CALCRETE GEOCHEMISTRY IN THE COBAR-GIRILAMBONE REGION, NEW SOUTH WALES

K.G. McQueen

CRC LEME OPEN FILE REPORT 200

January 2006

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Cataloguing-in-Publication
McQueen, K.G.
Calcrete geochemistry in the Cobar-Girilambone region, New South Wales.
ISBN 1 921039 39 6
1. Geochemistry – Lachlan Fold Belt New South Wales
2. Mineral Exploration
3. Regolith – New South Wales
I. McQueen, K.G.
II. Title
CRC LEME Open File Report 200
ISSN 1329-4768

Address and affiliations of author

K.G. McQueen
Cooperative Research Centre for Landscape
Environments and Mineral Exploration
C/- Australian National University
Department of Earth and Marine Sciences
Canberra 0200, Australian Capital Territory

Table of Contents

Page

I **Table of Contents** **ii**
II **List of Figures** **ii**
III **List of Tables** **iii**
1 **Abstract** **1**
1 **Introduction** **2**
2 **The gold-calcrete association** **2**
3 **Nature and occurrence of calcrete in western New South Wales** **2**
4 **Sampling for this study** **4**
5 **Sample preparation and analysis** **5**
6 **Morphological characteristics** **5**
7 **Age of the calcrete** **8**
8 **Geochemical observations** **8**
  8.1 Calcrete major element characteristics 8
  8.2 Minor and trace element characteristics ` 10
  8.3 Gold concentration in calcrete 17
9 **Source of cations** **19**
10 **Potential use in exploration** **19**
11 **Areas of interest** **21**
  11.1 *In situ* anomalous areas 21
  11.2 *In situ* sites with low-level anomalous gold 23
  11.3 Displaced/transported anomalies 23
12 **Recommendations** **24**
Acknowledgements **24**
References **25**

Appendices

Appendix 1 Results of internal standard (replicate) and duplicate analyses **27**
Appendix 2 Strontium isotope determinations **27**
Appendix 3 Geochemical data and GIS **See accompanying CD**

List of Figures

Page

Figure 1 **Schematic model showing possible mechanisms for concentrating gold with calcrete over buried gold mineralisation.** **2**
Figure 2 **Map of southeastern Australia showing the mapped distribution of highly calcareous soils and the general area where regolith carbonate sampling could be applied in geochemical exploration.** **4**
Figure 3 **Typical regolith carbonate or calcrete morphologies in the Cobar-Girilambone region.** **6**
Figure 4 **Some microtextures in pedogenic calcrete from Cobar-Girilambone.** **7**
Figure 5 **Bivariate plot of Ca vs Mg (wt%) of calcrete samples.** **9**
Figure 6 **Bivariate plot of K vs Al (wt%) for calcrete samples.** **9**
Figure 7 **Bivariate plots of Sr vs Ca+1.649Mg and Ba vs Ca for calcrete samples.** **10**

Page
Figure 8 Bivariate plots of Ba vs S and U vs Ca+1.649Mg for calcrete samples. 11
Figure 9 Bivariate plot of As vs Fe for calcrete samples. 11
Figure 10 Bivariate plots of Th vs Fe and Th vs Ca+1.649Mg for calcrete samples. 12
Figure 11 Bivariate plots of V vs Fe and V vs Ca+1.649Mg for calcrete samples. 12
Figure 12 Bivariate plots of Cr vs Fe shwoing two distinctive correlation trends. 13
Figure 13 Bivariate plots of Cr vs Ni for calcrete samples. 13
Figure 14 Frequency distribution histogram for Cu contents of calcretes. 14
Figure 15 Frequency histogram and cumulative frequency plot of log transformed Cu data for analysed calcrete samples. 14
Figure 16 Frequency distribution histogram for Zn contents of calcretes. 15
Figure 17 Frequency histogram and cumulative frequency plot of log transformed Zn data for analysed calcrete samples. 15
Figure 18 Frequency distribution histogram and cumulative frequency plot of log-transformed Mn data for analysed calcrete samples. 16
Figure 19 Bivariate plot of Mn vs Ca+1.649Mg for calcrete samples. 16
Figure 20 Bivariate plots of Ni vs Fe for calcrete samples. 17
Figure 21 Frequency distribution histogram for Au contents of calcrete. 18
Figure 22 Frequency histogram and cumulative frequency plot of log transformed Au data for analysed calcrete samples. 18
Figure 23 Models for lateral dispersion of Au involving initial detrital transport followed by recycling into calcrete (1) and direct groundwater transport of Au (2). 20

List of Tables

Page

Table A1 Results of internal standard (replicate) and duplicate analyses 26
Table A2 Strontium isotope ratios for carbonate component and residues in calcrete samples from the Cobar-Girilambone region. 26

Abstract

Calcrete is widespread in the regolith of the Cobar-Girilambone region, most commonly occurring as nodules in the lower part of the soil profile or as laminated masses and coatings on underlying saprock/bedrock. A wide-spaced, reconnaissance sampling program has established the nature and geochemical composition of this calcrete and indicated its potential as a geochemical sampling medium for mineral exploration in the region. The calcrete includes calcite- and dolomite-rich varieties, but with some (possibly mixtures) lying between these compositions and a few containing magnesite. Nodular and near surface calcrete tends to be calcite-rich, whereas hardpan and coating calcretes on bedrock are more commonly dolomitic. Strontium and Ba are concentrated with the calcrete. In the Cobar-Girilambone region, as in most parts of southern Australia, there is an association of dispersed gold with calcrete and calcrete generally has anomalous gold concentrations in areas close to, or down drainage from, known gold mineralisation. Results of this study suggest a regional threshold of 4 ppb Au and a local (deposit) threshold of 12 ppb. Calcrete samples with anomalous levels of Au were detected at a number of sites with no known gold mineralisation. Some other elements were also found to be concentrated in calcrete in areas where these have been dispersed from known sources. These elements include Ag, Cu and Bi (e.g. in the Cobar Gold Field and at the McKinnons gold deposit) and Ni and Co (in areas of weathered ultramafic rocks). Calcrete deposits with anomalous Au contents occur in transported regolith down drainage or palaeodrainage of major gold mineralisation (e.g. southwest of the Cobar Gold Field). The scale of this dispersion and accumulation in calcrete suggests that calcrete sampling could be used for regional reconnaissance exploration (similar to regional stream sediment sampling) as well as for local detection of mineralisation in areas of *in situ* regolith. Much of the mineralisation in the Cobar-Girilambone region is polymetallic, containing base metals with associated Au. Analysing Au in calcrete could provide a useful pathfinder strategy in base metal exploration as well as a technique for locating gold deposits.

1 Introduction

Regolith carbonates (generally referred to as “calcrete”) are widespread in the upper part of the regolith in the area from Cobar to Nyngan and north to the edge of the Eromanga Basin. The calcrete occurs in a number of facies and forms, including nodular, powder, laminated hardpan, coating and veining morphologies. This material accumulates Au and other elements and is useful for both regional and local anomaly detection.

The data reported here relate to a wide spaced, regional sampling program of calcrete, carried out to investigate the nature and geochemical characteristics of calcrete in the Cobar-Girilambone region and to test its usefulness as a sampling medium for Au exploration. The study included a total of 210 calcrete samples collected over an area of approximately 16,800 km^2, stretching from Nyngan to 60 km west of Cobar and Nymagee in the south to just north of Byrock. Full analyses and a GIS data base in ArcINFO (and reduced version in MapINFO) are included on the accompanying CD, together with a digital version of this report.

The regolith-landform setting of the Cobar-Girilambone region is described in a number of published regolith-landform maps (e.g. Gibson, 1996; Maly 2004; Maly *et al.*, 2004a and b; Buckley, 2004).

2 The gold-calcrete association

Calcrete (generally the pedogenic form) has been successfully used as a sampling medium for Au exploration in the Yilgarn and Gawler Cratons. In these areas the association of Au with pedogenic carbonate is thought to be due to the cycling of Au from depth to the surface by vegetation, mobilisation of the Au as organo-complexes and re-precipitation with carbonate under evaporative conditions (e.g. Figure 1; Lintern & Butt, 1997). However the precise processes and mechanisms of the accumulation of Au with regolith carbonates are not currently fully understood.

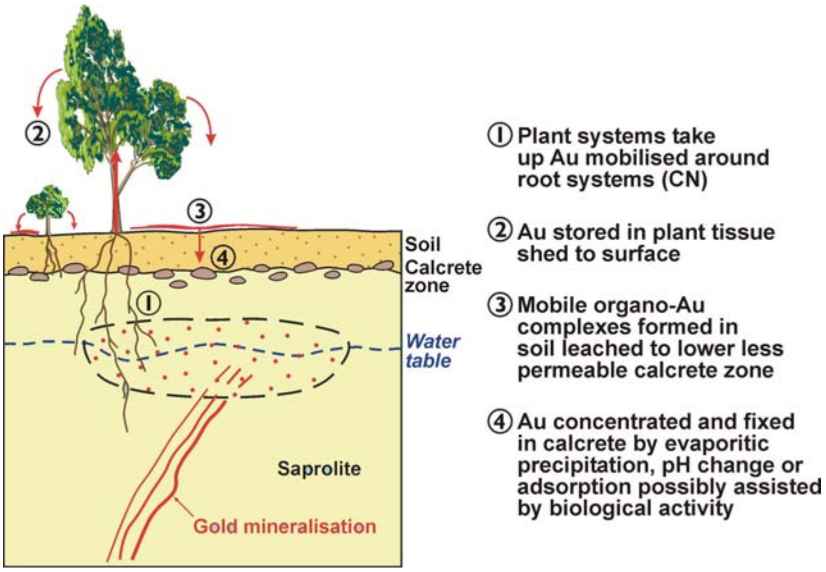

Figure 1. Schematic model showing possible mechanisms for concentrating gold with calcrete over buried gold mineralisation (modified from Lintern & Butt, 1993).

Carbonates form in the regolith mainly by the interaction of Ca^{2+}, Mg^{2+}, bicarbonate (HCO_3^-) and water. Calcite and dolomite will precipitate from solution where saturation is reached and may redissolve and be remobilised under fluctuating chemical conditions. Saturation can occur if water is removed by evaporation or evapo-transpiration and may be enhanced in areas with carbonate-rich source rocks. It has been suggested that Au deposition occurs coincidentally by a similar process of concentration of highly soluble Au complexes (possibly organo-complexes) in near surface regolith and saturation due to removal of water by plants (Lintern & Butt, 1998; Gray & Lintern, 1994). Evidence for biological activity associated with some regolith carbonates (such as calcified fungal hyphae, algal filaments and rhizomorphs) raises the possibility of direct organic interaction in the concentration and precipitation of Au.

Results from previous studies in New South Wales have indicated a strong affinity between Au and Ca in this region, suggesting that with a proper understanding of origins, facies and landscape settings, regolith carbonates may be a valuable sampling medium (e.g. Hill *et al.*, 1999; McQueen *et al.*, 1999).

3 Nature and occurrence of calcrete in western New South Wales

Regolith carbonates are widespread in many of the arid and semi-arid regions of Australia, occurring over about 21% of the total land area of the continent (Chen *et al.*, 2002).

Throughout southern Australia they occur in association with coastal calcarenite dune complexes and further inland with a wide range of geological and landscape settings. Their regional distribution is largely controlled by a fundamental relationship between:

1. the degree of leaching of carbonates, which is mainly proportional to the amount of rainfall, but also to landscape setting and factors such as groundwater pH; and,
2. the availability of carbonate (i.e. CO_3^{2-} generally related to respiration and organic activity) and appropriate cations, derived from one or a combination of atmospheric sources (rainfall and aeolian accessions), bedrock weathering (particularly of primary carbonates, and mafic lithologies) and reworking of older regolith carbonate accumulations.

Carbonates are generally considered to precipitate in the regolith in areas where annual rainfall is less than about 500 mm. However, in central and northern Australia there are large areas with low rainfall and no or very limited regolith carbonate development. Rainfall chemistry appears to be a particularly important control on regolith carbonate distribution (Hill *et al.*, 1999). Areas in southern Australia with widespread pedogenic carbonates occur south of the Menzies Line in Western Australia (Butt *et al.*, 1977; Lintern & Butt, 1998) and its equivalent across South Australia and New South Wales. North of this zone groundwater-related valley carbonates and red-brown hardpans are more common (Hill *et al.*, 1999). This boundary, at approximately 30° S latitude, marks the northern extent of calcium- and magnesium-rich winter rains derived from the Indian and Southern Oceans (Keywood, 1995; Keywood, *et al.*, 1997).

Regolith carbonates in southeastern Australia can be broadly subdivided into a number of facies based on morphology (Hill *et al.*, 1999). These include:

- **Nodular carbonate facies and coated grains** consisting of weak to strongly indurated carbonate-rich bodies exceeding 2 mm in diameter. They mostly occur above or cemented within hardpans and are typically composed mainly of calcite with some dolomite in the lower parts of the facies.
- **Carbonate rhizoliths,** which are elongate accumulations of mostly micritic calcite with “root-like” morphologies and orientation, that are up to several centimetres in diameter and rarely have internal structure.
- **Carbonate hardpan facies** made up of hard, relatively impervious layers of indurated carbonate which occurs in a variety of settings. Their internal morphology is usually complex, incorporating coalesced nodules, coated grains and other carbonate indurated fragments. Their carbonate mineralogy is variable and may consist of calcite and dolomite.
- **Boulder carbonate facies** with discrete boulder and cobble sized blocks of carbonate indurated regolith, usually within a matrix of powder carbonate or nodular carbonate facies.
- **Powder carbonate facies** composed of fine-grained, structureless, unconsolidated to weakly consolidated carbonate material, usually dolomite or magnesium-rich calcite, typically found in the lower parts of profiles, such as gradationally underlying carbonate hardpans.
- **Tabular massive carbonate facies** composed of lensoidal carbonate accumulations commonly forming mounds or domes within thick alluvial sequences. The main carbonate mineral is typically dolomite, however calcite- and ankerite-rich varieties also occur.
- **Septarian magnesite accumulations** found in association with mafic and ultramafic bedrock, a major source of the magnesium. The carbonate mineralogy is near pure magnesite..

In western New South Wales carbonates have accumulated both within soil and colluvium/alluvium as well as deeper in regolith profiles where carbonate-bearing solutions have ponded, typically within the upper saprolite/saprock zone or at the soil bedrock interface. There is a strong association between regolith carbonate accumulations and calcareous soils (Figure 2). However, regolith carbonate accumulations are more widely distributed than the areas of mapped calcareous soils, particularly in regions where there is a large aeolian component in the regolith.

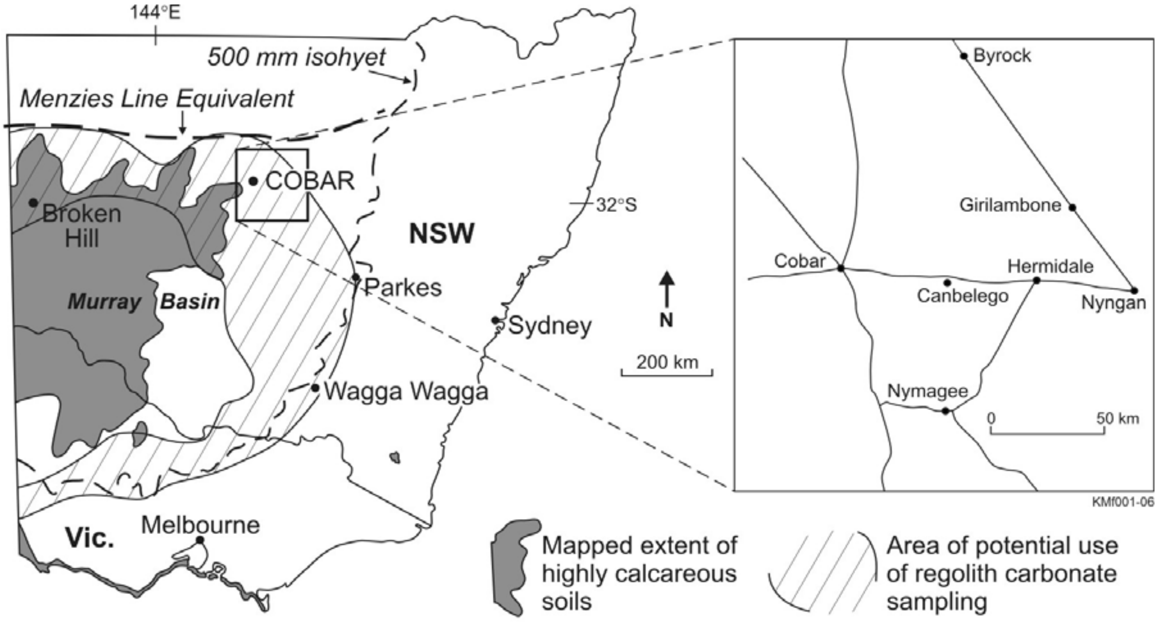

Figure 2. Map of southeastern Australia showing the mapped distribution of highly calcareous soils (after Northcote, 1978) and the general area where regolith carbonate sampling could be applied in geochemical exploration for Au and Au-bearing polymetallic deposits. Also shown is the 500 mm isohyet (western limit of >500 mm rainfall) and the Menzies line extension. Expanded area shows the limits of the Cobar-Girilambone region examined in this study.

4 Sampling for this study

Calcrete samples were collected from a wide area across the Cobar-Girilambone region (Figure 2). Most samples were from *in situ* regolith-landform settings (although the overlying soil typically has a widespread aeolian transported component). Calcrete was generally found at 1-2 m depth, commonly near the base of the soil. Some samples were collected in transported regolith, mainly alluvium in palaeochannels. Here the sample depth varied according to the thickness of alluvium, with calcrete commonly developed near the base.

Samples were collected from available exposures into the regolith, including borrow pits and quarries, road cuttings, farm dams and gully sections. Some samples were collected from excavated material adjacent to telephone cable trenches, power poles, farm dams, old prospecting pits, rabbit burrows and uprooted trees. A small number of samples were collected by auger and air core drilling. Where possible, care was taken to sample material below exposed surfaces. This is because there is evidence that Au may be easily leached from calcrete (e.g. D. Gray has found that distilled water at room temperature can leach Au from calcrete, at least when it is in powdered or finely divided form). This sampling approach was not always possible, so where exposed calcrete was sampled the largest pieces were taken to minimise the effect of any surface leaching of Au from the calcrete.

5 Sample preparation and analysis

Bulk samples (0.5-1 kg) were coarse crushed inside thick plastic bags in a hydraulic press. The samples (<500 g) were then pulverised in a mild steel mill and submitted to Amdel Laboratories Ltd in Adelaide for digestion and analysis. A portion of each pulverised and homogenised sample was subjected to a multi acid digest using hydrofluoric, nitric, perchloric and hydrochloric acids (Method A9612-12). This solution was analysed by ICP OES (Scheme IC3E) for Ba, Ca, Cr, Fe, K, Mg, Mn, Na, Ni, P, Ti, V, S and by ICP MS (Scheme IC3Mfor Ag, As, Bi, Cd, Ce, Cu, Ga, In, Mo, Nb, Pb, Rb, Sb, Se, Sr, Re, Th, Tl, U, W, Y, and Zn. Fifty g of each sample was subjected to aqua regia digest followed by solvent extraction and analysis by graphite furnace AAS for Au (Scheme AA9, detection limit 1 ppb). Analysis of replicate samples indicated standard deviations of less than 2.3 at 9 ppb Au and 2.4 at 23 ppb Au. Check samples were submitted for analysis by INAA at Becquerel Laboratories Ltd and results were within the above standard deviations.

6 Morphological observations

Common regolith carbonate or calcrete facies in the Cobar-Girilambone region include:

- **nodular carbonates** (including rhizolithic forms) in soil and alluvium;
- **carbonate hardpans**, composed of coalesced nodules and more massive and laminated carbonate, which are generally developed in settings where there has been concentration or ponding of groundwater;
- **carbonate hardpan** forming coatings and veinings on bedrock; and
- **powder carbonate** associated with the hardpan facies (Figure 3).

In this region regolith carbonates, particularly the hardpan facies, contain significant dolomite, as well as calcite and magnesian calcite. Calcite is generally more abundant in the upper parts of profiles. Nodular carbonates in soil are generally calcite-rich. There are also some localised occurrences of magnesite-rich carbonates. The dolomite-rich hardpan carbonates and some of the nodular forms are commonly well indurated and may be present in lag where the carbonate-rich zone has been exposed by surface deflation or gully erosion.

Detailed microscopic observations of pedogenic calcretes from near Cobar indicate that some carbonate deposition is displacive but that some is also replacive(Figure 4). The carbonate accumulations appear to form by a two-stage process involving:

1. initial deposition of carbonate in voids and cracks in soil and saprolite (i.e. a veining stage involving some displacement);
2. later replacement of the clay component in the soil/saprolite by fine-grained carbonate (i.e. replacement stage).

Vein infill and partial and complete pseudomorphous replacement textures can be clearly seen at the micro-scale. Replacement appears to have been near isovolumetric and to have involved dissolution and removal of aluminium silicates accompanied by deposition of carbonate, possibly in the first instance as a gel. Quartz grains appear to be largely unaffected by this process, although there is some evidence for minor grain etching.

Textural evidence also indicates that carbonate accumulations may undergo subsequent dissolution and re-deposition of carbonate, including as sparry veins and aggregates. Coarser grained sparry carbonate also occurs as void linings, some with colloform textures.

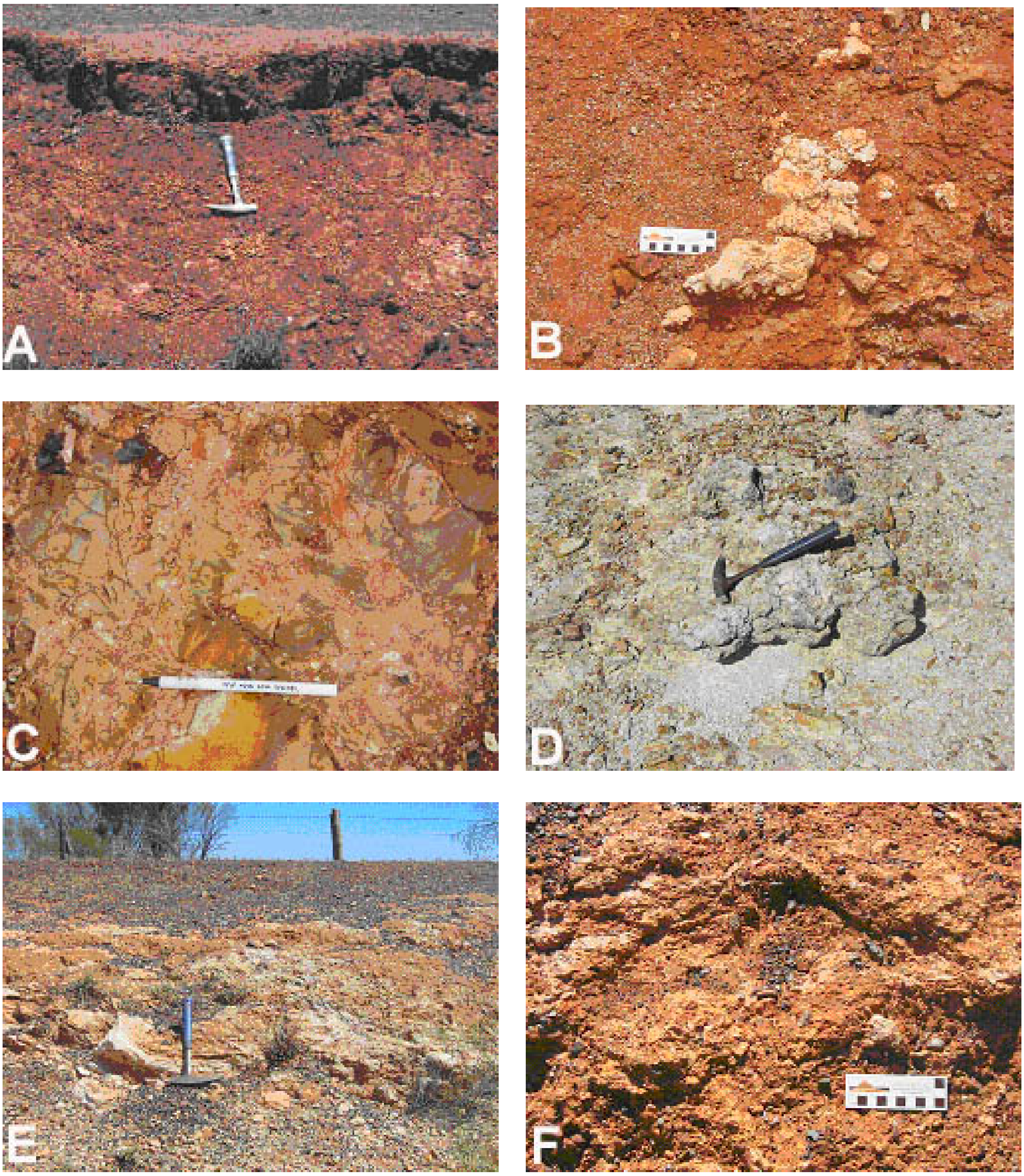

Figure 3. Typical regolith carbonate or calcrete morphologies in the Cobar-Girilambone region. **A**. Nodular calcite-rich calcrete in lower part of soil profile (borrow pit 31 km southwest of Cobar GR 0375600 6487300). **B**. Coalesced calcrete nodules in lower part of soil, scale is in cm (borrow pit on Bourke Road 21 km north of Cobar GR 0393992 6535061). **C**. Calcrete coating and veining bedrock, pen is 12 cm long (cutting on Hillston Road 55 km south of Cobar GR 0402760 6463353). **D**. Massive cementing calcrete above saprolite (borrow pit on Bourke Road 11 km north of Cobar GR 0392801 6525046). **E**. Laminated calcrete hardpan below soil and above saprolite (borrow pit 20 km west of Cobar GR 365623 6511617). **F**. Veins, powder and small nodules of calcrete formed in transported palaeochannel alluvium (Airport South quarry 10 km southwest of Cobar GR 386044 6505357). Grid references are in AGD 66.

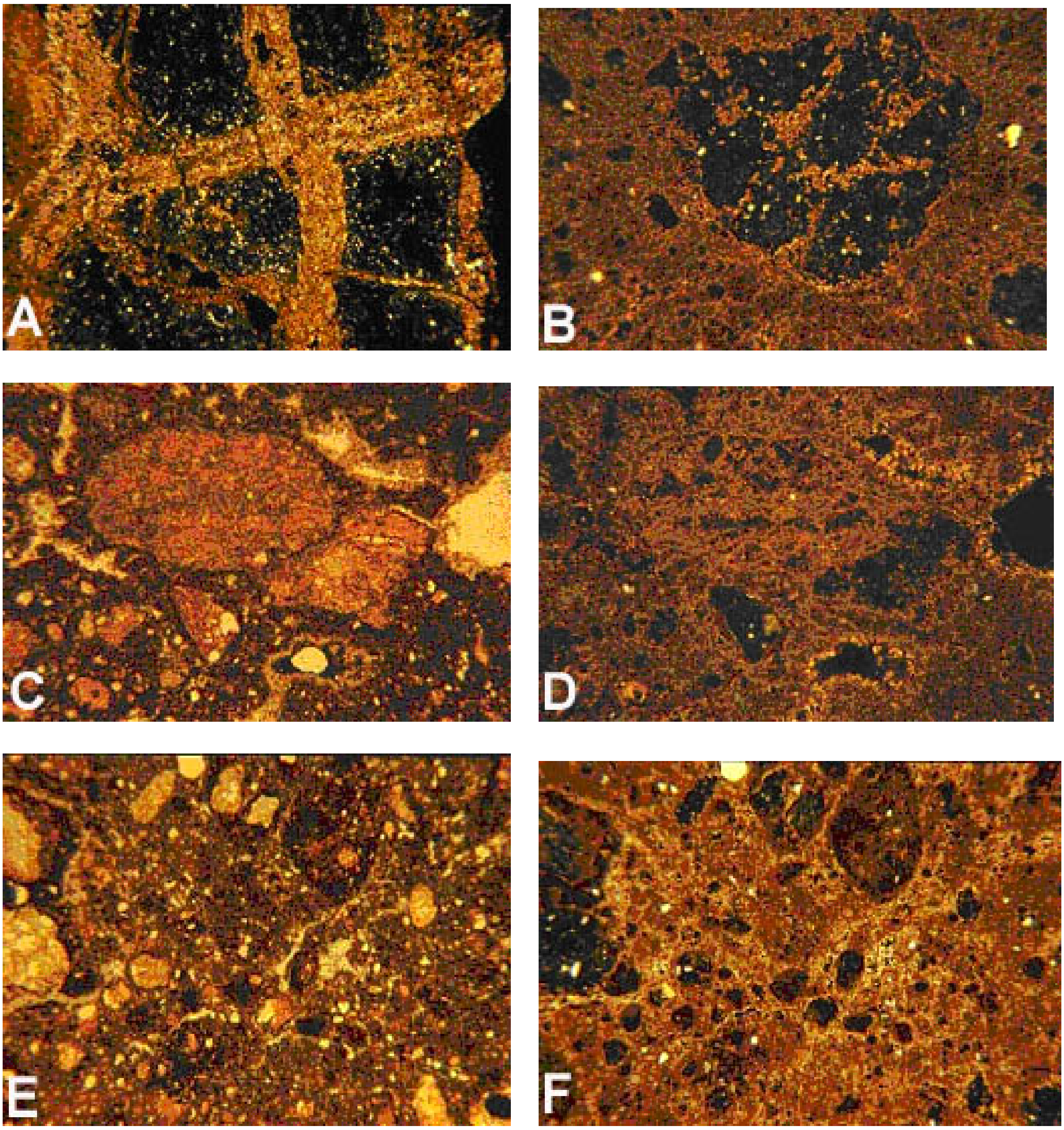

Figure 4. Some microtextures in pedogenic calcrete from Cobar-Girilambone. **A**. Calcite veins along cracks in soil. This appears to be an initial stage of calcrete formation and calcite deposition is partly displacive (transmitted cross-polarised light, sample CC3). **B**. Relict pedogenic clay-quartz clast in nodular calcrete showing veining of clast in surrounding mass of carbonate (transmitted cross-polarised light, sample CC13). **C**. Section of calcrete nodule showing preserved pedogenic fabric of original soil (transmitted plane light, sample CC13). **D**. Same field as C in cross-polarised light, showing that most of the sample consists of carbonate with scattered relict quartz grains (white and light grey) and some clay patches (dark). This texture is consistent with replacement of the clay component in soil by carbonate. **E**. Section of calcrete nodule showing preserved soil texture (transmitted plane light, sample CC13). **F**. Same field as F in cross-polarised light, showing large areas of the sample replaced by carbonate with relict quartz grains. Width of field in all photomicrographs is 3 mm.

In some calcrete samples, fine-grained micritic carbonate has recrystallised to form small, coarser grained aggregates rimming quartz and saprolite grains (rims ca. 0.03 mm wide). This appears to be some type of nucleation effect.

Highly alkaline conditions would appear to be necessary to allow dissolution of the clay component of soil and saprolite and simultaneous replacement by carbonate.

7 Age of the calcrete

It is widely believed that calcrete formation in the semi-arid areas of southern Australia was initiated during the periods of greatest aridity throughout the Quaternary. Field evidence in the Cobar-Girilambone region is at least consistent with this. Evidence includes such features as calcrete coatings on Cainozoic silcrete, calcrete formation within and at the base of soils with a Quaternary aeolian component, and calcrete infillings within cavities and along fractures in near-surface weathered bedrock, including Tertiary sediments. Calcrete is also commonly found as post-sediment infillings and cements in many of the mid-Tertiary palaeochannel sediments. It is likely that there have been multiple episodes of calcrete precipitation and redissolution, possibly extending back to the Miocene. Permeable and well-drained sediments in recent drainage channels in the area generally lack carbonate, suggesting that the present day free-flowing surface waters are undersaturated with carbonate. Calcrete may be presently forming in evaporitic environments in other parts of the regolith.

Wasson (1976) published C^{14} dates of 28.1±0.9 Ka and 25.93±.47 Ka for calcrete from the Belorabon area southwest of Cobar. These were for nodular and soft calcretes in a sedimentary sequence of aeolian sediments. However, C^{14} dating of calcrete can be rather speculative, given the limited time range of the C^{14} method (<50 Ka for the technique at the time of analysis) and uncertainties related to potential contamination by both modern and dead carbon (Chen *et al.*, 2002).

8 Geochemical Observations

8.1 Calcrete major element characteristics

The proportion of carbonate in the calcrete samples collected in this study varies widely from several percent to nearly pure carbonate. This reflects inclusion of variable amounts of clay and other regolith components (including detrital quartz and iron oxides) in the cemented carbonate zone and within nodular carbonate. Major element compositions indicate that the carbonate component in the calcrete largely ranges between calcite and dolomite with a small number of samples containing magnesite (Figure 5). There is a large group of samples that cluster along a trend towards pure calcite and some that fall on the dolomite trend, but also many that are either mixtures of dolomite and calcite or that contain high-Mg calcite. A small amount of non-carbonate Mg may also be present in the samples (e.g. this probably accounts for samples plotting just below the dolomite trend in Figure 5 and some samples plotting off the calcite trend towards dolomite).

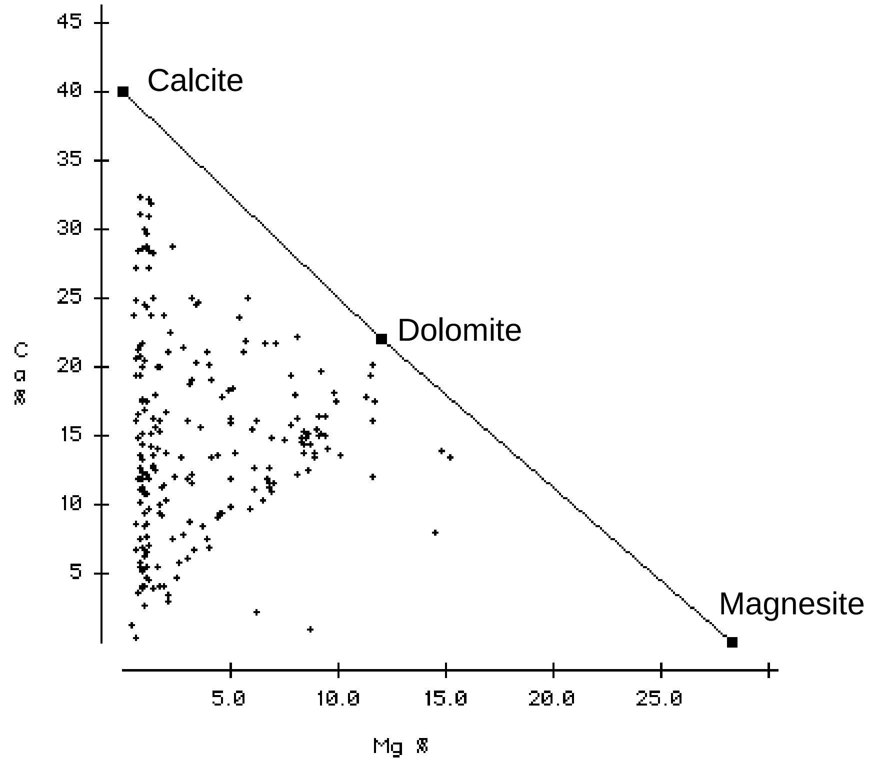

Figure 5. Bivariate plot of Ca vs Mg (wt%) for calcrete samples from the Cobar-Girilambone region. Most samples lie within the compositional field of calcite-dolomite with several containing magnesite.

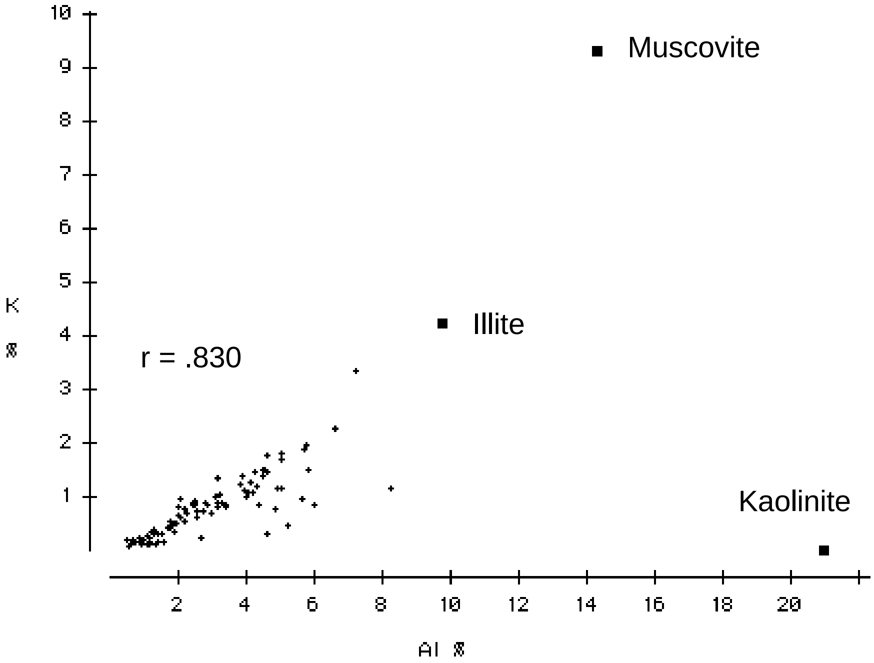

Figure 6. Bivariate plot of K vs Al (wt%) for calcrete samples from the Cobar-Girilambone region. Most samples plot on a trend matching a specific kaolinite-muscovite mixture close to the illite composition. A small number of samples are more kaolinite rich (r=correlation coefficient).

Where calcite and dolomite are both developed in the same regolith profile, calcite is typically more abundant in the upper part of the profile. This has been attributed to near surface dissolution of carbonate by downward percolating rainwater and reprecipitation of calcite before dolomite, high in the profile, due to changes in pH and pCO_2 (Hutton & Dixon, 1981; Hill *et al.*, 1999). The formation of impermeable carbonate hardpans may also have some control on the vertical transition from calcite to dolomite dominated facies. Such hardpans are typically dolomite-rich and overlain by more calcite-rich carbonate facies. They represent a hydromorphic barrier restricting the access of more Ca-rich surface waters to the lower parts of the profile and they are more likely to be related to Mg-rich groundwaters, particularly where these have been ponded or introduced by a fluctuating water table. The high proportion of dolomite in the hardpan facies could also reflect a greater influence on carbonate genesis from lateral groundwater movements along the bedrock-alluvium boundary.

The calcrete samples contain variable amounts of K and Al reflecting the varying abundance of clay mineral impurities. These two elements generally show strong positive correlation and their ratios are consistent with the main clay component being comprised largely of illite with some kaolinite, or possibly muscovite-kaolinite mixtures that approximate the illite composition (Figure 6).

The Fe content of the calcrete samples generally ranges from <0.05 to 5 wt%. There are a few samples with Fe contents up to 17 wt%. Iron shows a weak negative correlation with carbonate (represented by Ca+1.649Mg) suggesting that it is not significantly present in the carbonate but most likely present in iron oxide/oxyhydroxide impurities.

8.2 Minor and trace element characteristics

Sr and Ba (part of the evaporitic association)

Elements such as Sr and Ba are concentrated with the calcrete. Barium concentrations are commonly above 500 ppm (70% of samples) and Sr above 450 ppm (70% of samples, with one sample containing 1.47% Sr). There is a positive correlation of Sr with carbonate content (Ca+1.649Mg) and weaker positive correlation of Ba with Ca (Figure 7). Barium shows a strong positive correlation with S (Figure 8). These correlations are consistent with substitution of Sr for Ca in calcite/dolomite and concentration of Ba in barite associated with the calcrete. The one sample with very high Sr is a nodular calcrete from Nullamut Tank, (ca. 20 km north of Cobar) and is associated with gypsiferous clays. This sample also has a high S content, suggesting the presence of gypsum and possibly celestite ($SrSO_4$) in the calcrete.

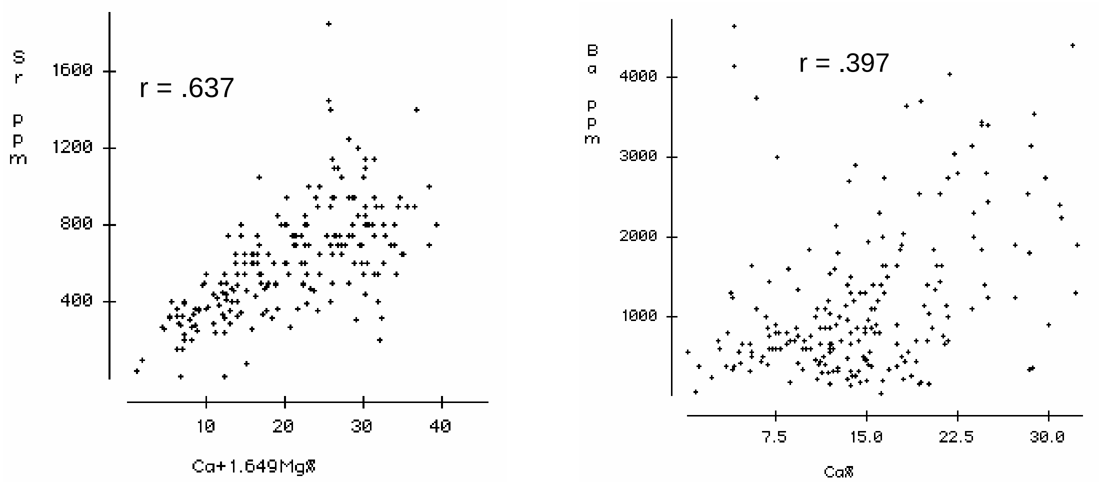

Figure 7 Bivariate plots (wt%) of Sr vs Ca+1.649Mg (reflecting relative weight proportions of Ca and Mg in carbonate) and Ba vs Ca for calcrete samples from the Cobar-Girilambone region (r=correlation coefficient).

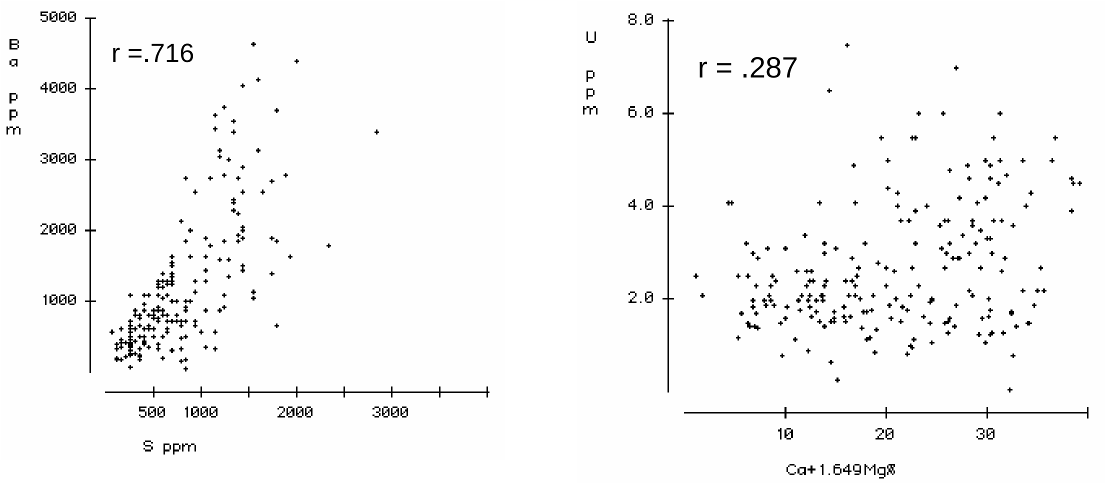

Figure 8. Bivariate plot (wt%) of Ba vs S and U vs Ca+1.649Mg for calcrete samples from the Cobar-Girilambone region (r= correlation coefficient).

U

Calcretes, particularly "valley calcretes" in the northern Yilgarn, are known to accumulate U, generally where there are U-rich source rocks in the weathering catchment. Calcretes from the Cobar-Girilambone region have low concentrations of U (<8 ppm, with 80% of samples <4 ppm). There is no apparent correlation between U content and Ca+1.649Mg (Figure 8) or Fe in the samples. There is no correlation between U and Th or U and K contents.

As, Th, V and Cr (iron oxide/oxyhydroxide association)

A number of trace elements analysed in the calcrete samples (including As, Th, V, Cr) show positive correlation with Fe and are negatively correlated with Ca+1.649Mg, suggesting that these elements are contained within iron oxide/oxyhydroxide impurities in the calcrete. This Fe-associated suite of trace elements is also recognised in other regolith samples enriched in secondary Fe oxides/oxyhydroxides. Detailed studies on ferruginous lag around Cobar has shown that hematite exposed at the surface accumulates Th and this material shows a marked positive correlation of Th and Fe (McQueen & Munro, 2003; McQueen *et al.*, 2004). Other elements accumulated by hematite in this lag include As, Sb, Cr, Sb and Bi.

Arsenic contents of calcrete are generally low (91% <15 ppm, considered a threshold for anomalous values). There is a positive correlation between As and Fe contents of the calcrete samples. Samples with the highest As contents (up to 46 ppm) show high Fe content consistent with the presence of hematite/goethite in impure calcrete. (Figure 9).

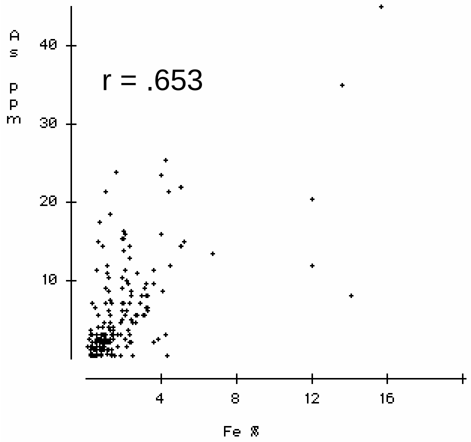

Figure 9. Bivariate plot (wt%) of As vs Fe for calcrete samples from Cobar-Girilambone (r = correlation coefficient).

Thorium contents range from 1 to 25 ppm (90% of samples <15 ppm) and Th is positively correlated with Fe in a subgroup of the samples (Figure 10). Thorium shows a negative correlation with Ca+1.649Mg.

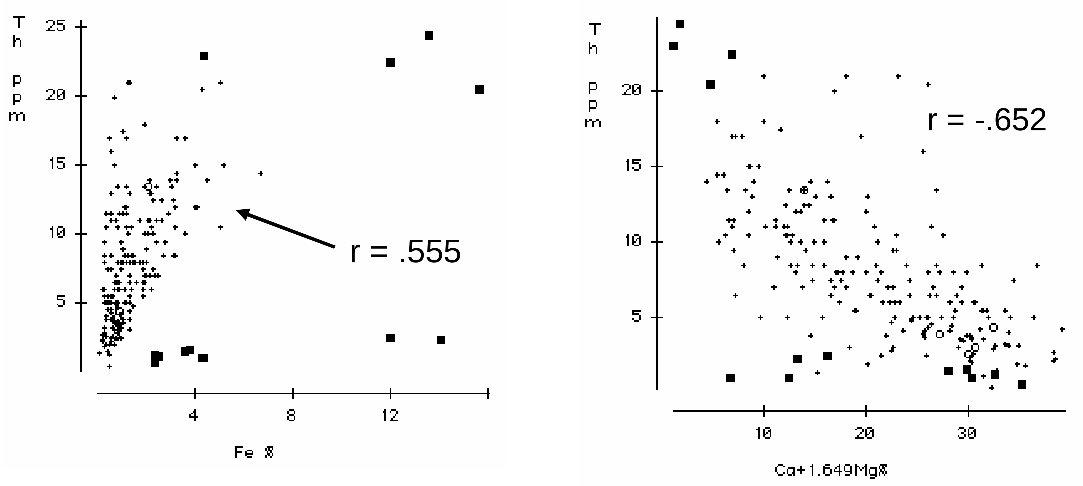

Figure 10. Bivariate plots (wt%) of Th vs Fe and Th vs Ca+1.649Mg for calcrete samples from the Cobar-Girilambone region. Closed squares indicate samples with distinctly different, high-Fe trends, probably reflecting Fe in hematite (upper trend) and goethite (lower trend). Closed squares define the same samples on both plots.

Vanadium contents range from <1 to 180 ppm. There appear to be two distinct populations in the V data (Figure 11). One population contains <35 ppm and the second 35-100 ppm V. The major control on this distribution appears to be the Fe content of the calcrete. A small number of samples form an anomalous population above 100 ppm. These samples do not appear to show any special location features. Vanadium shows a strong positive correlation with Fe about two ratio trends. One trend shows a lower V/Fe ratio than the main population, possibly reflecting high Fe in goethite rather than hematite. Hematite appears to be the preferred host for V. Vanadium shows a strong negative correlation with Ca+1.649Mg, suggesting that it is not hosted in the carbonate component of the calcrete.

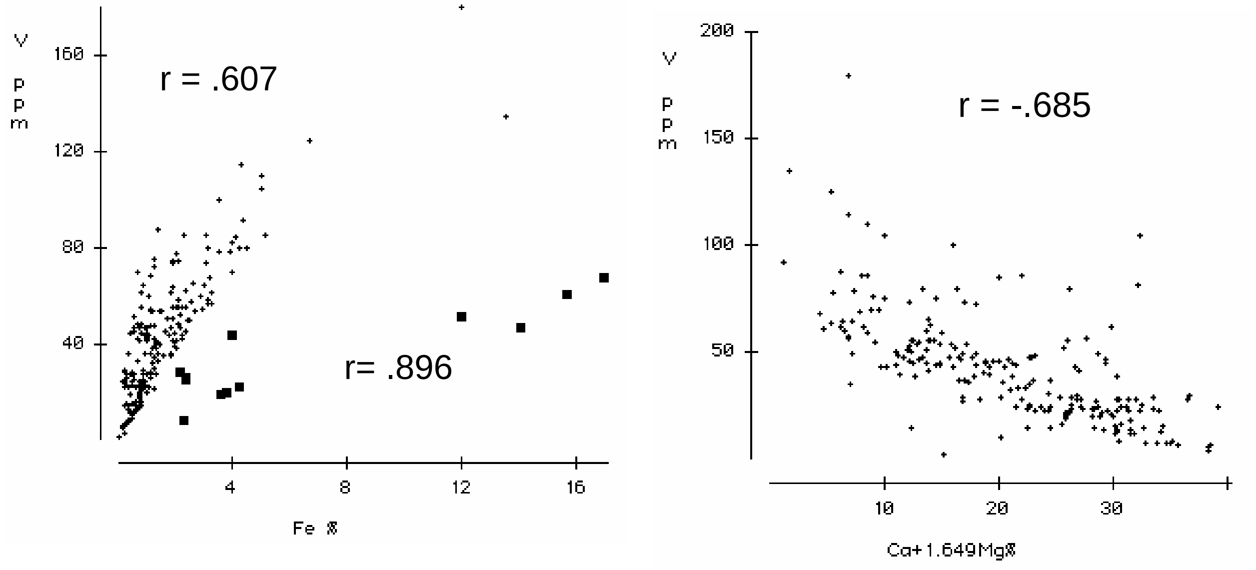

Figure 11. Bivariate plots (wt%) of V vs Fe and V vs Ca+1.649Mg for calcrete samples from the Cobar-Girilambone region. Closed squares define a separate V vs Fe trend for some Fe-rich (probably hematitic) samples (r = correlation coefficient).

Chromium contents of the calcretes are generally <60 ppm (94% of the samples) and show strong positive correlation with Fe content (Figure 12). There is also a strong positive correlation between Cr and V on two separate ratio trends. Samples from areas adjacent to ultramafic rocks and very ferruginous settings show high Cr contents (60-4400 ppm) and also a strong positive correlation with Fe but with a much higher Cr/Fe ratio. There is generally a strong positive correlation between Cr and Ni in samples with both high and low Cr content (Figure 13)

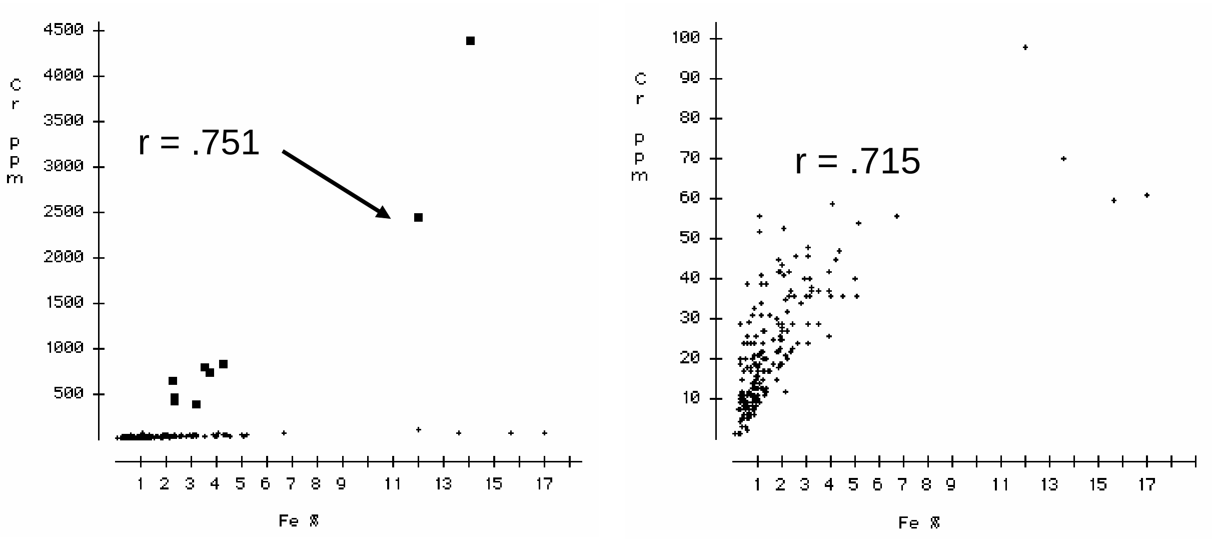

Figure 12. Bivariate plots (wt%) of Cr vs Fe showing two distinctive correlation trends for high (closed squares) and low (small circles) Cr values (r = correlation coefficient).

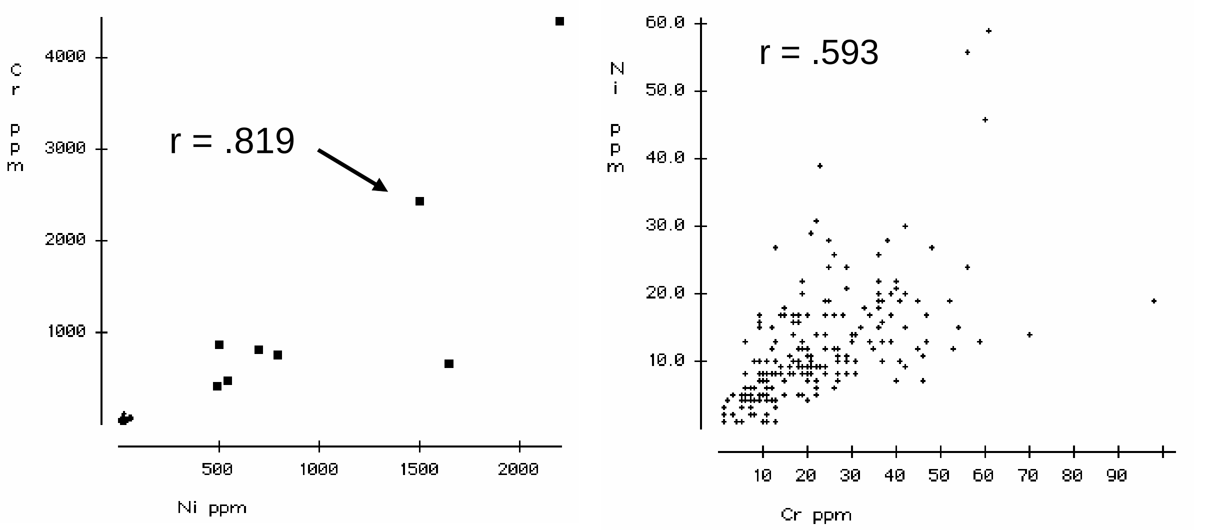

Figure 13. Bivariate plots (wt%) of Cr vs Ni for calcrete samples from the Cobar-Girilambone region. Closed squares are for high Ni and Cr samples (r = correlation coefficient).

The calcrete analyses show Ti values from 60 to 4350 ppm. Titanium shows a strong positive correlation with V and moderate positive correlation with Fe, and also with Cr in the low-Cr suite of samples (<100 ppm Cr). The Ti values show a strong negative correlation with Ca+1.649Mg. These observations suggest that analysed Ti is probably hosted in hematite impurities. The multi acid digestion technique would not have dissolved any detrital rutile and possibly ilmenite in the calcrete samples.

Ag

The Ag content of the calcrete samples is generally low (86% of samples <0.5 ppm, considered a regional threshold for anomalous values). Samples from areas of known Au mineralisation commonly contain above 0.5 ppm Ag. Calcrete samples from adjacent to the McKinnons Au deposit contain the highest Ag values (8-13 ppm). One sample (CC168) from calcrete in a palaeochannel near Pine Tree Tank on the Byrock 1:100 000 sheet contains 6 ppm Ag (with 5 ppb Au).

Cu

Most of the calcrete samples contain less than 50 ppm Cu (Figure 14; 94% of the samples contain <50 ppm, considered a regional threshold for anomalous values). This population of data shows a near log normal distribution (Figure 15). Anomalous samples contain up to 125 ppm Cu. Samples with elevated Cu occur near sites with known Cu mineralisation (e.g. near the New Cobar Au-Cu deposit) but there are also some anomalous samples from sites with no known mineralisation (e.g. Miandetta quarry). High Cu levels do not appear to be positively correlated with Fe and hence Fe oxide/oxyhydroxide impurities.

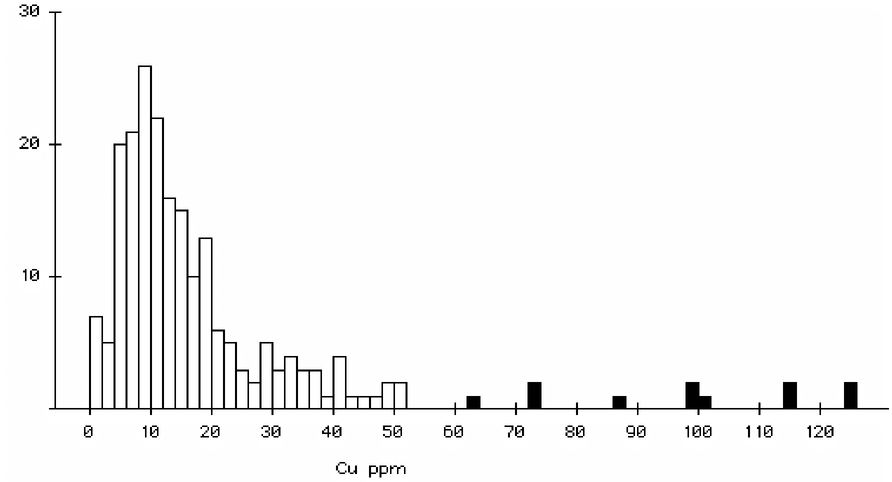

Figure 14. Frequency distribution histogram for Cu contents of sampled calcretes from the Cobar-Girilambone region (closed symbols represent anomalous values).

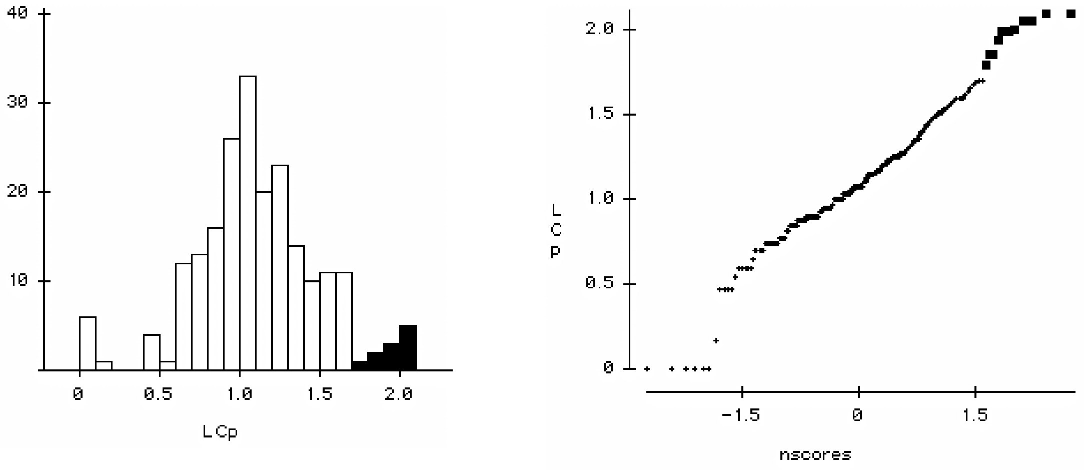

Figure 15. Frequency histogram and cumulative frequency plot of log-transformed Cu data for analysed calcrete samples from the Cobar-Girilambone region. There are two distinct populations in the data representing background (<50 ppm, open symbols), and anomalous samples (>60 ppm, closed symbols).

Zn

Zinc contents of the calcrete samples are generally less than 76 ppm (Figure 16; 92% of samples contain less than 76 ppm Zn, considered a threshold for anomalous values). This population of data show a near log-normal distribution, similar to that of Cu (Figure 17). Anomalous Zn values are up to 330 ppm and high levels are not linked with high Fe contents. Most of the samples with high Zn contents occur in calcrete samples from sites of known mineralisation including near New Cobar, Gilgunnia, Smiths Creek anticline, McKinnons and the CSA mine (at the latter site there may have been contamination from the nearby mill). There are some samples from sites with no known mineralisation that show elevated Zn (e.g. the area 0.6-2 km east of Cobar Airport and a site south of the CSA turnoff).

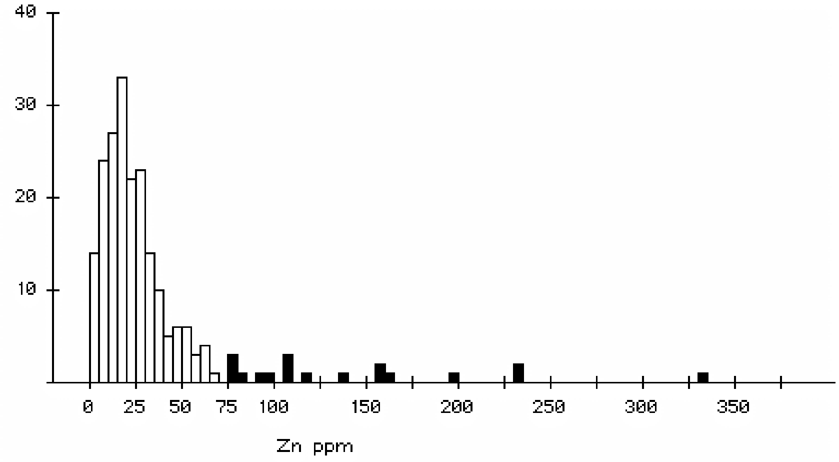

Figure 16. Frequency distribution histogram for Zn contents of sampled calcretes from the Cobar-Girilambone region (closed symbols represent anomalous values).

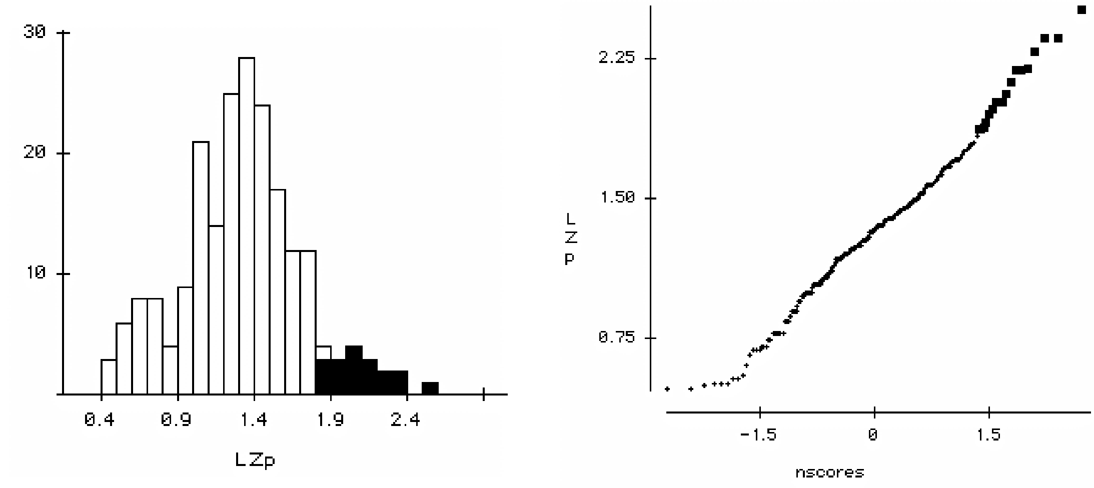

Figure 17. Frequency histogram and cumulative frequency plot of log-transformed Zn data for analysed calcrete samples from the Cobar-Girilambone region. Values above 76 ppm (closed symbols) are considered to be anomalous.

Pb

The Pb content of the calcrete samples mostly ranges from <5 up to 65 ppm (97% of samples contain <65 ppm, considered a threshold for anomalous values). There are a small number of samples with Pb contents between 65 and 600 ppm. Elevated Pb values are present in some samples close to sites of known mineralisation, including at New Cobar, Gilgunnia, McKinnons and the CSA mine. Two calcrete samples from near the CSA mine contain 430 and 600 ppm Pb (these very high levels are possibly related to contamination and are correlated with high Zn contents). Generally there is not a strong correlation between Pb and Zn contents or between concentrations of Pb and contents of other elements.

Bi

Bismuth values measured in the calcrete samples are mostly <0.7 ppm (97% of the total samples). Two samples from the McKinnons Au deposit contain 17 and 78 ppm Bi. Samples from the Cobar Gold Field also contain elevated contents of Bi.

Sb

Measured Sb levels in the calcrete samples are mostly <4 ppm (98% of the total values). Higher Sb contents (8-18 ppm) are present in samples from a site east of McKinnons (CC44) and at the old Cobar Wiltye workings in the Cobar Gold Field.

Mn

The Mn content of the calcrete samples ranges from 20-1100 ppm. There are three populations in the data set, defined by values of <160 ppm, 160-600 ppm and >600 ppm Mn (Figure 18). In samples with Mn contents greater than 600 ppm there is a moderate positive correlation with Ca+1.649Mg suggesting that in these samples the Mn is hosted by the carbonate component (Figure 19). Manganese does not correlate strongly with Fe in the calcretes.

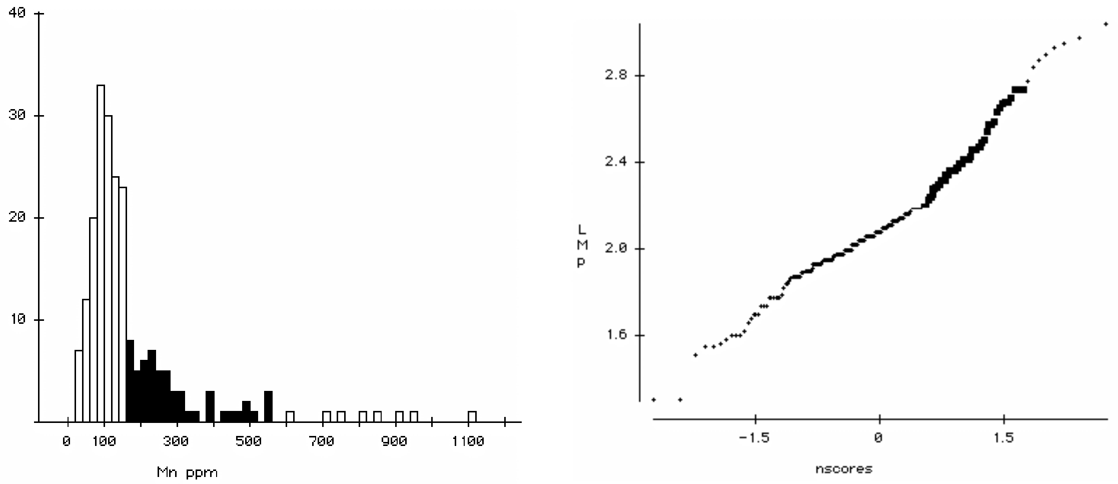

Figure 18, Frequency distribution histogram and cumulative frequency plot of log-transformed Mn data for analysed calcrete samples from the Cobar-Girilambone region, showing three populations in the total data set.

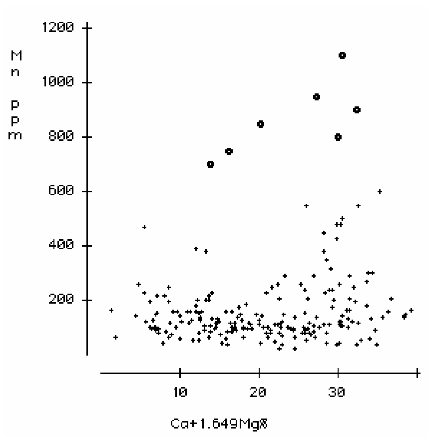

Figure 19. Bivariate plot of Mn vs Ca+1.649Mg for calcrete samples from the Cobar-Girilambone region. Some samples with high Mn content (large circles) show positive correlation with carbonate.

Ni

Most of the calcrete samples have low Ni contents (80% of samples <20 ppm). In these samples Ni shows a moderate positive correlation with Fe suggesting that it may be hosted in iron oxide impurities. Calcrete samples collected over and adjacent to ultramafic rocks contain 500-2200 ppm Ni, indicating that where abundant, Ni is readily taken up in calcrete (typically dolomitic). In these high-Ni calcretes, Ni is positively correlated with Fe, but with a markedly different correlation trend (Figure 20). This suggests that calcrete sampling may be useful for locating poorly exposed or subsurface ultramafic intrusions. There are a small number of samples that contain 30-100 ppm Ni and these are associated with mafic and chloritic lithologies or areas with very abundant iron oxides.

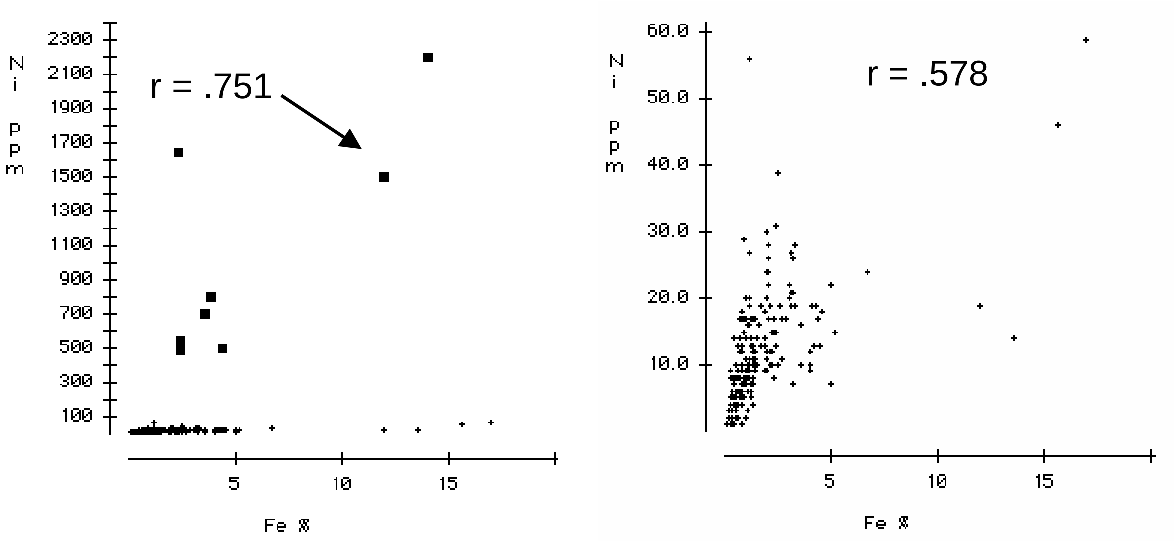

Figure 20. Bivariate plots (wt%) of Ni vs Fe for calcrete samples from the Cobar-Girilambone region showing high Ni samples (closed squares) and low Ni samples (small closed circles). The high Ni samples are from sites over known ultramafic-mafic rocks (r = correlation coefficient).

Co

Those samples analysed for Co show elevated Co values 20-130 ppm in calcretes from adjacent to ultramafic rocks. Most calcretes contain less than 20 ppm Co and in these samples Co is positively correlated with Fe suggesting that like Ni, the Co is hosted by iron oxide impurities.

Ti

The calcrete analyses show Ti values from 60 to 4350 ppm. Titanium shows a strong positive correlation with V and moderate positive correlation with Fe, and also with Cr in the low-Cr suite of samples (<100 ppm Cr). The analysed Ti is probably hosted in hematite impurities. The multi acid digestion technique would not have dissolved any detrital rutile and possibly ilmenite in the calcrete samples.

8.3 Gold concentration in calcrete

The majority of calcrete samples contain no detectable Au (<1 ppb). Samples from sites close to or down drainage from known Au mineralisation generally contain detectable Au and a number of samples from sites where there is no known Au mineralisation also contain detectable Au. The frequency distribution for Au analyses is illustrated in normal and log values in Figures 21 and 22. A regional threshold of 4 ppb Au is suggested, based on values from sites near known Au mineralisation and consideration of the log-probability distribution for the entire data set. It is possible that the threshold could extend to 3 ppb (refer Figure 22).

However, it was decided to take a more conservative value that is also 4 times the detection limit. A value of 3 ppb is generally considered as the regional threshold in the Gawler Craton (M. Lintern *pers. comm.* 2000). A local (deposit) threshold of 12 ppb is suggested for the Cobar-Girilambone region, based on the data from known Au deposits and the log-probability frequency distribution. High Au values (>12 ppb) are not correlated with Ca+1.649Mg. Fe, As or Ag content of the samples.

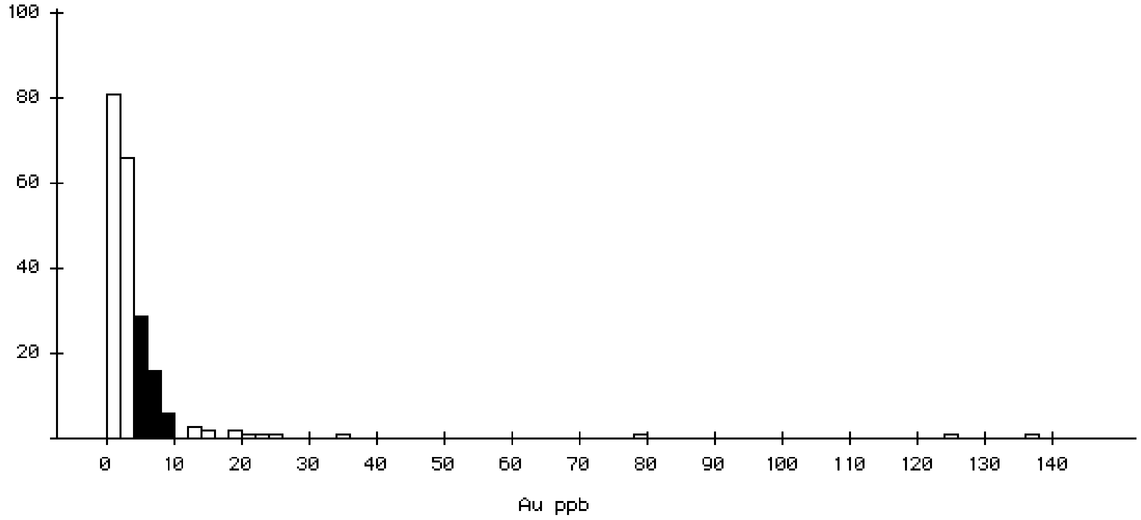

Figure 21. Frequency distribution histogram for Au contents of sampled calcretes from the Cobar-Girilambone region. Three populations are defined (background, lower open values; regionally anomalous, closed symbols; anomalous, higher values with open symbols).

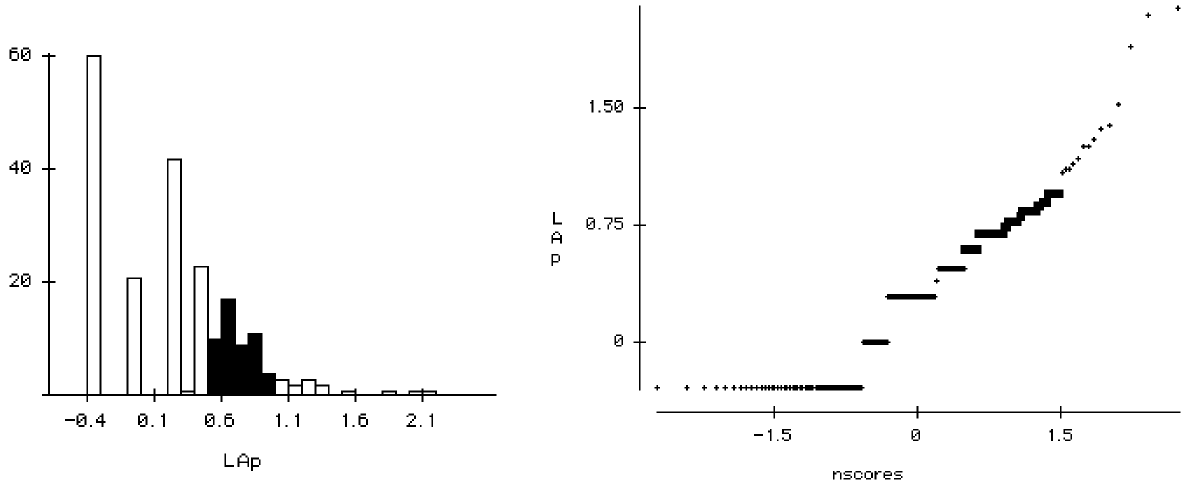

Figure 22. Frequency histogram and cumulative frequency plot of log-transformed Au data for analysed calcrete samples from the Cobar-Girilambone region. There are three populations in the data representing background (<4 ppb), regionally anomalous (5-11 ppb, shown in black) and strongly anomalous samples (>12 ppb).

9 Source of cations

The ultimate source of the cations concentrated in calcrete can be either bedrock or transported materials (such as wind blown dust, aerosols and rainwater). Cations accumulate in groundwater during weathering and chemical leaching. The predominant bedrocks in the Cobar-Girilambone region are turbiditic metasediments with very low Ca and low Mg contents (the main cations in the carbonates). Cobar Supergroup rocks making up the Cobar Basin typically have <1.5% CaO and < 3.2% MgO. Mafic and chloritic lithologies in the Girilambone group can have higher CaO and MgO. The overlying soils, which have a significant aeolian dust component generally contain more Ca and Mg with 5-12% CaO and 2-4% MgO. Strontium isotope determinations on four representative samples from across the region indicate a range of Sr^{87}/Sr^{86} ratios from 0.71195 to 0.71624 (Appendix 2). These values are consistent with a predominantly marine source for the Sr, rather than a bedrock source (the modern marine Sr^{87}/Sr^{86} is 0.70918) This suggests that the Sr and geochemically associated Ca have probably been introduced in dust, aerosols or rainwater from seawater or marine-derived carbonate accumulations (Dart *et al*, 2005). Trace elements have probably also been introduced with these materials accounting for some of their background content in the calcrete. Significantly elevated levels of many trace elements and gold in areas of known bedrock concentrations clearly indicate that the weathered bedrocks are also a source of cations.

10 Potential use of calcrete in exploration in the Cobar-Girilambone region

Calcrete offers a number of advantages as a sampling medium for geochemical exploration:

- Calcrete is an easily identified, consistent sampling medium;
- Calcrete precipitates and is preserved under high pH conditions and may represent a pH contrast to underlying neutral-acid regolith, thus potentially providing a geochemical trap for the precipitation and concentration of mobilised metals;
- Calcrete is known to have associated Au concentrations that in some cases enhance anomalies associated with underlying or nearby Au mineralisation;
- Gold deposits have been discovered using calcrete sampling (particularly in the Yilgarn and Gawler Cratons).

Calcrete is not without its problems or complexities as a geochemical sampling medium:

- Calcrete may occur in different forms and positions in the regolith possibly representing different ages or stages of remobilisation;
- It is important to understand the regolith-landform setting and likely element dispersion pathways for the environment hosting the calcrete as this can affect the suitability of the technique or interpretation of results (e.g. nodules in residual soil over *in situ* weathering profiles, hardpan calcrete related to local groundwater ponding on bedrock, calcrete cementing transported regolith in palaeochannels will all reflect different dispersion pathways and sources of gold);
- Calcretes are commonly impure and may incorporate varying amounts of other regolith materials that contain anomalous concentrations of some elements (e.g As or Pb in hematite);
- The high pH of calcrete concentrations may reduce the mobility of some elements and inhibit the formation of widespread hydromorphic anomalies (e.g. Zn and Cu).
- Calcrete formation may dilute or redistribute existing geochemical anomalies in the regolith for some elements.

To date, calcrete has not been widely used as a sampling medium in western NSW. This has probably been due to a number of factors including concentration on other media such as soil and lag; greater interest in base metal rather than Au exploration, and possibly failure to recognise the presence of calcrete in the regolith.

This reconnaissance study has shown that calcrete over or adjacent to areas of known Au mineralisation in the Cobar-Girilambone region contains anomalous Au concentrations. Close to known Au mineralisation, values are typically above 10 ppb and up to 35 ppb. This suggests that calcrete sampled from *in situ* regolith-landform settings can be used to detect or confirm the local presence of Au mineralisation. The presence of calcrete appears to be an indicator of a geochemical environment conducive to precipitation of chemically mobilised Au. The total carbonate content of the calcrete may not be a significant control on the Au concentration. Thus calcrete offers the advantage of a consistent sampling medium as well as an indicator of a geochemical environment where Au can be concentrated from a large volume of underlying or adjacent *in situ* or locally transported regolith.

The study has also revealed low-level Au anomalies (4-10 ppb Au) around the Cobar Gold Field, particularly down the present and palaeo drainage to the west and southwest. This appears to reflect widespread dispersion of Au by lateral movement along the present and palaeo drainage to the west, most likely by detrital transport of Au followed by reworking into calcrete, or possibly by groundwater movement (Figure 23). Dispersion of this scale suggests that calcrete sampling could be used in a similar way to reconnaissance stream sediment sampling for locating areas of interest for more detailed follow-up, particularly where Au-bearing materials have been transported down drainage including in palaeochannels. In this situation calcrete offers the advantage of Au concentration from a large volume of the transported regolith.

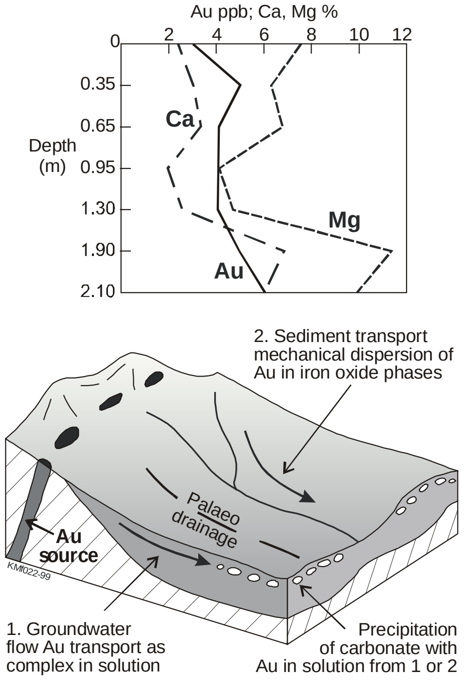

Figure 23. Models for lateral dispersion of Au involving initial detrital transport followed by recycling into calcrete (1) and direct groundwater transport of Au (2). Profile shows pattern of Au and Ca-Mg distribution in displaced anomaly west of the Cobar Gold Field.

In the Cobar-Girilambone region calcrete is ubiquitous in the regolith, although not as abundant or obvious as in the Gawler Craton or parts of the Yilgarn. It can be readily identified in the field from its white, pink or pale-grey colour, bleached and etched appearance when exposed at the surface, morphology, and reaction with hydrochloric acid (two concentrations of acid should be used: a 5% HCl solution which will react with calcite but not dolomite; and concentrated HCl which will react vigorously with calcite and dolomite and weakly with magnesite). Careful observation in addition to acid reaction is required, as thin coatings of carbonate on other materials will react strongly and other non-calcrete materials may also give a reaction (e.g. primary carbonates).

Calcrete is easiest to recognise and sample in exposures such as pits, costeans and natural cuttings. Generally it is not easy to sample in RAB or Air Core drilling due to the pulverisation of the sample (although the calcrete geochemical signature commonly shows up in bulk samples collected near the base of the soil). We have trialed small diameter spiral auger drilling, but this also tends to crush the calcrete unless it is very abundant in the profile. Careful sieving or hand sorting of the sample is required to pick out the carbonate. Hand or large mechanised augering, followed by sieving, is likely to be the best method to sample buried calcrete. It may be possible to develop an improved drilling technique such as some type of scaled down Calwell bucket hole drill. Another approach could be to sample the bulk soil from the calcrete-rich horizon, making sure to analyse for Ca and Mg to monitor the calcrete content.

It is important to recognise the presence of calcrete in bulk soil and drill samples during soil or air core sampling programs as it can give rise to elevated Au values that may contrast with samples without a calcrete component. The regional air core drilling and sampling program conducted by CRC LEME and the NSW Department of Primary Industries in the Girilambone region has clearly identified an association of Ca with Sr and Ba reflecting the development of an evaporitic concentration of these elements largely in calcrete. Many samples from this zone also show elevated Au related to its concentration with the calcrete.

It is important to consider the possible effect of non-carbonate components in the calcrete on the overall geochemical signature. For example, calcrete with a large ferruginous component such as hematite or goethite-rich pisoliths may show anomalous values of elements hosted by the oxides/oxyhydroxides. It may be possible to determine the hematite content of the calcrete using the level of correlation between Fe and Th.

11 Areas of interest

The main purpose of this reconnaissance study was to establish if there is an association of Au with calcrete in the Cobar-Girilambone region, by analysing samples from near and over areas of known Au mineralisation. A second objective was to determine the overall geochemical characteristics of the calcrete and establish background levels for Au and some other trace elements. In addition to achieving these objectives the study has identified a number of sites of potential interest worthy of follow-up investigation. These are described below.

11.1 *In situ* anomalous sites

Miandetta (AGD66 0497298E 6509691N, samples HC12, CC 169, CC170, CC171, CC172)
A suite of samples showing highly anomalous Au contents (up to 140 ppb Au) were collected around the old ballast quarry just north of Miandetta. These included dolomitic coatings on

ferruginised saprock in the quarry and dolomitic nodular calcrete from the soils to the west. The old quarry exposes a highly sheared serpentinite body emplaced into metasediments (probably Girilambone Group). This serpentinite body is probably part of a larger mafic-ultramafic alaskan-type intrusion. There is also considerable silicification and ferruginisation of the small knoll on the western side of the quarry and locally transported ferruginous lag gravels. There are some small shafts and test pits in the immediate vicinity and historic Au workings in the general region.

Hermitage Plains (AGD66 0470144E 6472317N, sample HC11)
A largely unexposed mafic-ultramafic intrusion was discovered by the author during reconnaissance field work and follow up of a small aeromagnetic anomaly on the Hermidale 1:100 000 sheet. Further investigation, including work by Larry Barron and the NSW Geological Survey has confirmed that this is an alaskan-type intrusion. A dolomitic nodular calcrete sample from this site contains anomalous Au (13 ppb Au).

Byrock Road (AGD66 0425953E 6597976N, sample CC166)
Along the Byrock road about midway between the Cobar-Bourke road and Byrock there is a small borrow pit on the north side of the road. This pit exposes strongly sheared and brecciated metasedimentary rocks and granitic pods that appear to be part of a ENE trending shear zone. Calcrete coating the bedrock at this site contains 9 ppb Au. This area also appears to be close to a major NNE trending terrain boundary separating the northern end of the Lachlan Fold Belt from the Bourke terrain, which may be part of the Thompson Fold Belt.

Bald Hills area (AGD66 0404798E 6575394N to 0414102E 6583280N, samples CC182, CC181 and CC180)
Several samples of calcrete collected from exposures and borrow pits along the Byrock road south and southeast of Bald Hills contain elevated levels of Au (14-18 ppb), well above the regional threshold of 4 ppb. These calcrete samples are dolomite-rich and possibly reflect the presence of weathered mafic source rocks in this area. The Bald Hills – Mt Dijou area contains a number of small historic Au mines. The deposits here are vein and lode-style systems associated with mafic volcanic and intercalated metasedimentary rocks. Reconnaissance air core drilling in this area by CRC LEME and the NSW Department of Primary Industries (Chan et al, 2004) has indicated that these rocks extend under shallow cover further to the east and southeast than shown on existing geological maps.

North of CSA turnoff (AGD66 0383980E 6520189N, sample CC86)
A large quarry just north of the turnoff to the CSA mine from the Cobar-Louth road provides a good exposure of an *in situ* weathering profile with overlying soil and ferruginous lag. A nodular calcrete sample from the base of the soil at this site contains 8 ppb Au.

Langtons Prospect (AGD66 0392149E 6503914N, sample CC108)
During exploration of this site south of the Peak by Delta Gold in 1995, a single BLEG sample returned an anomalous result. Subsequent RAB drilling defined an area with >20 ppb Au and an RC hole intersected 0.3 ppm Au over several m. In 1998, as part of the present study, calcrete was sampled from the lower part of the soil along two of the RAB lines by auger drilling. This calcrete had up to 13.5 ppb Au. Drilling in early 2002 by Peak Gold Mines Pty Ltd defined a sub-economic gold deposit at the prospect.

11.2 *In situ* sites with low-level anomalous gold

There are a number of sites where calcrete samples were found to contain low anomalous Au contents (5-6 ppb). Most of these are in areas where there is regional Au mineralisation.

North of Mt Boppy (AGD66 0431628E 6511049N, sample CC139)
A sample of nodular calcrete from the walls of an excavated tank just north of Mount Boppy contains 5 ppb Au. This site lies in an area of known Au mineralisation and is 4 km northwest of the major Mount Boppy gold deposit near Canbelego.

North of Muriel Tank (AGD66 0456180E 6508510N, sample CC142)
Coatings of calcrete on saprock in a shallow borrow pit contain 6 ppb. This site is along strike from the Muriel Tank Gold Field.

Coolabah Road (AGD66 0411995E 6556672N, sample CC69)
A small borrow pit on the south side of the road from the Cobar-Bourke road to Coolabah shows hardpan calcrete on bedrock. A sample of this calcrete contains 5 ppb Au. The site is about 2.5 km northwest of a Cu-Zn(Au) occurrence (Emu Tank prospect).

Hillston Road south of Cobar (AGD66 0402161E 6474465N, sample CC131)
Laminated calcrete coatings on bedrock in a road cutting at this site contain 5 ppb Au. This site is well south of known mineralisation in the Cobar Gold Field.

Ivanhoe Road quarries (AGD66 0368224E 6503997N, samples CC67, CC68)
Two samples of nodular and massive calcrete from two large borrow pits on either side of the Cobar to Ivanhoe road contain 4-7 ppb Au. This site is removed from any area of known Au mineralisation.

11.3 Displaced/transported anomalies

A number of calcrete samples developed in transported regolith show anomalous Au concentrations. Samples collected to the southwest and down catchment (and palaeo-catchment) of the Cobar Gold Field generally contain 4-7 ppb Au. This can probably be explained by recycling of Au into calcrete from Au transported in detrital material during erosional stripping of the gold field.

Palaeochannel Byrock road (AGD66 0416154E 6589624N, samples CC168, CC167)
Calcrete developed in 2-3 m thick palaeochannel sediments exposed in a borrow pit along the Byrock road (near Pine Tree Tank) contains 5 ppb Au and 6 ppm Ag. Calcrete developed in the underlying saprock has no detectable Au. The palaeochannel sediments at this site appear to have been derived from the west (in the Bald Hills area) and the contained Au could represent a displaced anomaly.

Barrier Highway 20 km east Cobar (AGD66 0409496E 6511916N, sample CC138)
Nodular calcrete from the wall of an excavated tank just south of the Barrier Highway approximately 20 km east of Cobar contains 5 ppb Au. This site appears to be in a broad drainage channel and the contained Au could be derived from alluvium transported from the southeast.

Gravels 60 km west of Cobar (AGD66 0329968E 6507390N, sample CC31)
A road cutting in the old Cobar-Wilcannia road, just south of the present Barrier Highway approximately 60 km west of Cobar exposes coarse cobble and boulder conglomerates. These sediments are considered to be Cretaceous in age. Veining and laminated calcrete in these sediments contains 8 ppb Au. This could represent transported Au reworked into the calcrete. There is a small prospecting (?) pit in the gravels at this site.

Note on the map presentation
When referring to the plotted positions of the calcrete sampling sites in the accompanying GIS it is important to note that the road positions are from 1:100 000 scale data and are not accurate at detailed scales. This means that sample sites may appear to be in a different spatial relationship to the roads on the map than their true relationship on the ground (e.g. some sample sites may appear to be on the wrong side of the road).

12. Recommendations

- This study has demonstrated an association of Au with calcrete in the Cobar-Girilambone region. It is recommended that calcrete sampling be considered as a strategy for both regional and detailed geochemical exploration in this region and in conjunction with sampling of other media. In addition to Au exploration calcrete may also be useful in exploration for polymetallic mineralisation where Au is a major component.
- When collecting calcrete samples it is important to take note of their regolith-landform setting, particularly whether the calcrete relates to *in situ* or transported regolith.
- Ideally, freshly exposed calcrete should be sampled to reduce the possibility of surface leaching of Au. However, it should be noted that some exposed calcrete samples in this study still retained anomalous Au concentrations.
- Samples should be sequentially tested with dilute (5%) and concentrated hydrochloric acid to establish the presence of calcite and dolomite.
- In addition to Au and other target elements, the samples should be analysed for major elements such as Ca, Mg and Fe to confirm the relative abundance of carbonate and establish if significant iron oxides are included in the sample.
- Minor and pathfinder elements may be useful in picking up other anomalies (e.g. Cu and Zn) or for defining local host rocks of interest (e.g. high Ni in calcrete over buried ultramafic intrusions).
- The Th/Fe ratios in calcretes may be useful for monitoring the content of pisolithic hematite vs goethite in calcrete samples.
- A minimum list of recommended elements for routine analysis would be Ca, Mg, Fe, K, Au, Ag, Cu, Pb, Zn, Ni, Th. A “total” multi acid digestion has been used in this study for elements other than Au. However, an aqua regia disgest should be suitable in most cases as this will take up the Au and dissolve the carbonates and iron oxide impurities. Partial leach methods (including CN leach for Au) could be used to enhance the suite of carbonate-hosted elements, keeping in mind the variable abundance of dolomite.
- This study has not shown any clear differences in Au concentration between calcite- and dolomite-rich calcrete facies. However more detailed investigation of this aspect is probably warranted.

Acknowledgements

The chemical analyses for this study were conducted by AMDEL Laboratories Ltd in Adelaide. Robert Dart from CRC LEME, Adelaide University carried out the Sr isotope analyses. Kylie Foster assisted with some of the sample preparation. Hugh Glanville, Simeon Hui and Ian Roach helped construct the GIS data base for the study. The ASTER image included in the report is courtesy of the USGS-NASA. Mel Lintern and Keith Scott from CRC LEME reviewed and constructively commented on an early draft of the report. All this assistance is acknowledged with appreciation.

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Appendix 1

Results of internal standard (replicate) and duplicate analyses.

As a test of analytical precision of both the Au (aqua-regia, solvent extraction, graphite furnace) and major and trace element (multi acid digest, ICP-MS, ICP-OES) methods a number of samples were analysed in replicate and duplicate. Check analyses for Au were also carried out by INAA. The results from these samples are summarised in the accompanying table and figures.

Table A1. Results of replicate Au analyses of internal standards (Au$_{1-3}$ method AA9).

Sample No.	Au$_1$ ppb	Au$_2$ ppb	Au$_3$ ppb	Au$_4$ ppb	Mean	SD	Standard error	Au ppb by INAA
A1-3	5	9	3	6	5.75	2.5	1.25	
CC34	7	11	12		10	2.65	1.32	8.2
CC68	4	7	<1		3.8	3.25	1.88	
CC76	7	5	6		6	1	0.58	
CC72	25	22	28	23	24.5	2.65	1.32	22.7
CC76	7	5	6		6	1	0.58	
CC137	124	135	140		133	8.15	4.73	
HC23*	5	4			4.5			

* sample split before pulverisation

Appendix 2

Strontium isotope determinations

Four calcrete samples from the Cobar-Girilambone region were analysed for Sr isotopes by Robert Dart from the University of Adelaide. Analyses of the carbonate fraction were made on solutions derived by digestion with weak acetic acid. The residues were leached overnight in 2M HCl and also analysed. The Sr content of the solutions was determined by spiking.

Table A2. Strontium isotope ratios for carbonate component and residues in calcrete samples from the Cobar-Girilambone region (analyses provided by R. Dart)

Sample Number	**Location Easting**	**GDA 94 Northing**	**Carbonate 87Sr/86Sr**	**Residue 87Sr/86Sr**	**Sr content ID CO3 ug/g**	**Sr content ID Res ug/g**	**Sr content EXT ppm**
A1-2	386158	6505542	0.7127172	0.7993143	345	4	800
CC11	350564	6513135	0.716243	0.7734561	284	20	330
CC139	431742	6511233	0.7119649	0.7350262	502	8	950
CC173	472259	6509446	0.7134788	0.7595555	620	11	950

Appendix 3

Geochemical data and GIS

See accompanying CD