TNY007.

Additional geochemical anomalies occur within the vicinity with a multi-element anomaly coincident with The Peak and sporadic Pb and/or Zn anomalies extending up to 1 km southeast of Hera.

REGOLITH EXPRESSION

Bottom of hole samples in weathered bedrock from RAB drilling, using 25 m spaced holes on 100 m spaced lines, were analysed for Cu, Pb, Zn, Ag, As, Fe and Mn. A coherent Pb anomaly >1000 ppm, over a strike length of 400 m, is coincident with the up-dip projection of the known mineralisation. This high amplitude Pb anomaly lies within a larger anomalous area (>200ppm Pb; Figure 4A). A similar anomalous zone occurs approximately 250 m to the east of Hera, coincident with The Peak. Manganese results are similar to those obtained from Pb (Figure 4B) however Zn, Cu and As results were less conclusive (Weber, 1984). Background levels for Pb and Mn are 30 ppm and 55 ppm respectively. Additional RAB drilling to the north, east and south of Hera utilised sampling at the B-C horizon interface in order to increase the target size by assuming an increased geochemical dispersion. Although direct correlation between the two sampling methods is not available, both sampling methods identified the same anomalous trends. Statistically, threshold values for both methods are similar however background values are slightly greater for the B-C horizon samples, perhaps reflecting increased dispersion.

Conventional soil sampling results (samples at 25 m spacing) returned anomalous values of Pb and Au (single point) coincident with the up-dip projection of the known mineralisation. Values for Pb are significantly lower than those from weathered bedrock and are more widely dispersed. Gold appears to have a poor dispersion within the soil profile. Other elements such as Zn, As and Cu are anomalous above the Peak but have no anomalous response above the known Hera mineralisation.

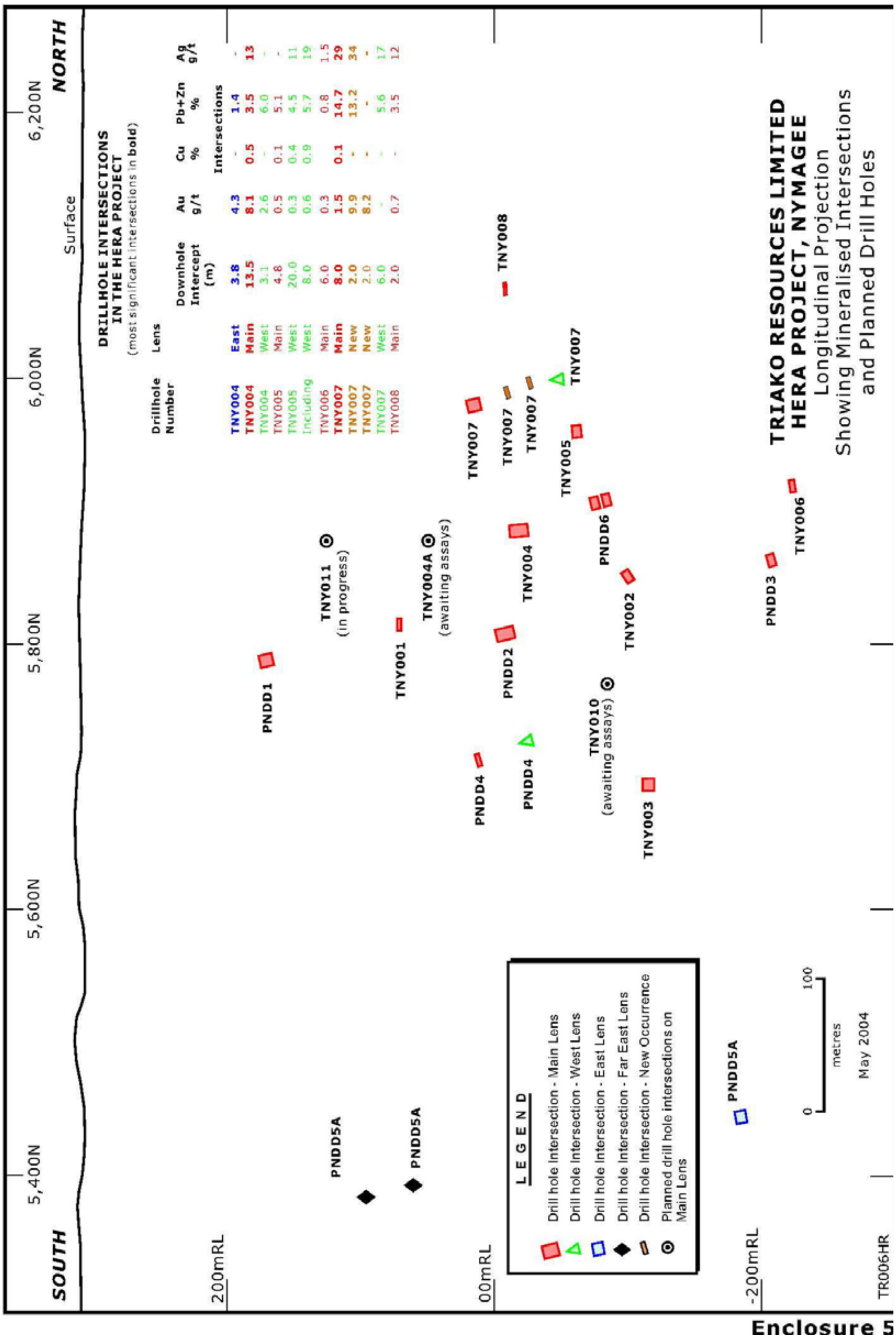
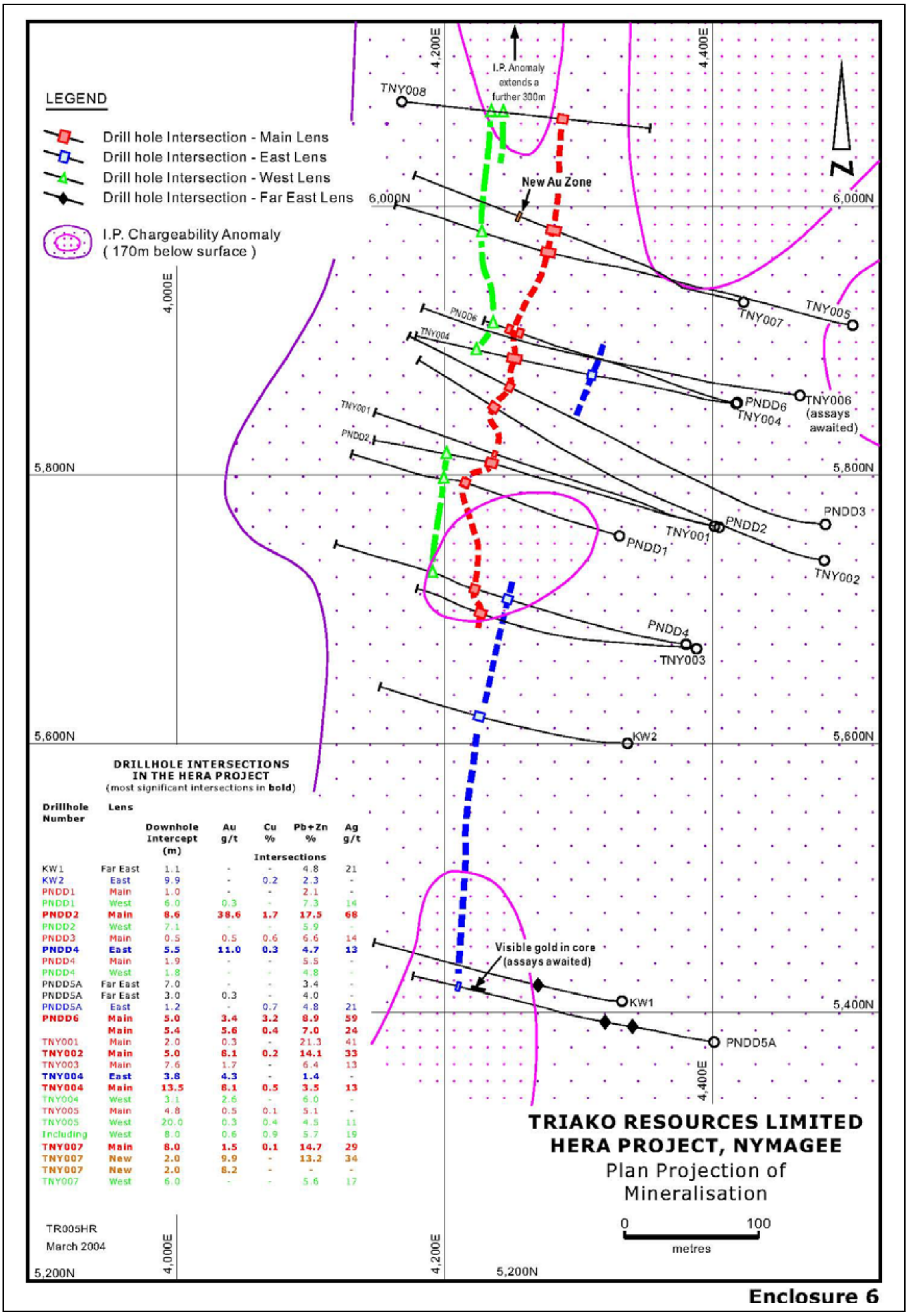


Figure 2. Longitudinal section, Hera prospect. (from Triako Resources Limited)



DRILLHOLE INTERSECTIONS IN THE HERA PROJECT
(most significant intersections in **bold**)

Drillhole Number	Lens	Downhole Intercept (m)	Au g/t	Cu %	Pb+Zn %	Ag g/t
				Intersections		
KW1	Far East	1.1	-	-	4.8	21
KW2	East	9.9	-	0.2	2.3	-
PNDD1	Main	1.0	-	-	2.1	-
PNDD1	West	6.0	0.3	-	7.3	14
PNDD2	**Main**	**8.6**	**38.6**	**1.7**	**17.5**	**68**
PNDD2	West	7.1	-	-	5.9	-
PNDD3	Main	0.5	0.5	0.6	6.6	14
PNDD4	**East**	**5.5**	**11.0**	**0.3**	**4.7**	**13**
PNDD4	Main	1.9	-	-	5.5	-
PNDD4	West	1.8	-	-	4.8	-
PNDD5A	Far East	7.0	-	-	3.4	-
PNDD5A	Far East	3.0	0.3	-	4.0	-
PNDD5A	East	1.2	-	0.7	4.8	21
PNDD6	**Main**	**5.0**	**3.4**	**3.2**	**8.9**	**59**
	Main	**5.4**	**5.6**	**0.4**	**7.0**	**24**
TNY001	Main	2.0	0.3	-	21.3	41
TNY002	**Main**	**5.0**	**8.1**	**0.2**	**14.1**	**33**
TNY003	Main	7.6	1.7	-	6.4	13
TNY004	**East**	**3.8**	**4.3**	-	**1.4**	-
TNY004	**Main**	**13.5**	**8.1**	**0.5**	**3.5**	**13**
TNY004	West	3.1	2.6	-	6.0	-
TNY005	Main	4.8	0.5	0.1	5.1	-
TNY005	West	20.0	0.3	0.4	4.5	11
Including	West	8.0	0.6	0.9	5.7	19
TNY007	**Main**	**8.0**	**1.5**	**0.1**	**14.7**	**29**
TNY007	**New**	**2.0**	**9.9**	-	**13.2**	**34**
TNY007	**New**	**2.0**	**8.2**	-	-	-
TNY007	West	6.0	-	-	5.6	17

Figure 3. Plain section, Hera prospect, (from Triako Resources Limited).

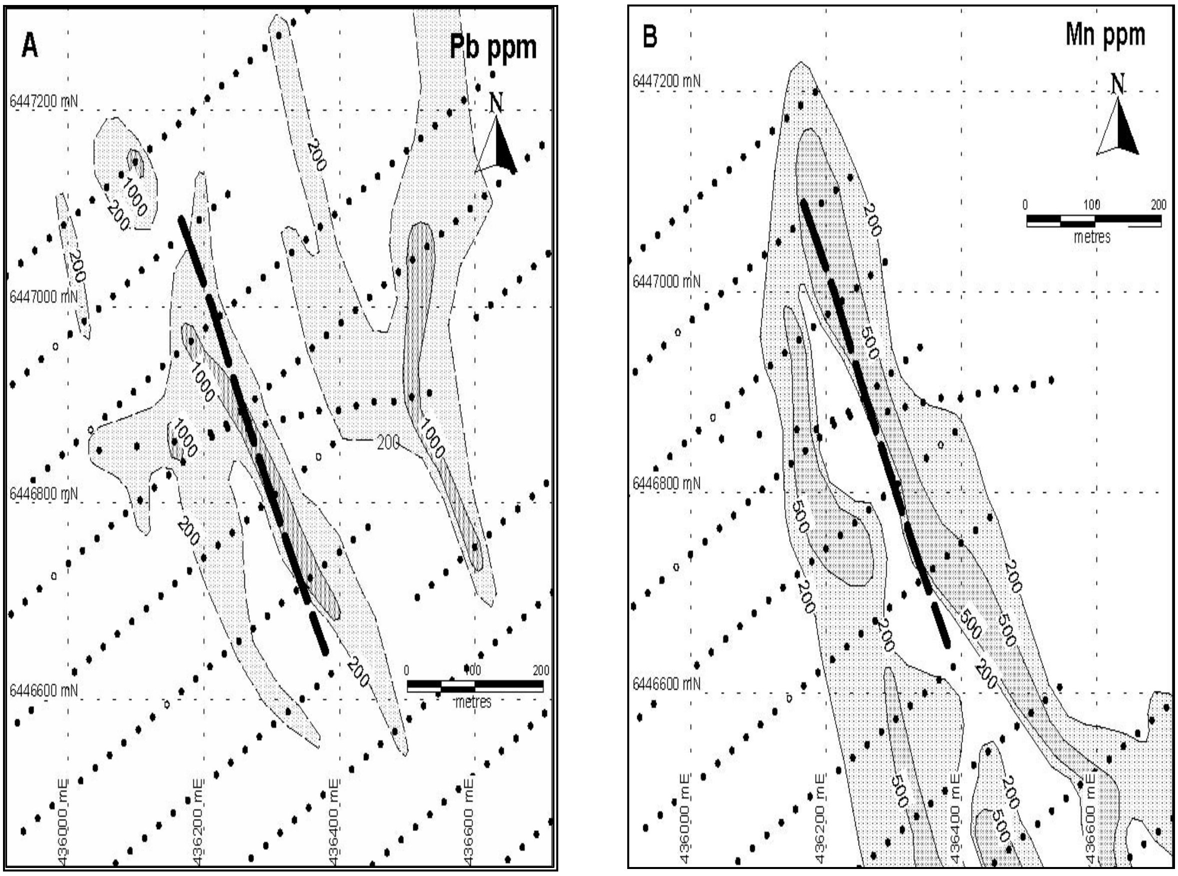


Figure 4. Distributions of Pb and Mn in weathered bedrock from RAB drilling. Up-dip surface projection of Hera mineralisation is shown as bold dashed line. Anomalous zone east of Hera is broadly coincident with the silicified hill referred to as The Peak.

Partial leach soil sampling results are broadly consistent with conventional soil samples. These samples (again at 25 m spacing) were only analysed for Cu, Pb, Zn and Cd. The best correlation to the known mineralisation was again from Pb and a coherent Pb+Zn+Cu anomaly occurs over The Peak. The partial leach samples were all taken within the immediate vicinity of Hera and it appears that this has resulted in an artificially high background value (8.8 ppm for Pb).

In summary, the Hera mineralisation has a distinct geochemical signature in both the weathered bedrock and residual/colluvial soil profile. The most effective indicator elements are Pb and Mn in weathered bedrock and Pb in the soil profile. It is difficult to predict the true geochemical dispersion as the Hera mineralisation is currently poorly constrained and additional, unidentified mineralised lenses may exist.

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THE STRATEGY FOR GEOCHEMICAL EXPLORATION AROUND THE CSA MINE

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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 an 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+/-Zinc) 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.

The CSA mine and tenements are currently operated by Cobar Management Pty Ltd (CMPL), a wholly owned subsidiary of Glencore International.Reserves, and resources on the QTS North System, as of November 2003, were 4.2mt at 7.83% Cu and 29 g/t Ag. Throughput is 600,000t per annum. Current development is at 1.3km below surface and the resource is open at depth, 1.8km from surface. Mineralization consists of steeply dipping sulfide and quartz sulfide lenses. These are hosted in the CSA siltstone and are structurally related to the Cobar fault.

CMPL have 4 exploration leases in the Cobar district, totalling 820 km^2 (Figure 1). These include;

- CSA Lease (EL5693) – surrounding the CSA mine.
- Delta Lease (EL5983) - wholly contained within EL5693.
- Restdown Leases (EL6140) - 30km to the ESE of Cobar and;
- Horseshoe Leases (ELA 2053), commonly known as the Muriel Tank goldfield - 60km east of Cobar.

Surface exploration recommenced at the CSA in 2002 after a hiatus of 4 years. Exploration targets include CSA-style and Peak-style mineralisation. The following paper will discuss the approach to surface exploration since 2002, concentrating predominately on geochemistry and regolith aspects of the near mine environment.

OVERVIEW OF EXPLORATION TARGETS

High priority exploration targets within EL5693 (Figure 1) typically relate to the styles of mineralization observed in the CSA mine environment. Priority 2 exploration targets relate to Peak-style mineralization associated with the Chesney Fault and interpreted offset faults. Priority 3 exploration targets are more generic by nature, targeting structurally controlled base metal and gold mineralization proximal to regional structures. These targets are primarily in the Restdown (EL6140) and Horseshoe leases (ELA2053).

SUMMARY OF CSA AND PEAK DEPOSIT CHARACTERISTICS

The general features of the CSA and Peak deposits are broadly similar including;

- steeply dipping and steeply north plunging pip-like lenses of sulfide veins;
- mineralized quartz veins;
- mineralised and silicified rock with both massive and banded sulfides;

The ore lenses are enveloped in north-north westerly trending, sub-vertical zones of silicification and quartz veining with chloritzation and carbonate veining. Strike lengths are short (less than 300 m) and widths are commonly between 10-30 m. The deposits have strong vertical continuity with vertical extents of greater than 1000 m. The small "footprint" of these targets, limited alteration halo and depth of mineralisation makes them tough targets, but the rewards are high.

EXPLORATION AT THE CSA SINCE 2002

Historical exploration data generated since 1960 has been compiled into a GIS database (drilling, geophysics, geochemistry). This data has been extensively reviewed and the following conclusions made:

- In general the geophysical data is of good quality (IP, magnetics, gravity), though some digital data sets are missing;

- The drill data base is reasonably complete, though some core is missing;
- There are significant geochemical surveys, however the data is of variable quality.

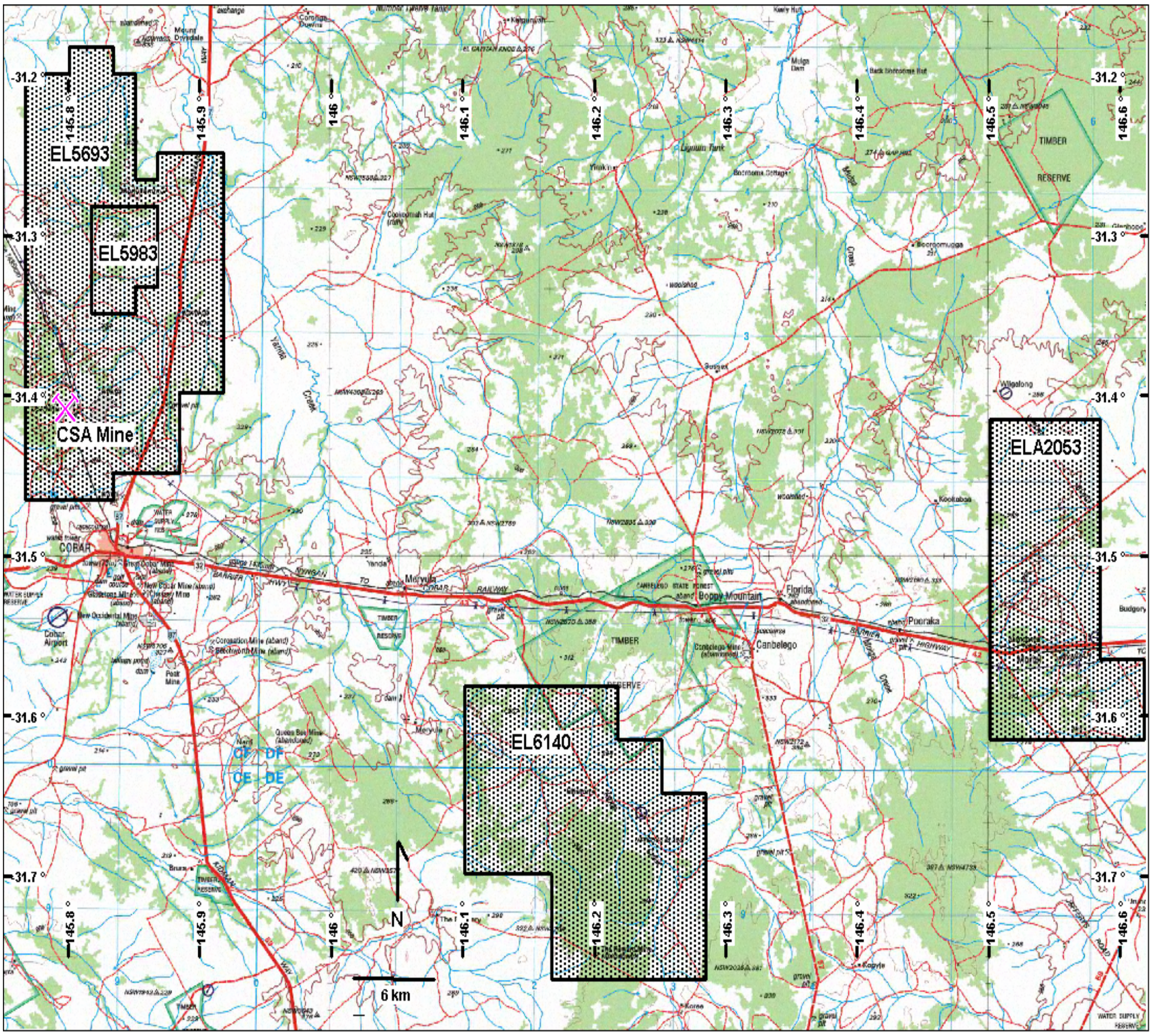

Figure 1. Granted tenements and tenement under application.

The main weakness in the data sets is the geochemical data. Although proposed sampling protocols were good, these do not appear to have been followed during sampling. The other weakness is that regolith features and variability were not considered, resulting in the sampling of areas of mixed, *in-situ* and transported regolith, including lag and eluvial soils. These two aspects will be discussed in detail below.

GEOCHEMISTRY

Previous explorers (mainly CRA and Golden Shamrock) undertook significant geochemical exploration on EL5693 and Mining Lease CML5, collecting some 12,000 samples. The key points from this geochemical sampling are:

- The general quality of sampling was found to be variable, based on sample description;
- One data set of several thousand samples contained numerous sample descriptions of red soils, quartz fragments and sometimes pisolites;
- The samples were not sieved to remove the fine fraction (as had been recommended in their sampling protocol);
- The red soils are known to contain transported dust, predominately derived from the west and this has had a dilution effect on the samples;
- The large survey failed to reveal known geochemical anomalies and as such has possibly concealed anomalies elsewhere on the tenement.

DESIGNING GEOCHEMICAL PROGRAMMES

At the same time as we established that there were difficulties in interpreting some of the previous geochemical programmes, we were working with CRC LEME to develop methods and protocols for upcoming geochemical programmes. From this work we established that we wanted to:

- Be consistent in the horizon and materials to be sampled for all programmes ("comparing apples with apples");
- Avoid sampling red soils, pisolites, lag;
- Sample the upper part of the weathered bedrock zone above the saprolite (~ about 2-3 m deep) in general (but variably deeper or shallower);
- Avoid sampling the saprolite zone, as it can be difficult to identify *in situ* saprolite from transported clays and there may have been metal leaching out of this zone.

The objective was to create a geochemical and geological data base that consists of samples collected from the same horizon and material, providing a high level of confidence in the data. Figure 2 shows a typical profile through the thin red soil layer into a zone of calcrete and mixed sediments and then through to the saprolite zone.

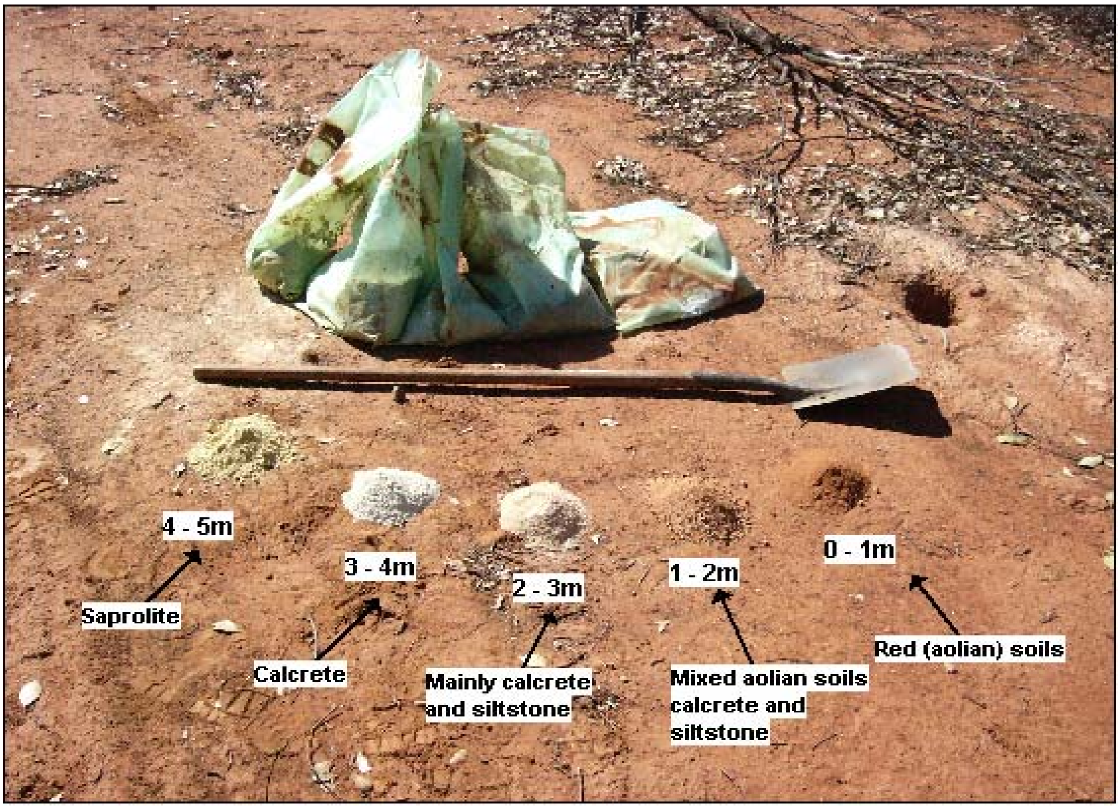

Figure 2. Typical profile through the red soil cover into calcrete/sediments at the Mopone prospect. Interval sampled was at 2-3 m.

INITIAL GEOCHEMICAL PROGRAMMES

In late 2002 limited geochemical programmes were conducted over a number of prospects using a hand held auger. A number of problems were encountered in the programme, including:

- Lack of moisture in the soil due to the drought meant samples were too dry to collect in the auger;
- The depth of cover prevented samples from being collected from the target zone.

As such, the programme suffered the same issues of variable sampling quality as the previous explorers.

Next we looked at RAB or Aircore drilling. Aircore was considered appropriate because:

- We could sample the target horizon better (as opposed to RAB);
- We could collect a good volume sample for assaying and geological logging;
- There was less risk of contamination, which was particularly important in the mine environment.

Initial trials with aircore drilling were successful in delineating the various regolith and lithological units, as can be seen in Figure 2.

GEOCHEMICAL PROGRAMMES COMPLETED TO DATE

Several aircore programmes were completed in mid to late 2003, resulting in some 1899 aircore holes for 5225 m and an average depth of 2.63m. Samples were assayed by ALS using method ME-MS43 for ***Cu, Pb, Zn, Ag, Se***, Mn, Fe, As, Au, S, Ba, ***Bi***, Ca, ***Cd, Hg,*** Mg, ***Mo, Te*** and Tl (the elements in bold italics are anomalous in the copper concentrate produced at the CSA mine, compared to the tailings grade).

CSA MINE AREA

The geochemical survey in the CSA mine area provided the most encouraging results of the surveys completed. Previously the mine area had been covered by wide-spaced good quality geochemical surveys, with limited close-spaced geochemistry. These programmes identified point anomalies but were too widely spaced to define coherent trends. In 2003 we undertook a 50 m by 50 m sampling programme (799 samples) encompassing the mine area. This was extended north along the Cobar fault in 2004 by a wider spaced survey (200 m by 50 m grid for 477 samples).

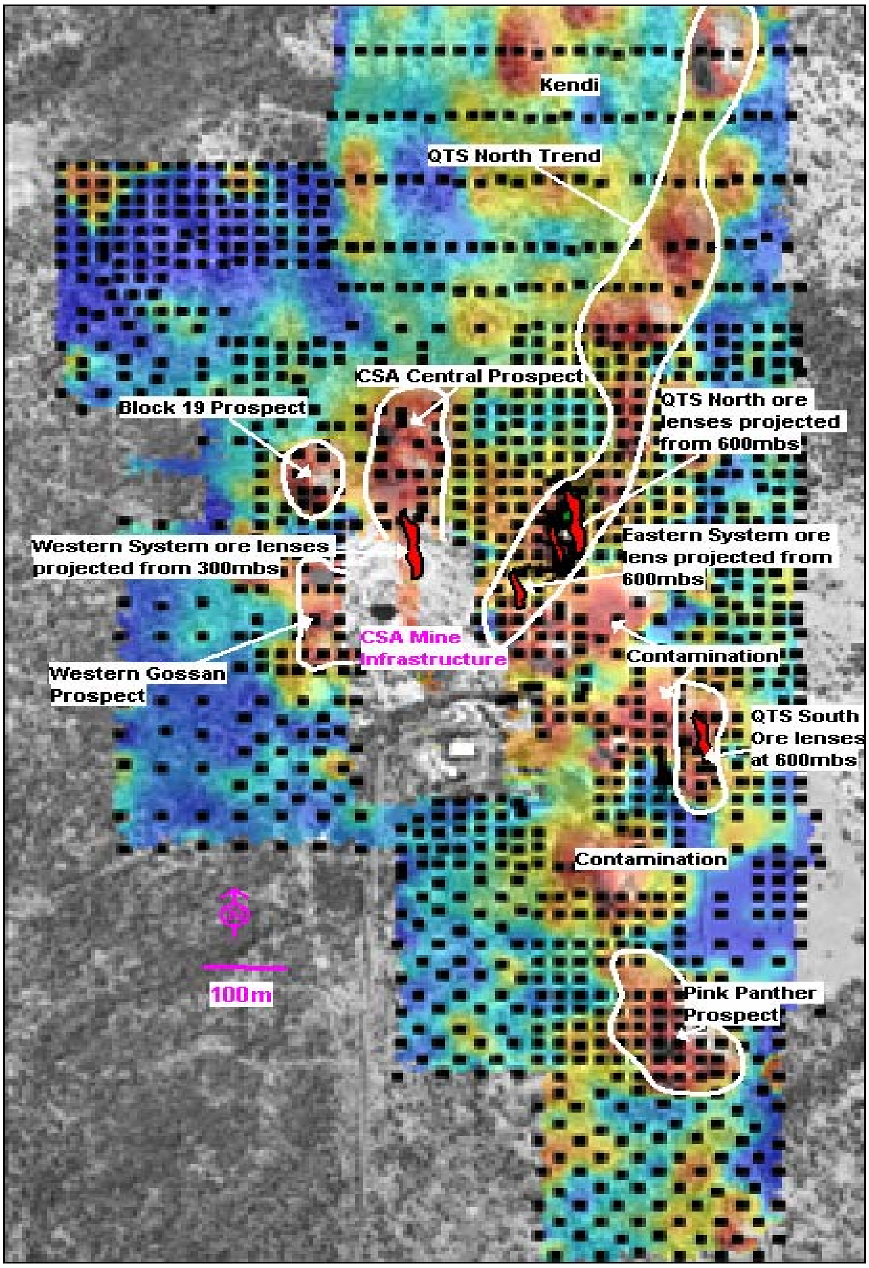

Figure 3. Near mine and Kendi geochemical sampling and prospects with copper contours. Samples are on a 50 m grid near the mine and a 200 m by 50 m grid over Kendi. Data is contoured in *Encom Discover* software. The maximum copper value is 422 ppm.

From this programme we were able to:

- Identify subtle Cu+Pb+Zn anomalism associated with the QTS North and South mineralization that economically starts some 600m below the surface;
- Define a NE trending zone of anomalism, “QTS Trend”;
- Extend the Cu+Pb+Zn anomalism of the Western System north to the “CSA Central” prospect;
- Develop alteration and geological maps from logging rock chips;
- Combine the geochemical data with the geophysical data to define a number near mine exploration targets;
- Define a number of geochemical anomalies within the Kendi prospect area;

Figure 3 shows the extent of the geochemical survey (excluding the top part of the Kendi grid)

PRELIMINARY GEOCHEMICAL ANALYSIS

Initially all elements assayed were contoured in *MapInfo Discover* software. Elements that formed coherent trends included copper, lead zinc and some of the trace elements (cadmium, barium and selenium). At this stage mainly copper lead and zinc have been considered. The geological and surface regolith features were then reviewed to establish if there was any contamination generated by mining/milling activities. Several areas such as historical spoils dumps and the area next to the concentrate shed were identified as being contaminated. Geological logs of these areas were checked and were confirmed to be barren of visible alteration or veining.

The next stage involved calculating threshold levels for the elements assayed. Again only copper lead and zinc will be considered here. A number of methods were considered including, various percentile (90th, 95th and 97.5) and natural data points in the “log-normal” distribution of the data. Both methods provide similar results for copper and lead though zinc is lower using the 97.5 percentile compared to the natural break in the log-normal data. The “log normal data breaks” were used to produce the plots in figures 4 to 8.

Table 1 Threshold determination

	90^{th} %	**95^{th} %**	**97.5%**	**Natural break in the log/normal plot**
Cu (ppm)	54	91	160	138
Pb (ppm)	124	278	458	450
Zn (ppm)	139	212	388	600

The next stage involved projecting the ore lenses to surface to compare the geochemistry and surface geology with expected surface position of mineralisation. Each ore lens had some surface expression with the QTS North lens reflected by quartz veining and minor gossan development; the QTS South by ferruginous quartz veining intersected in aircore holes (and documented in previous trenching) and the Western lens by strong ferruginous alteration (Figures 4 to 8).

The threshold data was then used to develop geochemical plots to highlight geochemical trends in the near mine environment and along the Cobar Fault to the Kendi prospect. Initially, copper, lead and zinc were considered individually (Figures 4, 5 and 6). The values below the threshold were removed from the data sets and then re-contoured. Clearly copper is the best element for determining geochemical trends, highlighting the QTS North trend, Western System, the northern end of QTS South and the southern end of Block 19 (Figure 4). Lead is more restricted and reflects strong lead geochemistry through the Western System, CSA Central prospect, Block 19 and Western Gossan prospects (Figure 5). Minor lead anomalism is associated with the Kendi and Pink Panther prospects. Lead is considered significant as it is relatively immobile and may indicate the presence of mineralised structures. Zinc dispersion (Figure 6) is surprisingly restricted in extent (probably due to the high-cut off applied) reflecting the QTS System, Pb/Zn rich Western System and Block 19 South prospect. Zinc above threshold is devoid from Block 19 Nth, QTS North trend and Kendi prospects. Further work on estimating an appropriate zinc cut-off may better reflect the geochemistry of these prospects.

Next we developed copper + lead (Figure 7) and copper + lead + zinc additative plots (Figure 8) above threshold values. This was done by simply summing the assay grades for each element and then filtering out the values that fell below the sum of the threshold values. The copper + lead plot reflects copper as the commodity of interest and “fixes” it to lead, considered as immobile and possibly representing proximity to structures. As such the plot aims to represent copper associated with structures. The plot highlights the south and north end of the QTS North trend as well as the Block 19 prospects, Pink Panther and Western Gossan prospects. The copper + lead + zinc plot highlights geochemical anomalies in the near mine area including Block 19, QTS North and South, CSA Central, Western Gossan and Pink Panther. The QTS North trend and Kendi are not reflected in this plot.

DISCUSSION

The calculation of threshold values incorporating geochemical data relating to mineralisation (QTS North South and the Western System) at the CSA has allowed us to develop a preliminary "geochemical model" to explore along the Cobar fault. Using the mine geochemical data as a basis for comparison has highlighted prospects in the near mine environment (CSA Central prospect, Block 19, Western Gossan prospects and the QTS North Trend) as well as the Kendi prospect 2km north of the mine.

Geochemical plots are relatively simple at the moment, representing first pass evaluation of the major element data. Further refinement will look at reducing the strong bias to lead and zinc, increasing the influence of copper and incorporating minor element geochemistry. The strong influence of lead and zinc is probably a function of the Western lens mineralisation occurring at shallow depths (150 mbs), compared to the copper rich QTS System which contains economic mineralisation from 600 mbs.

Further refinements to the model may include partitioning the geochemistry to reflect the differences in lithology between the Western System, which occurs at the bottom of the Biddaburra formation (interbeded fine grained sandstones and siltstones) and the QTS System, which occurs in the CSA Siltstone (siltstones and occasional bands of fine grained sandstone). Ultimately the aim is to produce a geochemical model that reflects the near mine geochemistry and can be applied for exploration along the Cobar Fault.

REGOLITH MAPPING

We are currently undertaking a regolith-landform mapping project in conjunction with CRC LEME over the southern portion of EL5693 and CML5. The main thrust of this project is to provide a regolith map of the mining and exploration leases to assist with:

- Planning geochemical programmes – i.e. evaluating the type/ thickness of the regolith;
- Evaluating previous geochemical data – comparing assay results and regolith forms with sample descriptions (if available) to validate or reject data.

This project may be expanded as part of ongoing exploration mapping activities, particularly along the Cobar Fault.

GOING FORWARD

We are still at the early days of recent exploration programmes. At the time of writing we had completed some 20 trenches across the Block 19 and CSA Central prospects, following up surface geochemistry and known gossan outcrop. Mapping of these trenches has revealed strong gossan development over 150 m of strike length at Block 19 and several previously unknown ferruginous quartz vein systems through the CSA Central prospect. These will be drilled as rigs become available.

Other exploration activities will include:

- Further scrutiny of our geochemical data bases and development of "metal factor" calculations using trace element geochemistry;
- Combining geochemical and geophysical data sets to evaluate and prioritize targets;
- Undertaking more geochemical survey, particularly along the Cobar fault;
- Incorporating regolith mapping into our geochemical programmes.

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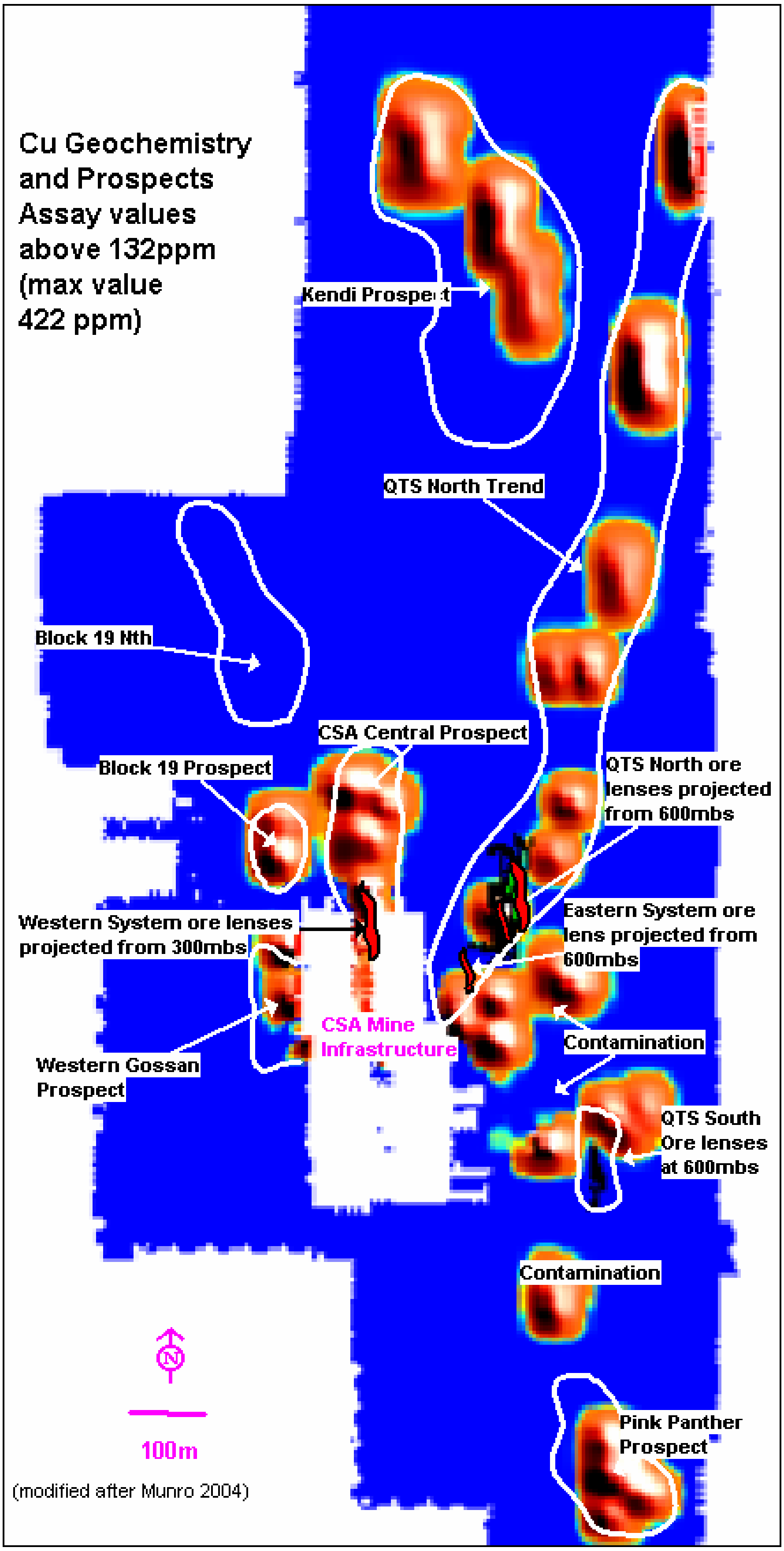

Figure 4. Copper geochemistry contours and prospects.

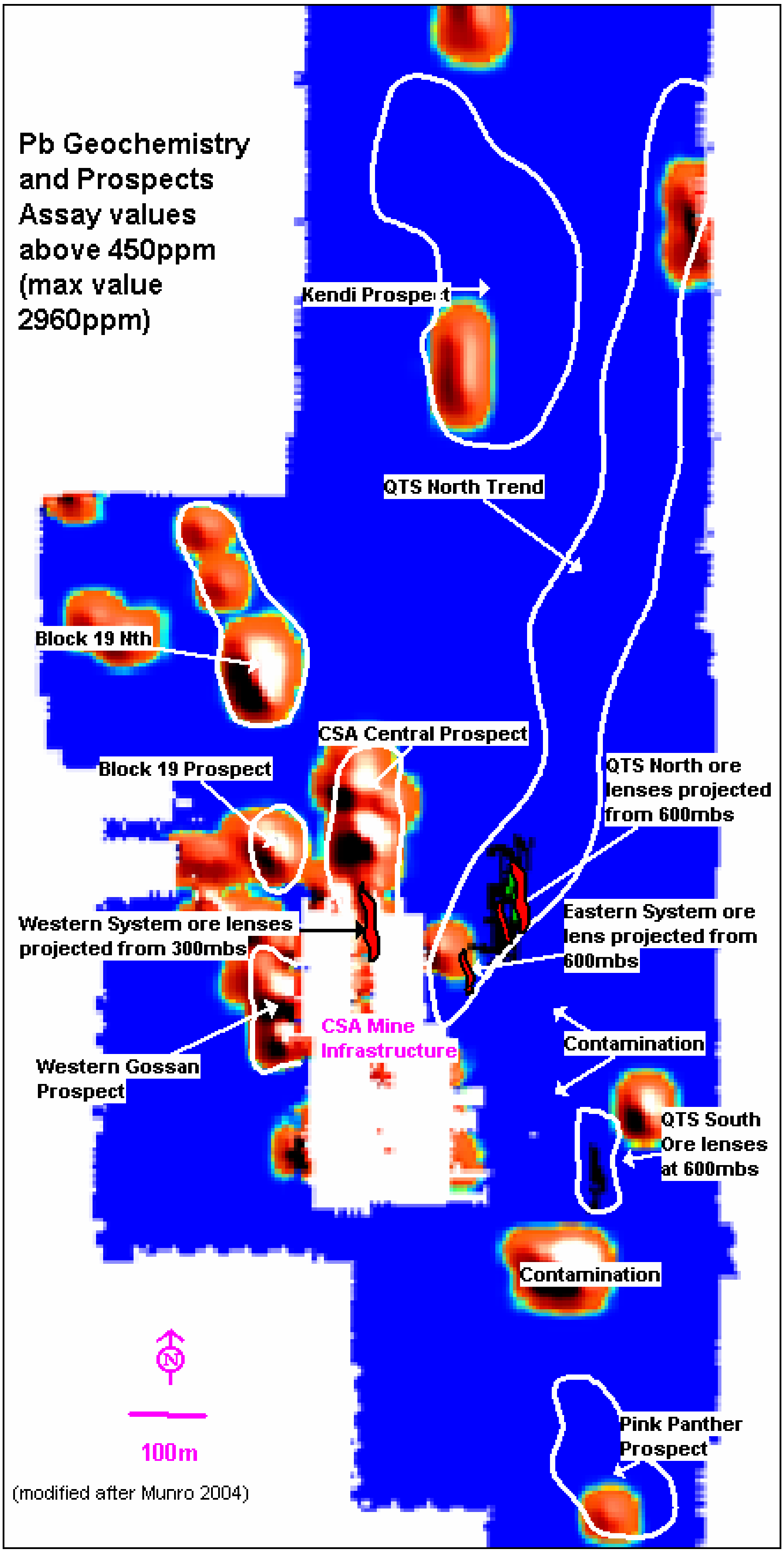

Figure 5. Lead geochemistry contours and prospects.

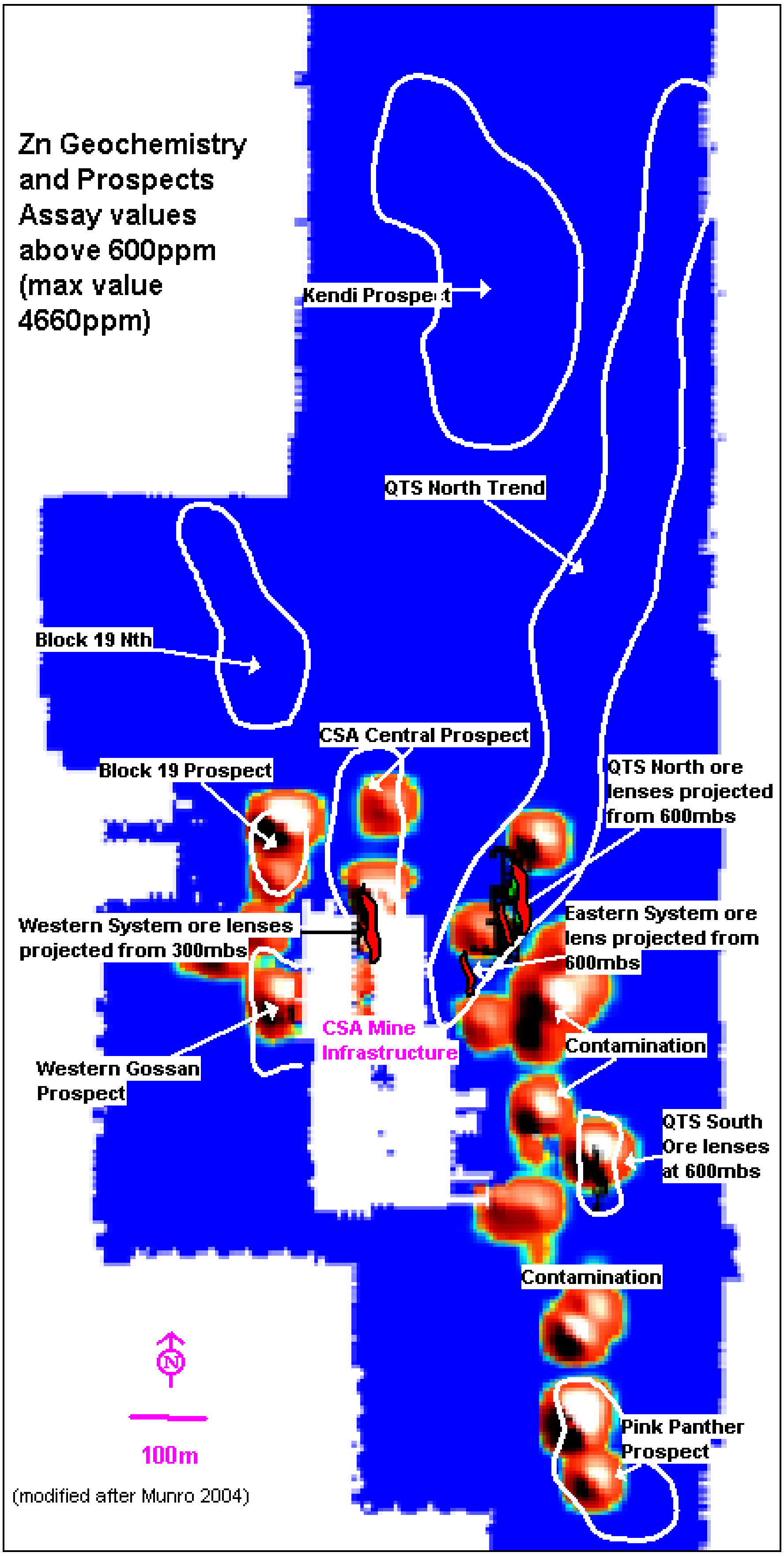

Figure 6. Zinc geochemistry contours and prospects.

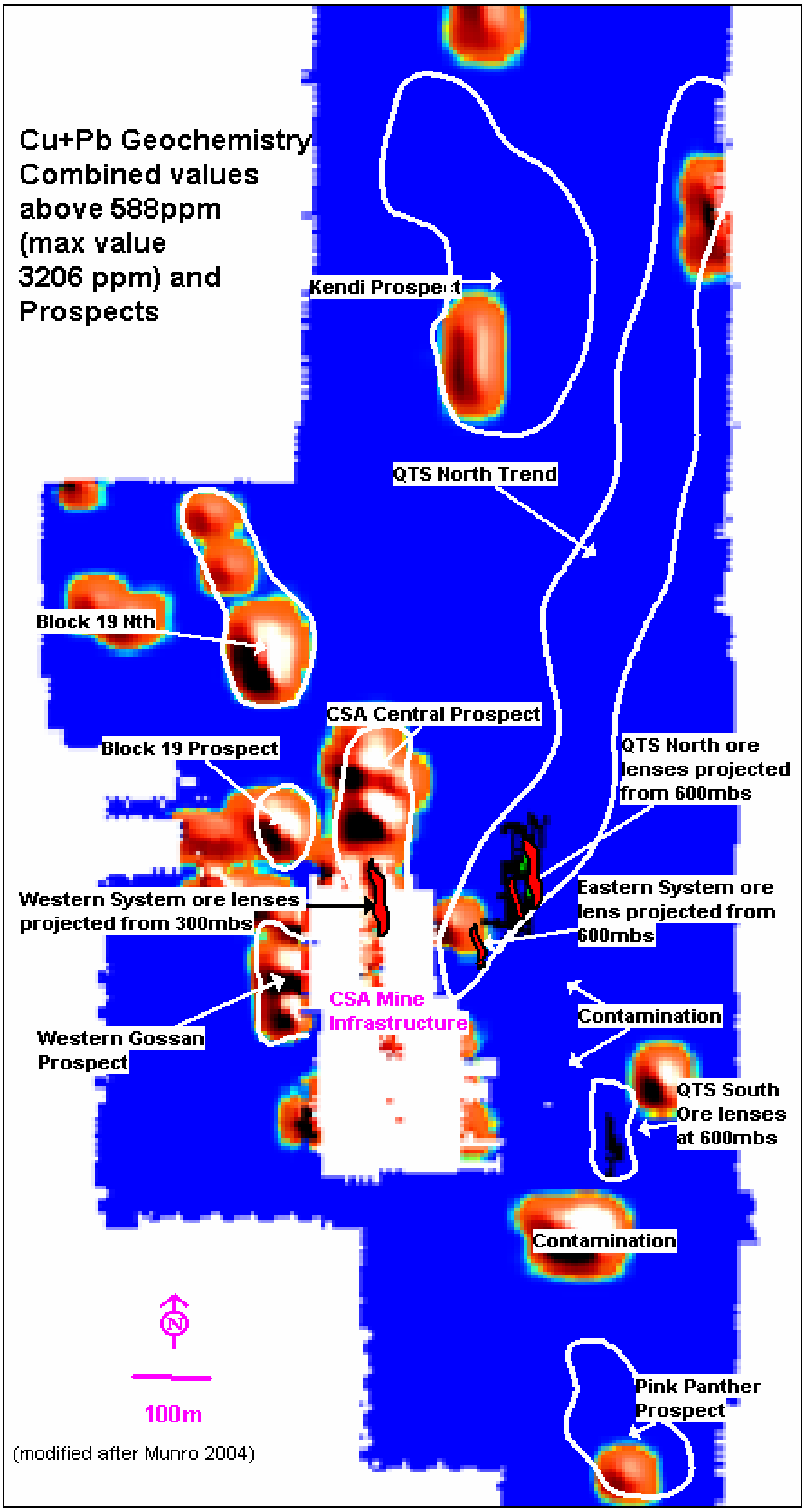

Figure 7. Copper + lead geochemistry contours and prospects.

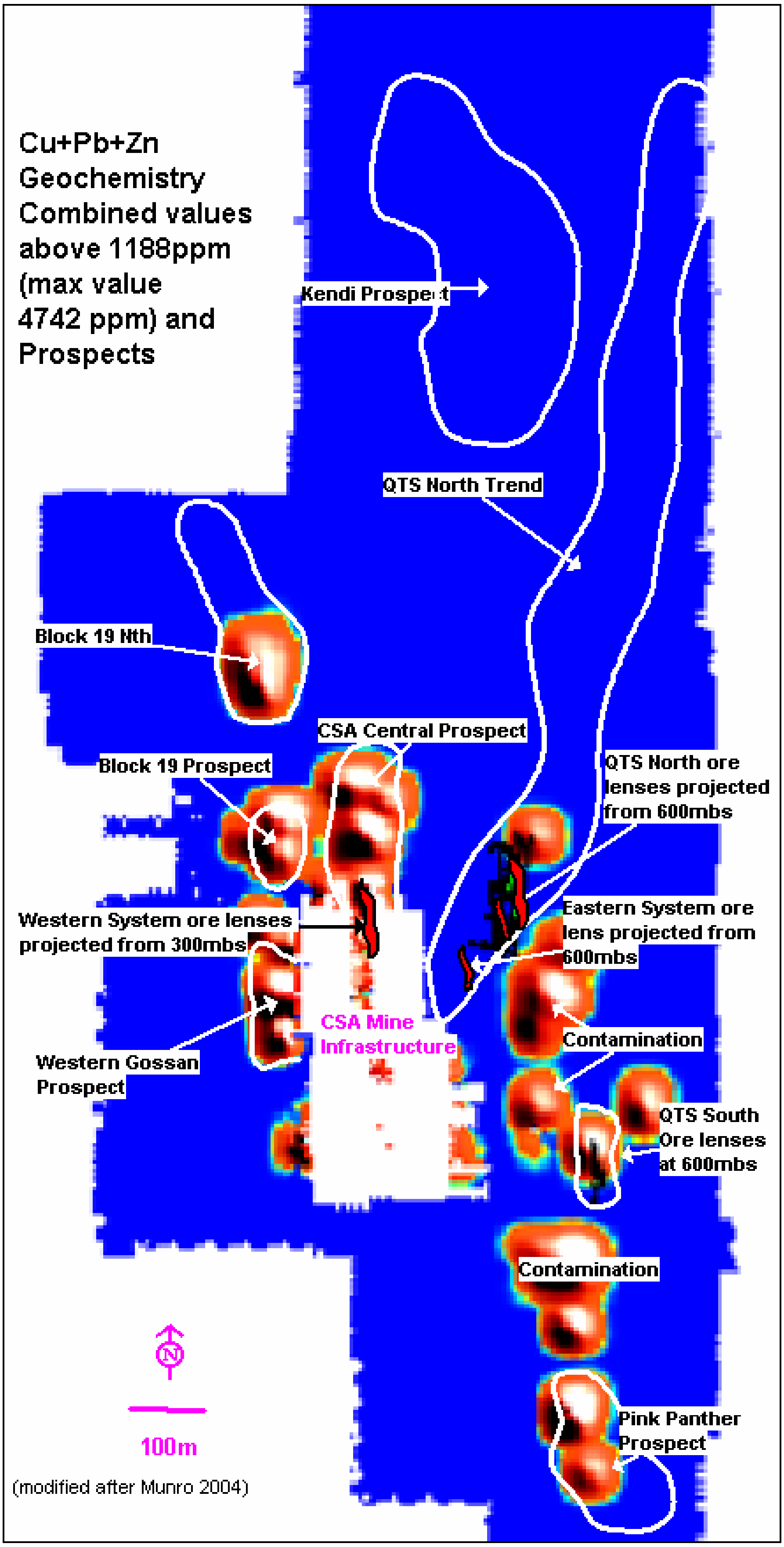

Figure 8. Copper + lead + zinc geochemistry contours and prospects.

THE AEOLIAN INPUT TO THE GIRILAMBONE REGOLITH-IMPLICATIONS FOR EXPLORATION

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INTRODUCTION

Significant additions of aeolian materials to soil-landscapes in Australia have been recognised and documented in several areas across southeastern Australia (Greene and Nettleton 1996, Cattle *et al.,*. 2002). Anderson (1888) commented on the magnitude of the red aeolian transported soil in the Girilambone region of NSW, which was evident as relatively uniform depositions across the landscape between Nyngan, Nymagee and Cobar. Anderson also remarked on the post-depositional reworking of aeolian sediments by fluvial processes. This mixes them with more locally sourced regolith materials and hence results in the lack of concentrated, discrete aeolian mantles. This highlights a particular problem in the Girilambone region when attempting to identify aeolian materials. Firstly, aeolian materials are being deposited on existing (transported) sediments, and secondly they are being mixed with other similar regional (alluvial and colluvial) materials, as well as residual regolith materials.

It is important to recognise and understand aeolian materials, as they can adversely affect mineral exploration techniques (e.g. by dilution of geochemical signatures, Greene *et al.*, 2001), and complicate regolith landform mapping (Chan *et al*., 2002). The implications of the aeolian addition are primarily influenced by the amount and nature of the addition. Therefore, the aim of this project was to develop a set of characteristics for distinguishing the aeolian components in soils in the Girilambone region.

AEOLIAN MATERIALS AND MINERAL EXPLORATION- POTENTIALS FOR CONTAMINATION

Mineral exploration in areas of significant aeolian cover needs to consider the two following aspects.

Masking and dilution of anomalies

If aeolian materials are incorporated into soil profiles, geochemical expressions can be confused or masked, so that non-mineralised areas can report misleading results from introduced material (Barbier 1987; Greene *et al.* 2001). If aeolian materials are mixed into existing soils then the original geochemical signatures are diluted. Dickson and Scott (1990) reported that the occurrence of aeolian mantles, such as those present in the Lachlan Fold Belt, have the potential to detrimentally affect aerial gamma-ray surveys. They discovered that there is potential for local variability in U and Th contents relating to aeolian additions, particularly where aeolian characteristics are similar to that of fine-grained sedimentary rocks, such as shale and sandstone. Potassium is usually lower in aeolian deposits as a consequence of the weathering environment (Dickson and Scott 1990). Futhermore, they found that soils containing significant aeolian additions overlying volcanic bedrock had elevated concentrations of Th compared to the volcanic bedrock. These Th contents were in fact similar to those in soils derived from weathered granitic bedrock. Consequently, the aerial gamma-ray signature of the volcanic areas resembled that of the granites.

Soil as a sampling medium

In comparison to drilling to bedrock, the utilisation of soils as a sampling medium for mineral exploration may potentially reduce exploration expenses (McQueen *et al.* 1999). However, the predominately fine aeolian material potentially causes problems during the collection and chemical analysis of the <80 mesh soil fraction commonly used for soil surveys during exploration. Characterisation and therefore exclusion of the aeolian fraction in soil samples would improve exploration interpretation of soils samples in regions of aeolian overburden.

RESEARCH DESIGN AND SAMPLING SITES

A detailed study was made of the characteristics of regolith materials found at three major study sites. The sites were chosen to (i) include a range of transported and *in situ* materials reworked to different extents, and (ii) highlight areas where there was a marked contrast in the nature of the transported material compared with the underlying substrate. The three sites included areas of outcropping leucitite lavas in the Girilambone region; profiles on the Cobar palaeoplain in the Girilambone region; and a dune-swale system in the Windarra area west of Cobar.

Leucitite lava outcrops in the Girilambone region
Three leucitite lava outcrops (El Capitan Knob, Mountain Tank, and Byrock Hill) were chosen to represent "natural dust traps" (NDT). These young Tertiary leucitite outcrops were formed by lava flow inflation and have been positive landscape features since the Miocene (Gonzalez 2001, McQueen pers comm., 2003). They are litho logically distinct from the surrounding bedrock and any aeolian transported material. Soils on the leucitite basalts are skeletal (to a maximum depth of approximately 0.1 m). Sampling sites were chosen towards the top of these topographic highs to avoid any alluvial or colluvial contamination, thus leaving the only options available for the derivation of the soils to be residual or aeolian.

Girilambone region profiles
Ten sampling sites throughout the Girilambone region, situated within the Cobar palaeoplain, were chosen to examine trends across various mapped regolith landform units and to contribute detailed regolith studies to the CRC LEME drilling programs in the area: Hermidale (2001) and Byrock (2003). The site discussed in this paper is the colluvial rise-erosional plain site CBAC144 (as mapped by CRC LEME Girilambone Project 2001-03).

Windara dune-swale land system
A longitudinal dune (in a dune-swale land system) approximately 100 km west of Cobar was also included to incorporate a site known to contain aeolian materials (Greene and Nettleton, 1996), and to compare the characteristics of the NDT aeolian deposits with that of a wind blown landform evident in the landscape.

METHODS
A range of particle size, mineralogical, geochemical, and micromorphological techniques were used to investigate the characteristics of aeolian materials from the three study sites.

Particle size distribution (PSD)
The PSD of selected soil samples, with no chemical or mechanical pre-treatments, were determined using the laser detection technique on the Malvern Mastersizer 2000. Each sample was briefly dispersed in water and analysed: 30 seconds, break 10 seconds and repeated three times. The average calculation(s) within the 0.2 µm to 2000 µm detection limits were collected from the Malvern built-in software and for all data points 2µm<1000 µm, data was interpolated at 2 µm intervals. The weighted frequency (dV/d logD) was calculated for all data points, weighting the data according to the width of the interval or particle diameter and plotted on a log scale (Bagnold 1960). Caution needs to be taken concerning the bias effects of the laser detection technique (of the Malvern Mastersizer 2000), particularly when the sample is dominated by both sand and silt fractions. In such a case, the clay fraction may be underestimated (Campbell, 2003).

Mineralogy
The mineralogies of selected soils and soil fractions were determined by powder X-ray diffractometry on a Siemens Diffractometer D501 equipped with graphite monochromator and scintillation detector. CuK-alpha radiation was used, with scans carried out from 2θ (2-70°), with a step width of 0.02°, and a scan speed of 1° per minute. Scans were interpreted with SIEMENS computer software package Diffrac*plus* Eva (1996-2001), and Siroquant 2.5 (2000).

Geochemistry
Major elemental compositions of selected soil and soil sample fractions were determined by standard XRF methods. ICP-MS was used to determine trace elements after complete dissolution with HF/$HFNO_3$ following Li-tetraborate fusion.

Micromorphological analysis
Samples were examined by scanning electron microscopy (SEM) and in thin section by optical microscopy (OM). For SEM, undisturbed soil samples were coated 3 times with Au using a "Sputter Coater" to improve sample conductivity and eliminate possibilities of organic material collapsing. Analysis was performed on a Cambridge 360 and a JEOL JSM6400 system. Thin sections were prepared by drying surface samples (0-0.1 m) in the Kubinia tins at 40° C and then impregnating with polyester resin for 6 weeks. Thin sections, vertical to the soil surface, were cut, polished, mounted on a glass slide, and reduced to 25 µm thickness. The optical properties of the specimen were viewed using a petrographic microscope and photographed. The description was in accordance to that detailed in Brewer and Sleeman (1988).

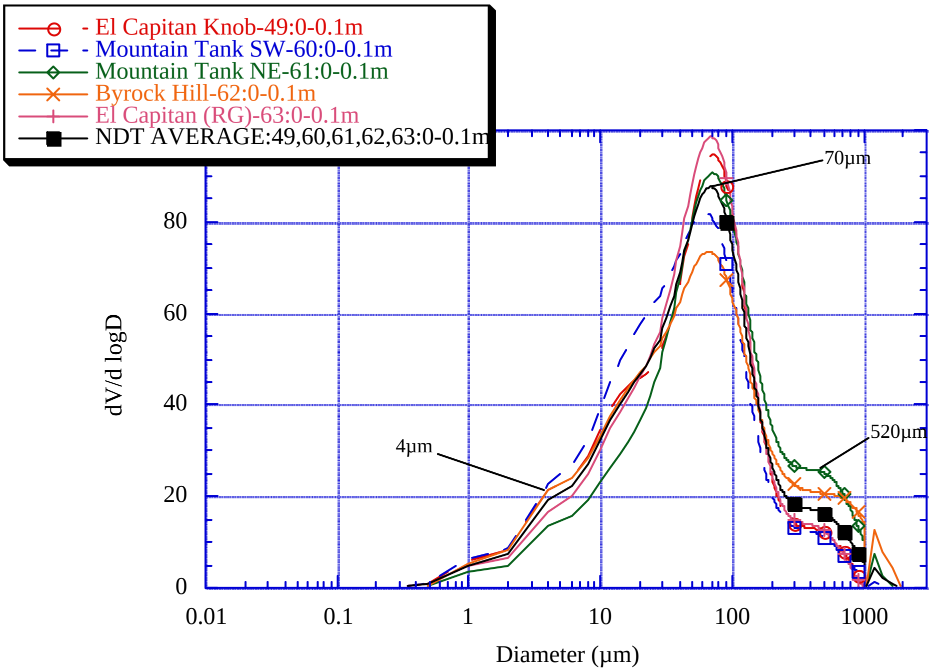
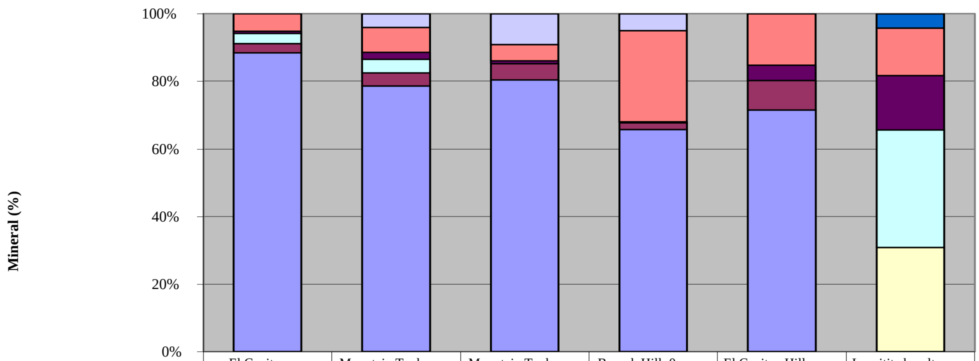


Figure 1. Particle size distribution and calculated average of bulk soils (0-0.1 m interval) for all studied NDT sites in the Girilambone region.



	El Capitan Knob: 0-0.1m	Mountain Tank SW: 0-0.1m	Mountain Tank NE: 0-0.1m	Byrock Hill: 0-0.1m	El Capitan Hill: 0-0.1m	Leucitite basalt: El Capitan Hill
Other Minor Phases (Wt%)	0	4	9	5	0	0
Amphibole	0	0	0	0	0	4
Mica + (including muscovite, biotite)	5	7	5	27	15	14
Fe, Ti Oxides (including hematite, rutile)	1	2	1	0	5	16
Pyroxene	3	4	0	0	0	35
Leucite	0	0	0	0	0	31
Kaolin	3	4	5	2	9	0
Quartz	88	79	80	66	71	0

Figure 2. Mineralogical analyses (wt%) for bulk soil samples from NDT's in the Girilambone region. Determined by quantitative XRD (SIROQUANT).

RESULTS

The PSD of all NDT soils displayed a well-sorted tri-modal pattern with a dominant size fraction peak at 70 µm (Figure 1). Determination of major mineral composition by XRD analysis on bulk soil samples (Figure 2) and investigations of micromorphological characteristics using SEM and thin section microscopy (Figures 3 and Figure 4 respectively) reveal the NDT soils contained both aeolian quartz and *in situ* mafic-derived clays, some of which evenly coat the quartz. These techniques confirm that the dominant 70 µm particle size fraction is represented by well-abraded quartz particles, consistent with aeolian transport. Selected geochemistry (Table 1) performed on 63-75 µm sieved fractions and bulk soil and leucitite basalt samples (Gonzalez 2001) confirm and add to the mineralogical results. These indicate the preferential concentration of SiO_2 in the 63-75 µm (suspected aeolian) size range and *in situ* contamination by the leucitite basalt, for example by elevated Cr, Nb and Ti/Zr. Therefore, the characteristics of ca. 70 µm diameter, well-abraded quartz particles, coated with *in situ* clay, were taken as indicative of aeolian materials that would have been similarly deposited in the surrounding Girilambone region.

Similar aeolian materials were detected across different regolith landform units throughout the Girilambone region, as expected with uniform aeolian deposition. For example, Figure 5 shows the PSD of the upper 0-0.5 m of a colluvial rise erosional plain CBAC144 site, indicates that the 70µm particles are present at all depths, but particularly the upper 0.3 m. Correspondingly, Figure 6, which shows XRD analysis of the major mineral composition also shows that quartz is concentrated in the upper 0.5 m of the profile. Thus the aeolian particles are most concentrated in the upper 0.2-0.3 m of the profile, and subject to a range of post-depositional processes.

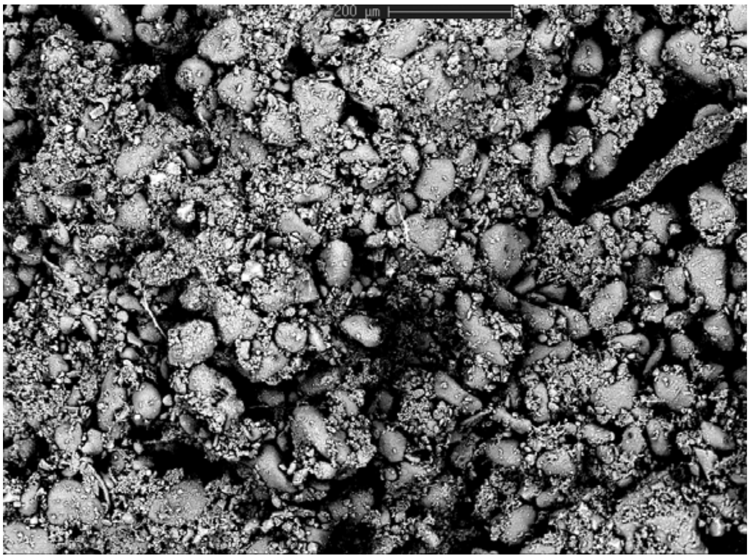


Figure 3. SEM image of soil (0-0,1 m) from the El Capitan NDT.

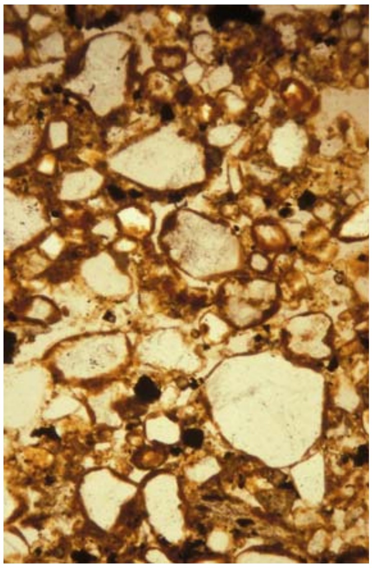


Figure 4. Thin section image of soil sample from El Capitan NDT.

Although not a major focus of this article, the study also established that aeolian material in the dune-swale system to the west of Cobar is represented by coarser (100-140 µm) well-abraded quartz particles compared with that further to the east in the Girilambone region. It is likely that this reflects a closer proximity to the source material, and agrees with Sprigg's (1980) major dust zones and with patterns of particle size distribution from west to east across southeastern Australia.

Through integrating a range of techniques and study site attributes, it was possible to derive a set of distinguishing characteristics for aeolian materials in the Girilambone region. These are:

- 70 µm quartz particles, *that are*
- highly-abraded, *that have*
- well-rounded clay coats, *and are*
- dominant in the surface 0.2 m, *with preservation* subject to:
  - redistribution and reworking by alluvial, colluvial and subsequent aeolian processes,
  - post-depositional alluvial and colluvial deposits, and/or
  - post-depositional surface processes, e.g. wind and water erosion.

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

The results from this study confirm that in the Girilambone region, the properties of the soils overlying the NDT's are critical in order to unambiguously characterise aeolian material deposited uniformly throughout the region. This would be expected in other regions where transported overburden or residual materials may present a similar suite of characteristics to the aeolian additions, and where post-depositional processes have been active in diluting any aeolian mantle.

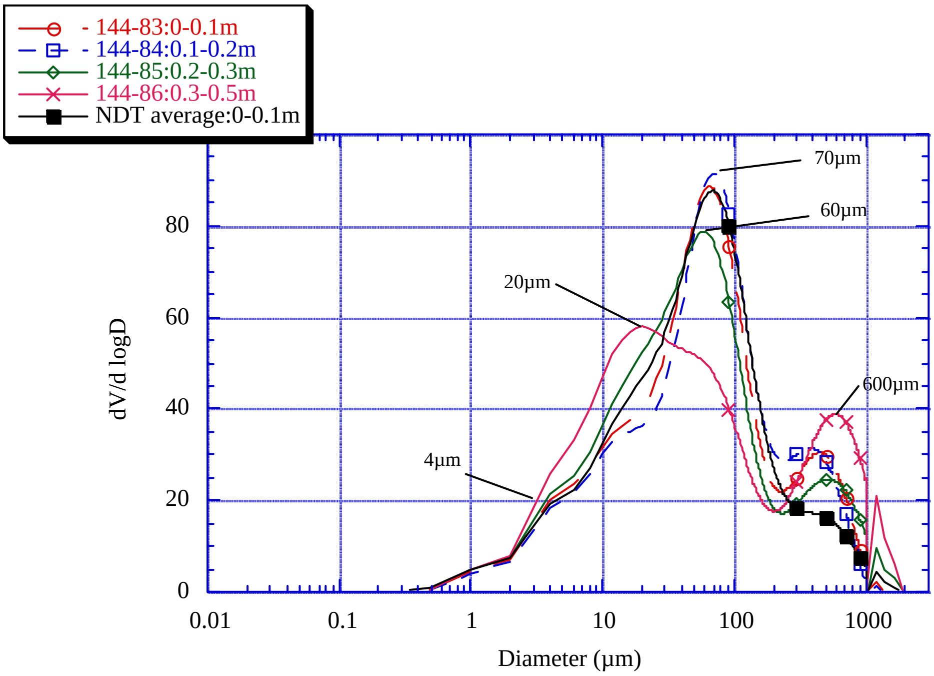
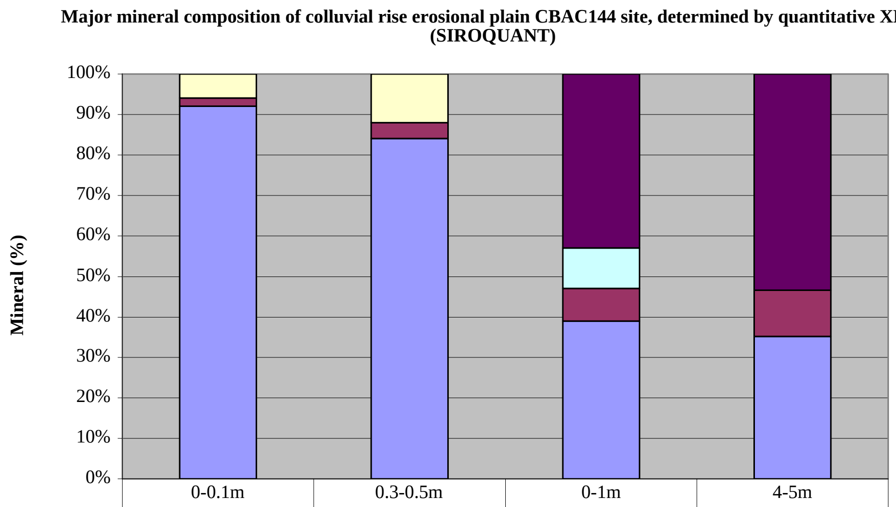


Figure 5. Particle size distribution for samples in the upper 0.5 m section of the profile on a colluvial rise erosional plain (CBAC144). Also shown is the average particle size distribution for the NDT's.



	0-0.1m	0.3-0.5m	0-1m	4-5m
Calcite (Wt %)	0	0	43	53
Goethite (Wt%)	0	0	10	0
Muscovite (Wt%)	6	12	0	0
Kaolin (Wt%)	2	4	8	12
Quartz (Wt%)	92	84	39	35

Figure 6. Mineralogical analyses (wt%) for bulk soil samples from a range of depths on the colluvial rise erosional plane (CBAC144) Girilambone region. Determined by quantitative XRD (SIROQUANT).

The following three main conclusions resulted from this research.

- Aeolian sediments are highly variable in character because of different source areas and degrees of post-depositional reworking. It is therefore essential that more than one diagnostic tool be employed to ensure the correct characterisation of aeolian materials (i.e. particle size, mineralogical, geochemical and morphological techniques), and that a range of different deposits are studied (ideally including sites of aeolian deposit preservation e.g. topographic highs, and/or where aeolian material contrasts with the underlying substrate).
- Understanding past and present soil-landscape processes is vital in determining the characteristics and distributions of aeolian materials in the landscape. In the Girilambone

region, chemical, physical and biological soil-landscape processes rework and redistribute aeolian materials so that discrete mantles are absent. Therefore the knowledge and awareness of well-defined characteristics to identify aeolian materials proves critical.

- Knowledge of the nature of aeolian materials in the Girilambone region will assist in interpreting soil-landscape processes, particularly in distinguishing aeolian materials from other transported alluvial and colluvial deposits. Understanding the characteristics of aeolian materials and their distribution therefore plays an important role in determining the appropriate range of techniques and approaches to use in formulating and conducting a mineral exploration program, particularly to avoid sampling aeolian contributions.

Table 1 Selected geochemistry on the soils overlying NDT: El Capitan and Mountain Tank, for 0 0.1m: bulk sample and 63-75 µm sieved fractions. Also selected geochemistry is reported for three leucitite basalt samples (Gonzalez, 2001).

Sample	SiO_2 (%)	Al_2O_3 (%)	Cr ppm	Nb ppm	Ti (%)	Zr (ppm)	Ti/Zr
El Capitan bulk sample	**66.0**	**9.7**	**228**	**120**	**2.19**	**770**	**28**
El Capitan 63-75µm fraction	**74.4**	**8.7**	**152**	**65**	**1.53**	**757**	**20**
Mountain Tank SW bulk sample	**58.6**	**10.6**	**263**	**126**	**2.57**	**777**	**33**
Mountain Tank SW 63-75µm fraction	**67.1**	**9.3**	**222**	**86**	**2.26**	**801**	**28**
Leucitite basalt sample: WT6	**42.1**	**7.8**	**348**	**179**	**3.24**	**883**	**37**
Leucitite basalt sample: WT7/8	**41.6**	**7.7**	**360**	**184**	**3.34**	**862**	**39**
Leucitite basalt sample: MT28	**42.8**	**7.8**	**438**	**174**	**3.08**	**762**	**40**

IMPLICATIONS AND RECOMMENDATIONS FOR MINERAL EXPLORATION

Soils in the Girilambone region are a mixture of aeolian, alluvial, colluvial and *in situ* materials. Once it has been established that the soil contains significant aeolian additions, the appropriate caution can be taken when formulating exploration programs and interpreting exploration data. Specific aeolian material characteristics at any given site can be efficiently factored in when sampling and during data interpretation. Due to the nature of the aeolian material in the Girilambone region (70,µm quartz particles) the implications for mineral exploration are greatest when geochemical detection methods are used on bulk soil samples, particularly those from the upper 0.2 m of the soil profile. The mechanical mixing as a result of aeolian additions may dilute geochemical anomalies and expressions of primary geological features. The extent of aeolian dilution is dependant on the proportions of aeolian materials and strength of the anomaly being investigated. This research recommends sampling the >100 µm soil fraction for this region, excluding the fine sand (around. 70 µm) fraction, which is predominantly aeolian. Another alternative to minimise aeolian contamination of the bulk soil sample would be to sample soil well below the aeolian depositional interface, for example deeper than 0.2 m, and greater in some cases.

Understanding the aeolian component of soils also has implications for the application of partial leach techniques in geochemical exploration. In the Girilambone region the diluting aeolian material is predominantly quartz (with possibly some zircon) and as such would not have introduced any extractable potential pathfinder elements. Therefore this technique should be less affected by the aeolian additions to soils in this region.

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PIPELINE RIDGE DISCOVERY

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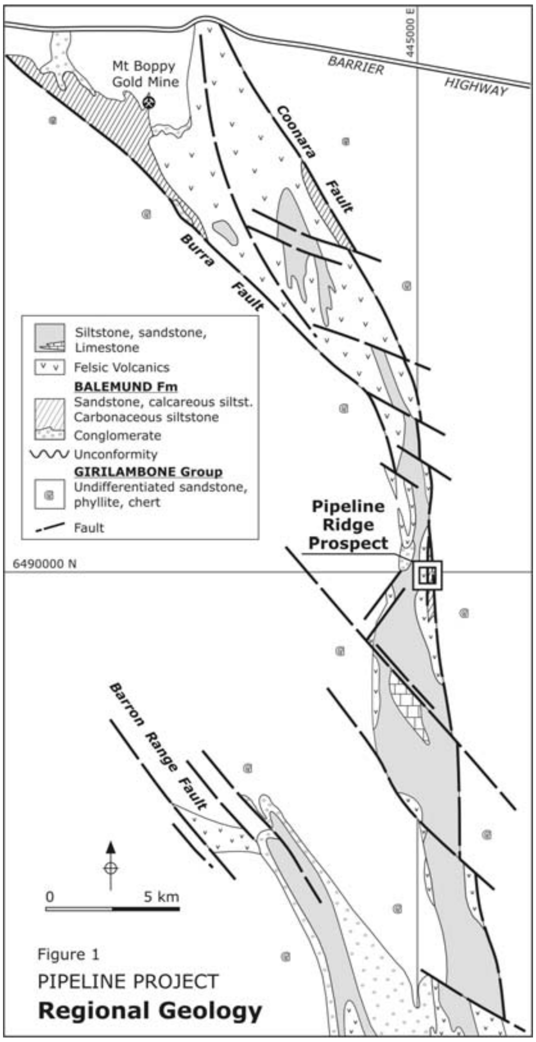

Figure 1. Regional geology of the Pipeline Ridge area.

INTRODUCTION

Mineralisation at Pipeline Ridge comprises galena-chalcopyrite-sphalerite-pyrite and minor pyrrhotite, hosted in silicified polymictic breccias, veinlets and disseminations. Gold and silver is associated with the sulphide zones.

The mineralisation at Pipeline Ridge was discovered in 1976, almost 28 years ago, by Mines Exploration Proprietary Ltd (MEPL), the result of a well thought out exploration programme based on sound geological concepts and the extensive use of bedrock geochemistry. Our reading of the historic data suggests the discovery team was well funded, had a sound geological grasp of where mineralisation was likely to be located in Siluro-Devonian Basins in the district, and systematically pursued their geological model. Pipeline Ridge was located within a lead-zinc anomaly some 1000 m long and 200 m wide. Follow-up dipole-dipole IP outlined a chargeability anomaly. The first drill hole tested this and intersected significant, but generally low grade base-metal mineralisation. The nature of the geochemical sampling programme that led to the discovery suggests an early appreciation of the problem of surficial cover (regolith) with respect to exploration geochemistry. The programme utilized a number of small drill rigs (auger, RAB and airtrac) to sample bedrock at 25 m intervals along lines initially 500 m apart.

This paper picks up the exploration story where MEPL geologists left off. It outlines a brief history of subsequent exploration, describes the regional setting and the geology and regolith geochemistry over the zone.

EXPLORATION HISTORY

After the initial discovery MEPL drilled nine diamond drill holes into sub-economic mineralisation and ultimately withdrew from the project. The next important phase of exploration in the project occurred in the early 1980s with the recognition, by Amoco, that mineralised zones encountered in drill holes were highly anomalous in gold and, to a lesser extent, silver. This gave much of the impetus to mineral exploration from the mid-1980s to the late 1990s, with a number of companies undertaking drilling program and/or surface geochemical surveys.

The surface geochemical work showed that that not only was the prospect anomalous in Pb-Zn (predominantly Pb), but that it also had a distinctive Au-As, and a lesser Sb-Ba signature. Drill programmes focused on delineating gold mineralisation, with several shallow reverse circulation and open hole percussion programmes taking place up to 1998. Widespread highly anomalous and locally high grade gold (+10g/t) was encountered especially in the weathered rock. In 1996 Golden Cross Operations Pty Ltd (GCO) drilled four additional diamond drill holes and undertook detailed re-logging of MEPL core with a specific emphasis on understanding the geology and alteration of the prospect.

REGIONAL SETTING

The Pipeline Ridge prospect is located 40 km southeast of Cobar in Central NSW at 146.42^0E/31.72^0S on the Nymagee 1:250,000 Sheet (Figure 1). It occurs in a high strain zone on the eastern side of the Kopyje Basin within Siluro-Devonian felsic volcanic rocks adjacent to the north-trending Coonara Fault. The fault forms the boundary between basin fill, comprising conglomerates, siltstones, felsic volcanics and micritic limestones of Siluro-Devonian age, and micaceous sandstones siltstones and cherts of the Girilambone Group of Ordovician age. A rifting model for the development of the basin followed by inversion in the mid to late Devonian is appropriate. Unconformities, characterised by channel-fill conglomerates were transformed into faults, often thrusts, and preservation of the Siluro-Devonian rocks occurred in a structural synclinoria. The entire basin is interpreted to be a synclinorial half-basin where the eastern limb is overturned and locally truncated by the fault. Subsequent sinistral fault movements in a transtensional environment have produced pull-apart extensional zones with east-west trending boundary faults.

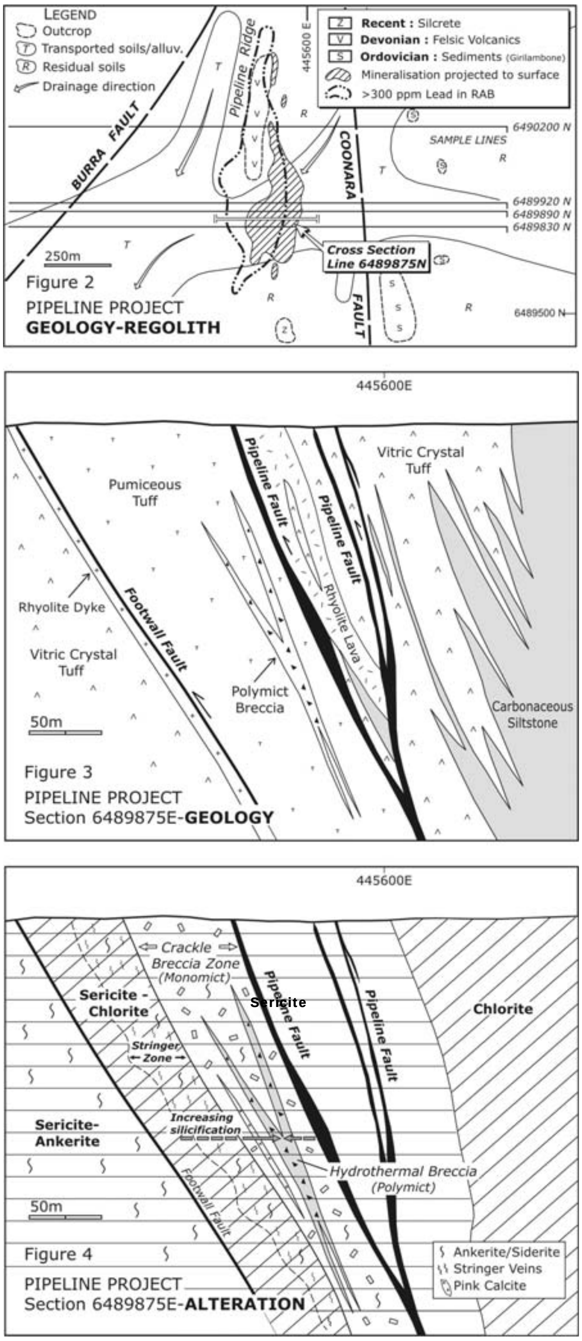

Figure 2-4 The geology and regolith and alterations of the Pipeline Ridge Deposit.

GEOLOGY OF PIPELINE RIDGE

Setting

The terrain in the prospect area is typical of the Cobar district with isolated low-lying hills, locally with outcrop or residual soil cover, and broad intervening valleys containing transported fill. Pipeline Ridge is a low, north-trending ridge of outcropping silicified felsic volcanic rock. The up-dip/up-plunge extension of drilled mineralisation occurs immediately to the east of this outcrop predominantly beneath cover. Mineralisation identified to date in drill holes extends over a strike length of 400 m within the larger geochemical anomaly which is over 1000 m long and 200 m wide. The prospect is located in a high strain zone on the east side of the Kopyje Basin where it is only about 0.5 km wide, adjacent to the Coonara Fault.

Regolith

Residual soils form on the margins of Pipeline Ridge and merge with sheetwash, transported soils and alluvium immediately over the mineralised zone where a broad drainage channel traverses the site from northeast to southwest (Figure.2). Shallow drilling in this zone indicates that transported cover is approximately 15 to 30 m deep and overlies highly weathered saprolitic material some 5 to 9 m thick. Fresh rock and sulphide mineralisation begins to occur at approximately 30 to 35 m depth.

Lithologies

From east to west six lithologies are recognised. These are; black siltstone, lithic vitric crystal tuff, a quartz-feldspar phyric rhyolite lava, a pumiceous crystal tuff, a quartz-feldspar phyric rhyolite dyke (or lava) and another lithic vitric crystal tuff (Figure 3). These units all dip between 65-75° E and form part of the eastern limb of an overturned syncline.

The easternmost siltstone and tuff are interbedded, with the tuff bounded to the west by a massive quartz-feldspar phyric rhyolite. Weak flow banding and perlitic textures indicate that the rhyolite is most probably a lava. These eastern units are separated from the central pumiceous tuff by the Pipeline Fault where movement is inferred to be reverse. It entrains fragments of Girilambone Group siltstone with a conspicuous crenulated cleavage. The pumiceous tuff hosts the bulk of the mineralisation. The Footwall Fault separates the pumiceous tuff from the massive quartz-feldspar phyric dyke and the westernmost unit, a lithic vitric crystal tuff.

Alteration

There are seven principal zones passing from hanging wall to footwall (east to west) comprising a chlorite zone, a sericite zone, a monomict crackle breccia zone which encloses a polymictic breccia zone, a stringer vein zone, a mixed sericite-chlorite zone and a sericite-siderite/ankerite zone (Figure 4).

The eastern chlorite and sericite zones comprise moderate to intense pervasive alteration.

The crackle breccia typically comprises hydraulically fractured tuff, which is generally moderate to strongly silicified, pyritic with minor base metal sulphides. Siderite/ankerite is generally moderate to strong and, locally, late calcite may fill fractures. Sericite is pervasive.

The polymictic breccia contains variable quantities of angular to sub-rounded exotic clasts including fine grained sediment, tuff and early polyphase vein quartz. This breccia has a gradational boundary with the surrounding crackle breccia. The matrix is comprised of abundant fine silica, sericite and carbonate and semi-massive pyrite with variable quantities of sphalerite, galena and chalcopyrite. Native gold and minor tennantite-tetrahedrite are associated with base-metal sulphides. Silicification is intense throughout. Late pink calcite locally occurs as veins. Drilling indicates that these breccias are 10 to 15 m wide, have short strike lengths (approx. 100 m) and plunge steeply to the north.

The footwall stringer vein zone is generally coincident with the mixed chlorite-sericite zone to the west of the breccia zones. It is usually moderate to locally strongly silicified and contains weak to moderately developed translucent quartz veinlets, <1 cm wide, and mid to dark grey chalcedonic veins generally 1-2 cm wide. Moderate, 2-3%, fine-grained disseminated pyrite occurs throughout. Pyrite and base metal sulphides are more abundant in association with stronger silicification and veining. Sericite overprints chlorite. Intense, pervasive sericite-siderite/ankerite alteration occurs in the westernmost tuff unit.

Copper, lead, zinc, gold and silver mineralisation is preferentially hosted within the pumiceous tuff unit, and more specifically, the mineralisation increases in intensity through the stringer vein, crackle breccia and polymictic breccia zones (Figure 4).

The rounded nature of exotic fragments in the polymict breccia suggests that these were emplaced during a fluidization event and the breccias are interpreted to be hydrothermal in origin. Strongest fluid flow, alteration and mineralisation occur in the polymictic zone, with hydraulic rupture and fragmentation occurring in the adjacent crackle and stringer zones. Petrographic studies suggest the main alteration event occurred at temperatures of around 250^0 C with sulphide mineralisation occurring at approximately 200^0 C (Hodge and Merchant, 1997).

SURFACE GEOCHEMISTRY

Figure 2 shows the projection of mineralisation to surface, and the outline of the original geochemical anomaly defined by MEPL. It indicates that the mineralisation is mostly buried beneath transported cover and to a lesser extent residual soils. The original anomaly is displaced westward of the projected mineralisation and locally encompasses the outcropping ridge. Four historic sample lines were chosen over the mineralisation and are compared in a series of stacked profiles in Figure 5. These include

1. GCO soil samples where the -80 mesh fraction (-80#) was analysed on line 6490200 mN. Samples are predominantly residual soils and over areas of outcrop in the vicinity of mineralisation.
2. Combined BLEG/-80# soils collected by Arimco, on line 6489920 mN which sample predominantly transported cover.
3. GCO Regoleach soils on line 6489890 mN which also sample predominantly transported cover.
4. RAB samples (sieved to -80#) on line 6489830 mN from the original MEPL survey. These sample weathered rock beneath transported cover.

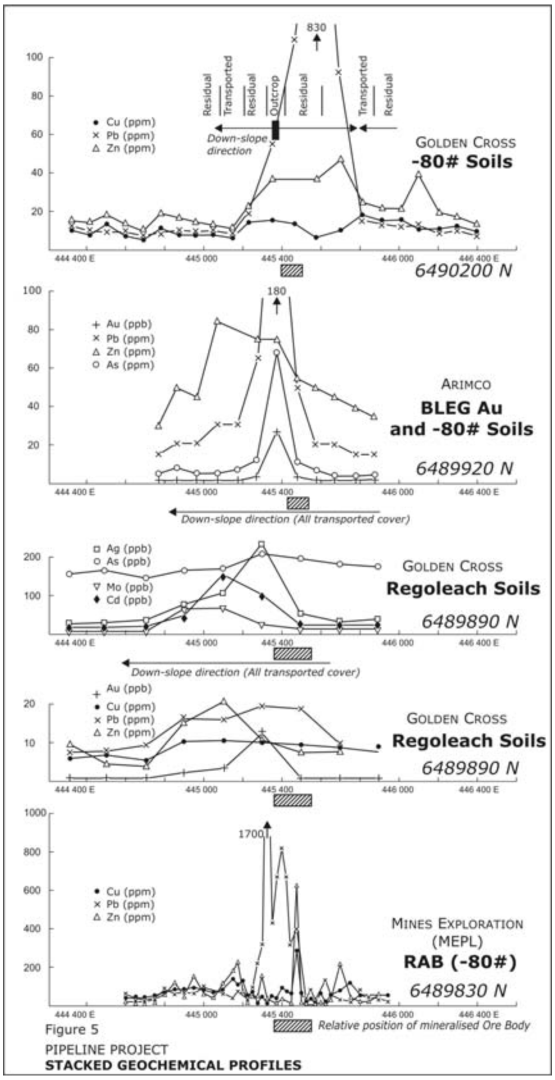

Figure 5. Stacked geochemical profiles of the Pipeline Ridge Deposit.

On the three southernmost lines, transport direction is to the west or southwest. On the northernmost line transport is west and east of the outcropping ridge. On the northernmost line anomalous Pb and Zn occur over the outcrop and in residual soils overlying and adjacent to mineralisation projected to surface. Anomalism also occurs in adjacent transported cover and might indicate intermingling of residual soils and transported cover by down-slope creep of the former.

In BLEG (Au) and -80# soils there appears to be distinctive down-slope dispersions in all elements especially Zn. Zinc in fact appears to be elevated immediately upslope. In Regoleach samples down-slope dispersion is also pronounced. Zinc, Mo, Ca and Ag are especially well transported.

The down-slope dispersion of elements in BLEG, -80# and Regoleach samples is reminiscent of stream sediment elemental dispersion. The up-slope dispersion of Zn in -80# samples might indicate hydromorphic rather than mechanical transport due to seasonal fluctuations in groundwater movements. In the original MEPL RAB survey Pb and Zn anomalism occurs over the mineralisation but as noted above is also displaced to the west and may also reflect the overall down-slope/down-stream drainage direction.

All of the sample media and analytical techniques have detected mineralisation. In all methods however there is a component of down-slope (down-stream) dispersion. All methods appear to be able to detect buried mineralisation (15 to 35 m below surface) and Pb, Au, As, Zn are probably the best indicators of this style of mineralisation. Anomalous Zn should be used with caution as dispersion trains may be extensive down-slope and extend up-slope. The RAB samples of weathered rock more accurately pinpoint the location of mineralisation, with soil sampling techniques showing broader dispersion, especially in the area of transported cover. This work underpins the importance of regolith mapping to understanding sampling and sample media.

CONCLUSIONS

Mineralisation at Pipeline Ridge was discovered almost 30 years ago by a team of MEPL geologists using a well thought out geological concept and a systematic bedrock sampling technique (RAB and auger). Subsequent geochemical surveys detected the mineralisation even though it is partly covered by transported material. Mineralisation is hosted predominantly within felsic volcanic rocks in a high strain zone adjacent to the Coonara Fault. A distinctive stratigraphy and alteration zonation pattern have been recognized. Most intense alteration (quartz-sericite-carbonate) and base-metal, gold and silver mineralisation occurs within polymictic breccia zones which are interpreted to have been hydrothermal conduits where fluidization and hydraulic fracturing took place. These zones plunge steeply to the north.

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USING LITHOGEOCHEMISTRY TO EXPLORE IN REGOLITH DOMINATED TERRAINS: AVOIDING CLOSURE, BACKGROUND AND WEATHERING EFFECTS

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Many ore deposits are the product of the precipitation of commodity elements and/or their mineral hosts from hydrothermal fluids moving through rocks or sediments. These mineralising fluids commonly react with the rocks hosting the deposits to produce “haloes” of distinctive mineralogical and geochemical character, zoned about the deposits.

Exploration companies commonly utilise lithogeochemistry to identify and vector within alteration haloes. However, examination of raw data is prone to error due to closure effects and/or pre-existing background variation. Weathering commonly degrades primary mineralogical and chemical zonation as well.

Closure can be avoided by using ratio formulations, or by utilising mass balance approaches based on fixing volume, mass or concentration changes between samples of parent and daughter lithologies. Simple ratio indicators (such as empirical alteration indices) avoid closure effects, but are difficult to apply to inhomogeneous host rocks because the primary geochemical variation in those host rocks can be larger than that attributable to alteration. Furthermore, because it is not easy to monitor mineral changes with empirical index values, false anomalies are difficult to detect.

Techniques that rely on parent-daughter comparisons are also unreliable in geological settings where variation in host rock composition can be expected e.g. if subtle or overt compositional shifts occur across stratigraphy. Spurious anomalies can be generated if great care to match the primary composition of the parent and daughter samples is not taken (or isn’t possible e.g. weathered or heavily altered rocks). Parent-daughter comparisons are also limited because only a limited number of samples can be compared at any time.

In recent years, developments in lithogeochemistry, coupled with novel techniques of projective geometry, have allowed quantification of alteration intensity using procedures such as Pearce Element Ratio Analysis (PER) and General Element Ratio Analysis (GER), (Stanley and Madeisky, 1996, Stanley 1998). These procedures allow lithogeochemistry to be used quantitatively to vector towards high intensity alteration, which in many cases equates to high potential for mineralisation.

Pearce Element Ratios (PERs) are molar ratios formulated using a conserved element as the denominator. The PER approach is focussed on predictable major element variations that result from known or likely mineral changes occurring during formative or later processes. Scatterplots are constructed such that background variation is represented by a linear mineralogical trend. Deviations from the linear trend are considered to be later, potentially ore-related, processes. In this way PERs can be used to filter out unwanted geochemical ‘noise’ and allow observation of alteration geochemistry associated with the target ore-forming event. The intensity of mineral changes should increase with proximity to ore. An example PER diagram showing the effects of the addition of various minerals, is shown in Figure 1.

General Element Ratios (GERs) are molar ratios, but unlike PERs do not use a conserved element. GERs rely on covariation of elements to pinpoint mineral controls on chemical variation and can be used in situations where no evidence of conserved elements exists. Because minerals commonly plot as points on GER plots, different minerals can be plotted at different locations on the diagram. A tie line can be established between altered and background mineral suites and samples can then be quickly assessed for their exploration significance. Careful GER design can also allow the tracking of multiple alteration stages. An example GER diagram is shown in Figure 2.

Application of PER and GER is illustrated for the Elura Pb-Zn deposit in N.S.W. and the Century Pb-Zn deposit in north Queensland, Australia. Some examples from other deposits will also be shown. The methodology can unequivocally identify alteration in a variety of host settings and deposit styles.

At Elura and Century, iron carbonate development and subtle potassic alteration are the dominant bulk alteration effects at both deposits. Various ‘pathfinder’ trace elements are associated with these mineral changes, but the relative timing of trace and mineral changes is difficult to constrain. Elura potassic alteration and pathfinder abundances grade in intensity towards mineralisation, whereas carbonate changes are quantised. Century alteration is somewhat quantised, but far more extensive than that at Elura, due to the size of the mineralising system. Combined use of trace element pathfinders with PER signatures is recommended to navigate through the alteration halo towards ore.

As almost all surface exploration drill holes completed in Australia pass through the regolith, it is imperative that alteration identified and quantified in fresh rock can be recognised in regolith samples. GER and PER diagrams can be used at both Century and Elura to identify the ore-related alteration in weathered saprolite. There are caveats however. At Elura, cryptic potassic alteration can be detected in certain weathered samples, but weathering processes generally destroy major element alteration indicators. Many trace elements pathfinders are also lost during weathering. Such destruction is not as extensive at Century, for either major of trace elements. The difference in weathering effects at the two deposits suggests that different processes and/or different landscape evolutions have occurred. Elura may have had multiple, possibly intense, weathering ‘events’ accompanied by preservation of the developed profiles. Weathering effects at Century seem to be more embryonic, possibly due to the stripping of weathered material coupled with less intense weathering conditions.

These results show that good geochemical orientation is required to establish an optimal sampling methodology and analytical suite for the expected sampling environment. Fresh rock samples are generally more effective media for the identification of alteration, but are of course more expensive to target than saprolite. However, certain portions of the saprolite may not be suitable sample media, depending on the style of alteration and the intensity of weathering.

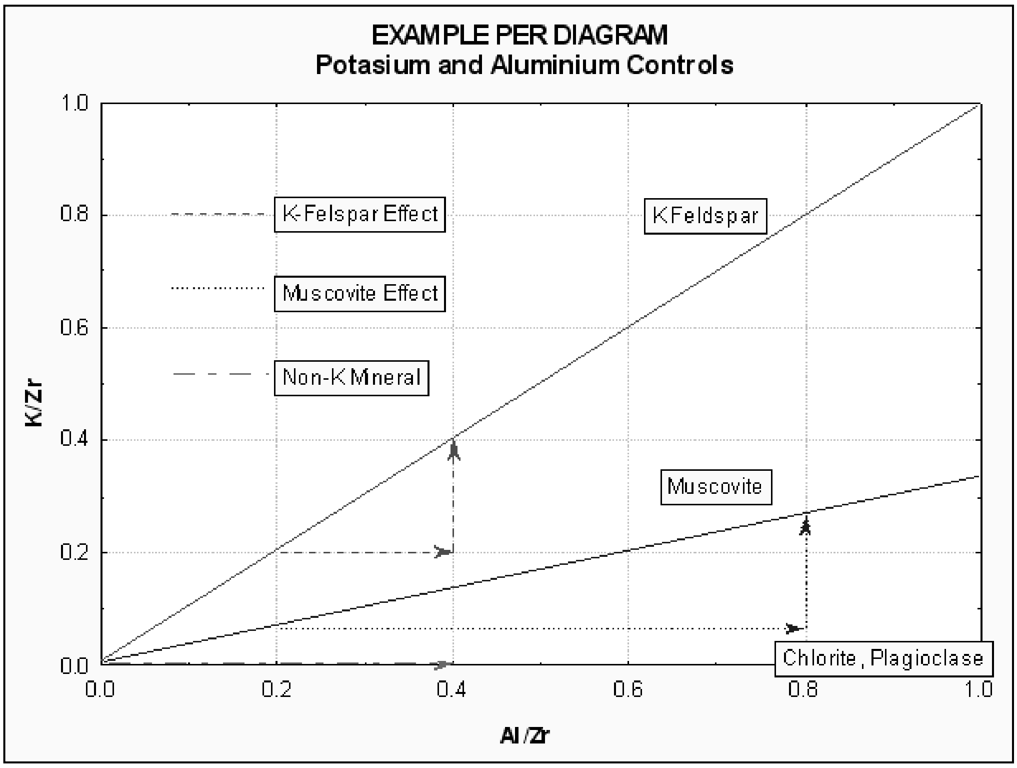

Figure 1. Example PER diagram showing various mineral controls on K and Al.

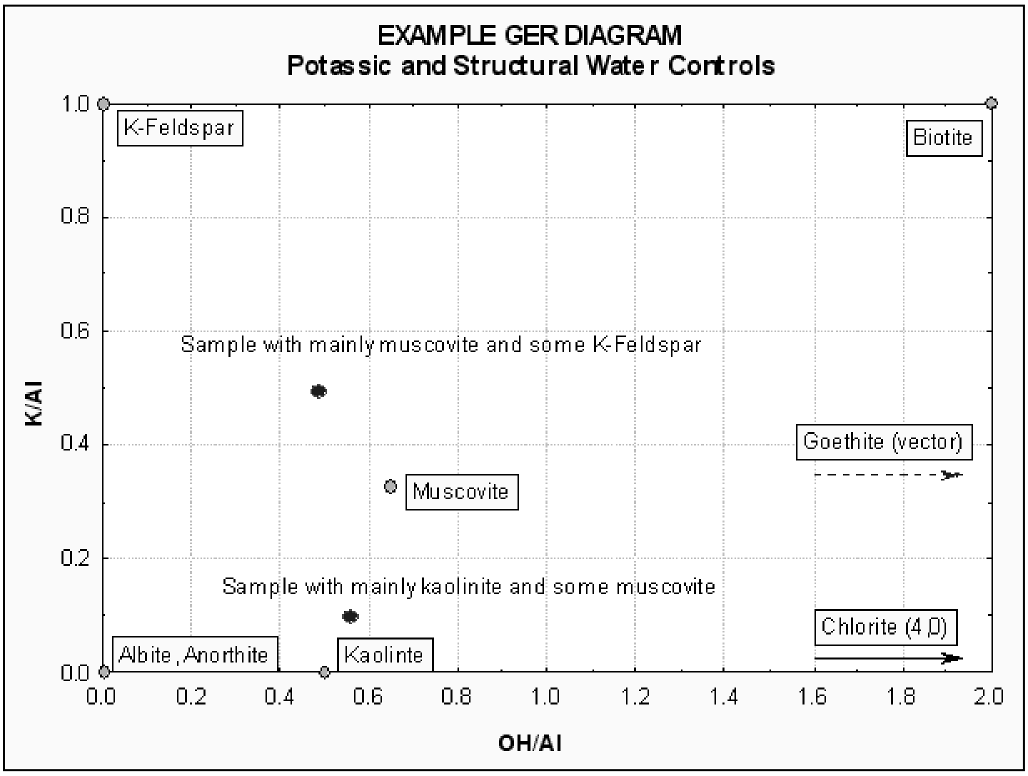

Figure 2. Example GER diagram showing mineral nodes and example sample positions.

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