# Exploration for Zn-rich mineralization in the semi-arid Cobar region of NSW, Australia

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**ABSTRACT:** Soils from the vicinity of the Endeavor Mine, in the Cobar region of western NSW, have been sieved into the (a) 2–4 mm, (b) 1–2 mm, (c) 0.5–1 mm, (d) 250–500 μm, (e) 125–250 μm, (f) 63–125 μm and (g) <63 μm fractions, with a magnetic fraction (m) also prepared from the coarser soil fractions. The chemical compositions of these soil fractions show that the coarse (2–4 mm) and magnetic fractions contain the highest As, Fe, and Pb contents whereas the fine (<63 μm) fraction is enriched in Al, Ca, Cu and Zn. Phosphorus and S have bimodal distributions.

Elevated Pb and As contents in the coarse or magnetic fraction of soils in the Endeavor Mine area reflect the underlying weathered Pb–Zn mineralization and may give rise to a larger anomaly than that defined by conventional magnetic lag sampling. Within this area of Pb and As anomalism, the fine fraction of the soils directly above the Northern Pods mineralization (*c.* 400 m below) exhibit enriched Zn, S and soluble salt contents (the latter measured as electrical conductivity). The association of elevated Zn, S and EC (electrical conductivity) suggests sulphide-derivation and such anomalism appears more prospective than Zn-only anomalism in fine soil fractions from transported material to the SW of the mine.

Unfortunately the preparation of the fine soil fraction is time consuming but, because the fine fraction of the Cobar region soils consistently represents 40–50% of the <2 mm soil fraction, the latter can be used as a surrogate for the fine soil fraction. Thus, cost effective exploration for base metal mineralization in the Cobar region could utilize the >2 mm soil fraction for determining Pb and As and the <2 mm soil fraction for S, Zn and EC. Use of the <2 mm soil fraction discriminants should be considered during exploration for Zn-only mineralization in semi-arid regions like that at Cobar.

**KEYWORDS:** *soil fractions, geochemistry, zinc exploration, regolith, electrical conductivity, Cobar region*

In the semi-arid Cobar region of western NSW, polymetallic ore deposits varying from Au- to Cu- to Pb–Zn-rich deposits occur along major shear and thrust fault systems as multiple lenses of steeply plunging pipe-like clusters within Palaeozoic metasediments of the Cobar Basin (Stegman & Stegman 1996). Although such deposits are vertically extensive, they commonly have only small surface footprints, typically with strike lengths of *c.* 250 m (McQueen 2008). The best studied of the Pb–Zn-rich Cobar-style deposits is the Elura mineralization at the Endeavor Mine (Fig. 1). This was discovered in 1974 during exploration which used aeromagnetics and geochemistry (Lorrigan 2005). Since that discovery, other outcropping or shallowly buried Pb–Zn-rich mineralization has been identified at Mrangelli in the late 1970s (Cohen *et al.* 2005), Wagga Tank in 1986 (G. Rabone pers. comm. 1987), Hera in 2000 (Skirka & David 2005) and recently, Cobar Consolidated Resources Limited (2006) has reported Pb–Zn–Ag mineralization defined by consistent Pb anomalism in soils over at strike length of 3 km at Gundaroo, 60 km south of Cobar (Fig. 1).

Weathering of the Pb–Zn-rich mineralization results in elevated Pb contents in the overlying lag. However, Zn in such lag does not generally form as extensive, or (in some cases) any, coherent anomaly. Thus, at Mrangelli (22 km WSW of Cobar, Fig. 1) outcropping partially weathered sulphides occur in silicified sandstone and produce a 7 × 3 km anomaly defined by Pb>50 ppm in magnetic lag. However, the anomaly defined by Zn >50 ppm in magnetic lag is only 2.1 × 1 km, although a larger Zn anomaly can be obtained if the non-magnetic lag is used (Table 1; Alipour *et al.* 1997). At the Endeavor Mine (43 km NNW of Cobar, Fig. 1), where the main lens of the

*Geochemistry: Exploration, Environment, Analysis*, Vol. **11** 2011, pp. 93–101
DOI 10.1144/1467-7873/09-IAGS-008

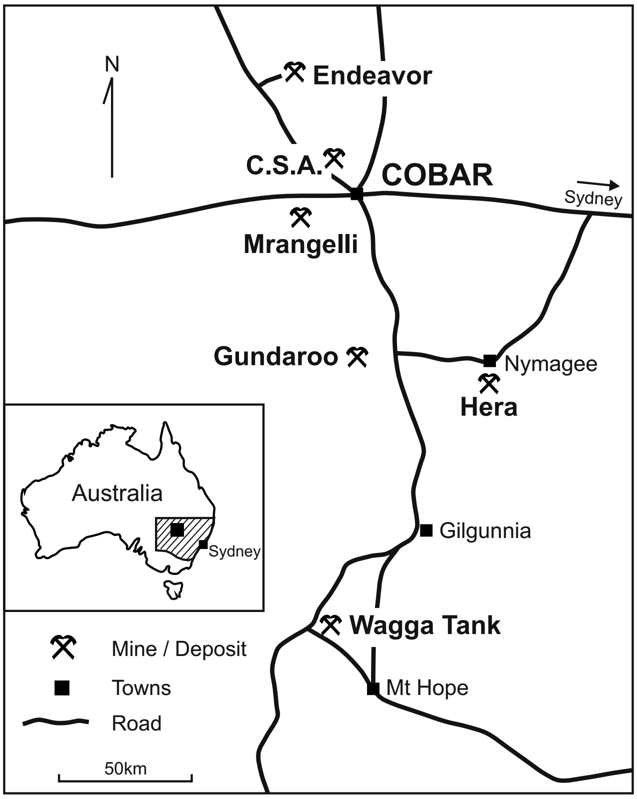

**Fig. 1.** Pb–Zn mineralization in the Cobar region, NSW.

Elura Zn–Pb–Ag orebodies was subcropping but a small patch of gossanous float was present (Schmidt 1980), Pb in magnetic lag (>50 ppm in an area 2.5 × 1.6 km) defines the underlying mineralization well (Lorrigan 2000, 2005; Fig. 2). However, a Zn anomaly is not present in the lag and the soils overlying mineralization contain <50 ppm Zn (Taylor *et al.* 1984; Govett *et al.* 1984). However Zn >400 ppm occurs in soil for >1 km to the SW of the main lens (Lorrigan 2005; Fig. 2). Similarly at Wagga Tank (130 km south of Cobar, Fig. 1) Pb> 30 ppm in 1–2 mm soil material (in an area at least 400 × 400 m) readily defines subcropping mineralization, whereas Zn >50 ppm in lag occurs only at isolated points within that area (Table 1; Chaffee *et al.* 1989; Scott *et al.* 1991). The Hera Au–Cu–Zn–Pb–Ag deposit (80 km SE of Cobar, Fig. 1) occurs under thin colluvial cover on a slope adjacent to a silicified hill (Skirka *et al.* 2004; Skirka & David 2005) and is reflected by Pb>50 ppm for 600 m in the 2–4 mm and magnetic portions of soils from along a traverse across the deposit (Scott 2006). Zinc anomalism (>40 ppm for 550 m) is also present in the coarse soil fraction but not in the magnetic fraction. However, Zn is actually best developed (>50 ppm for 500 m) together with extensive As anomalism (>10 ppm for 300 m) in the fine soil fraction along a traverse over the lateral equivalent to mineralization (Scott 2006). Thus Zn does not form as coherent or extensive anomalies as Pb in lag (Table 1) and so, if Zn-only mineralization is not to be missed during geochemical exploration, the nature of the Zn distribution on soils needs to be better understood.

This orientation study documents the chemistry and mineralogy of transported soils showing Zn anomalism and residual soils above deep Pb–Zn mineralization relative to ‘barren’ soils distal to mineralization in the Endeavor Mine area. This study evaluates the significance of Zn in soil and makes recommendations on how best to use soils in regional exploration in semi-arid regions like western NSW.

## WEATHERING IN THE COBAR REGION

Weathering has affected the Cobar region throughout the Tertiary, with major periods of hematite formation being dated at 60 ± 10 and 15 ± 4 Ma (Smith *et al.* 2009) with the latter period corresponding to a change toward aridity which persists today (precipitation 300 mm and evaporation 2000 mm; Lorrigan 2005). Weathering extends to 60–80 m below residual soils which are generally <2 m thick. However, 15–20 m sequences of colluvial cover commonly occur throughout the region with sequences locally >60 m thick in palaeovalleys (Chan *et al.* 2004). Calcrete is often developed at the interface between residual and transported material. It is commonly present in the soils as small nodules and powdery material and is particularly obvious where rabbits have brought it to the surface during burrowing. Lags in the region tend to be composed of quartz, lithic and ferruginous nodules/fragments. Maghemite (which can be readily separated with a magnet) is common in the lags of the region (Lorrigan 2000, 2005).

Detailed regolith landform mapping in the Endeavor Mine area (Gibson 1998; Gibson & Pain 1999) discriminates between the areas of residual soils developed above rises with almost imperceptible slopes (0.5°) and areas of transported material (see Fig. 2).

## SAMPLES

During the 1999/2000 summer, soil was sampled from two pits into residual soil on Poon Boon Station (2 km north of the Endeavor headframe) and from two pits in transported soil at the Bengaccah Zn anomaly (2.6 km SSW of the headframe, Fig. 2). Approximately 3 kg of soil was collected from 0–15 cm and at 50–60 cm from the pits at the four sites although at one site the depth was 30–40 cm (sample 138467) where the soil was thinner and collection of the deeper sample was not possible). Soils from the Poon Boon sites were expected to represent background samples.

Four surficial soils (0–15 cm depth) were also collected from along a traverse across the projected position of Northern Pods mineralization (Fig. 2). This traverse was originally made to conduct a partial leach study over the Northern Pods (occurring 400 m below surface), with Samples 138538 and 138539 being soils with low Mobile Metal Ion (MMI) response (<0.5 ppm Zn) 250 m east of Samples 138440 and 138441 which are directly over the deep Northern Pods mineralization and show anomalous MMI response (>130 ppm Zn; D. Lawie, pers. comm. 2003). No samples were able to be collected directly above the subcropping main Elura orebody due to mine subsidence in that area.

## METHODS

Soil samples were wet sieved into (a) 2–4 mm, (b) 1–2 mm, (c) 0.5–1 mm, (d) 250–500 µm, (e) 125–250 µm, (f) 63–125 µm and (g) <63 µm fractions. A magnetic fraction (m) was prepared from the 2–4 mm fraction, with additional magnetic material being taken from the >4 mm and 1–2 mm fractions to obtain enough for chemical analysis, if necessary.

For the different soil fractions from the Endeavor Mine area, fractions coarser than 125 µm were crushed to <75 µm with a Mn-steel mill prior to analysis by Analabs (Welshpool, Western Australia). Samples were digested with $HNO_3$/HCl/HF/$HClO_4$ and then analysed by inductively coupled plasma atomic emission spectrometry (ICP-AES) for Al, Ca, Cu, Fe, K, Mn, Na, P, S, Ti, Zn and Zr. Inductively coupled plasma mass spectrometry (ICP-MS) was used for Ag, As, Cd, Pb and

**Table 1.** *Pb and Zn contents in lags and soils associated with Pb-Zn mineralization, Cobar region, NSW*

| Location | Minimum depth of cover(m) | Magnetic Lag (details in text) | | | | Soil <2 mm | |
|---|---|---|---|---|---|---|---|
| | | Pb | | Zn | | Pb | Zn |
| | | Threshold (ppm) | Dimensions (km) | Threshold (ppm) | Dimensions (km) | Threshold (ppm) | |
| Mrangelli | 0 | 50 | 7 × 3 | 50 | 2.1 × 1<br>5 × 1.9 (non mag) | 100[1] | Not reported |
| Endeavor Mine (Elura o/b) | <1 | 50 | 2.5 × 1.6 | Not observed | | 330[2]<br>20[3] | 400[2]<br>50[3] |
| Wagga Tank | <1 | 30* | >0.4 × 0.4 | 50* | Spotty | 30[4] | Not observed |
| Hera | <1 | 50* | 0.6 (along traverse) | 40* | 0.55 (along traverse) | 30[5] | Not reported |

* These values are actually from coarse material from the surficial soils

[1] <180 µm material (Cohen *et al.* 2005)

[2] Mine area threshold (Lorrigan 2005)

[3] Limited data from Taylor *et al.* 1984; Govett *et al.* 1984 and pits 1.7 km SW of mineralization (Taylor & Humphrey 1990)

[4] <63 µm material (Chaffee *et al.* 1989)

[5] Shirka & David (2005)

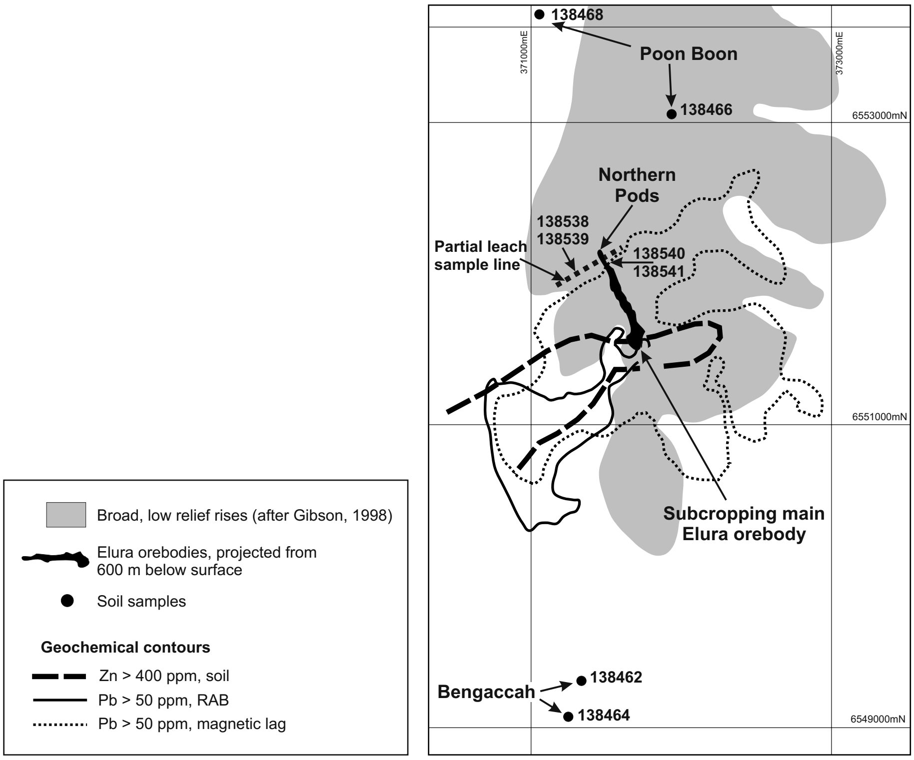

**Fig. 2.** Location of Endeavor Mine area soil samples relative to mineralization.

Sb because of the lower detection limits by this method. The 4-acid dissolution results in an almost complete dissolution of the sample although elements in resistate minerals like rutile, zircon and spinels may not be completely dissolved.

The mineralogy of selected soil fractions was determined by semi-quantitative X-ray diffractometry. Electrical Conductivity and pH were determined using 1:5 soil:water extracts from the fine (<63 µm) fraction of each of the soils.

## RESULTS

Soils developed upon transported material (Bengaccah) show little variation in size distributions between the surface (0–15 cm) and deeper samples (generally 60–70 cm). However, significantly more coarse (and less fine) material is present in the deeper samples from areas of residual soil (Poon Boon) (Table 2; Fig. 3).

Surficial soils developed upon transported material have <1% coarse material (>2 mm) and *c.* 50% finer than 63 µm, whereas the residual soils tend to have several percent coarse material and <40% fine material (Table 2). Quartz within soils in transported material (Bengaccah) also tends to be more rounded than elsewhere (Scott 2009).

Examination of the four coarser fractions (i.e. >250 µm) of the soils indicates that they contain a substantial amount of magnetic material which can be removed with a hand magnet.

**Table 2.** *Soil fraction weight percentages, Endeavor Mine area*

| Location | Sample | Depth (cm) | >2 mm | 1–2 mm | 0.5–1 mm | 250–500 µm | 125–250 µm | 63–125 µm | <63 µm |
|---|---|---|---|---|---|---|---|---|---|
| Bengaccah (transported) | 138462 | 0–15 | 0.9 | 2.1 | 3.3 | 6.2 | 13.7 | 23.7 | 50.1 |
| | 138463* | 50–60 | 0.9 | 1.6 | 2.0 | 4.3 | 11.5 | 25.7 | 54.0 |
| | 138464 | 0–15 | 0.9 | 3.3 | 4.5 | 7.0 | 15.9 | 26.0 | 42.3 |
| | 138465* | 50–60 | 1.3 | 2.7 | 2.9 | 5.5 | 12.0 | 25.7 | 49.9 |
| Poon Boon (residual) | 138466 | 0–15 | 4.3 | 2.3 | 1.5 | 3.7 | 15.5 | 33.6 | 39.1 |
| | 138467* | 30–40 | 53.9 | 4.0 | 2.1 | 2.6 | 6.2 | 10.8 | 20.4 |
| | 138468 | 0–15 | 1.5 | 0.5 | 4.8 | 7.8 | 27.6 | 16.3 | 37.0 |
| | 138469* | 50–60 | 2.6 | 3.7 | 3.2 | 5.2 | 13.4 | 22.1 | 19.9 |
| Northern Pods (residual) | 138538 | 0–15 | 20.9 | 3.2 | 2.6 | 4.0 | 10.8 | 23.5 | 34.9 |
| | 138539 | 0–15 | 16.4 | 3.2 | 2.5 | 4.3 | 10.3 | 26.3 | 37.0 |
| | 138540 | 0–15 | 4.6 | 3.0 | 2.6 | 5.0 | 14.3 | 31.2 | 39.3 |
| | 138541 | 0–15 | 2.0 | 2.4 | 2.7 | 6.3 | 14.4 | 28.6 | 43.6 |

Note: samples marked with * are collected at the same site as the sample above.

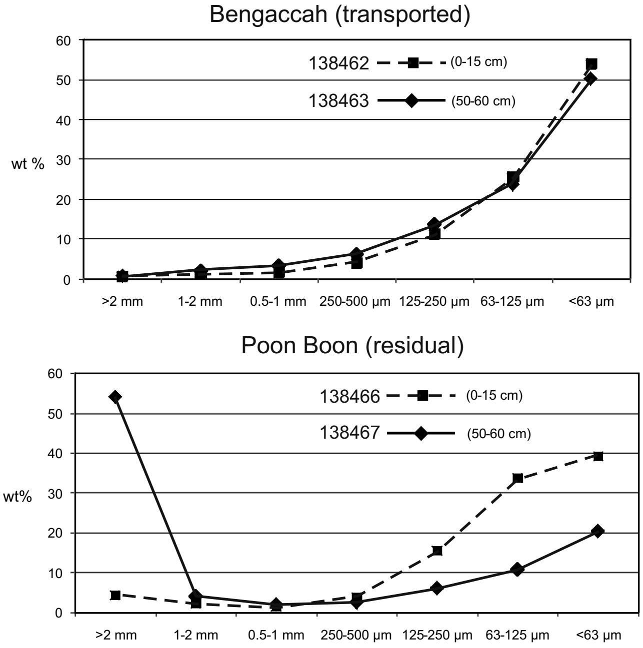

**Fig. 3.** Distribution of different size fractions in soils with depth, Endeavor Mine area.

The proportion of magnetic to non-magnetic material generally decreases with decreasing grain size so that the 250–500 µm material commonly has less than 10% magnetic component (Table 3; Fig. 4). Table 3 indicates that between 20 to 40% of material coarser than 1 mm is magnetic (i.e. particularly Fe rich).

The mineralogy of the coarse and fine soil fractions (Table 4) suggests that coarser fractions are charcterized by three Fe oxides: hematite, goethite and maghemite. (The latter can be readily removed by magnetic separation, leaving a lithic fraction; Table 4). The <63 µm fraction is richer in clay minerals (muscovite/illite and kaolinite) and contains goethite as the only Fe oxide.

Chemical analysis (Table 5) shows that the coarse (>2 mm) and magnetic fractions contain more As, Fe, Pb, Sb and Zr than the fine (<63 µm) fraction which is richer in Al, Ca, Cd, Cu, Na, Ti and Zn. Phosphorus and S are also generally elevated in the fine soil fraction. However, P abundances are also high (sometimes even slightly higher than in the fine soil fraction) in the magnetic fraction, suggesting a bimodal distribution for P. High S (>600 ppm) occurs associated with elevated Ca in the coarse fraction in the Bengaccah area, reflecting the presence of gypsum there (Table 4). Iron contents are lowest in material sized in the range 63–250 µm but slightly more abundant in the fine fraction (Table 5). Table 4 indicates that Fe in that soil fraction is present mainly as goethite rather than hematite and maghemite as occurs predominantly in the coarser soil material.

Table 6 shows that in Samples 138462 and 139464 (Bengaccah) and 138540 and 139541 (Northern Pods area), Zn and Cd are elevated in all soil fractions, with the values in the fine (<63 µm) fraction at least double those in corresponding samples from the Poon Boon area. (High Zn in the coarse fraction of 138462 may be due to its presence on soil nodules composed of calcite and gypsum). Sulphur also tends to more abundant in all four Northern Pods samples than in the Poon Boon samples. However there is no concentration of Pb in Northern Pods or Bengaccah samples.

Table 7 shows that pH is variable but electrical conductivity (EC) is strongly elevated in the fine fraction of all the Northern Pods soils relative to other soil sites.

**Table 3.** *Percentage of magnetic material in surficial soil fractions, Endeavor Mine area*

| Location | Sample | >2 mm A | 1–2 mm B | 0.5–1 mm C | 250–500 µm D | % Magnetic material in the >1 mm fractions (A and B) |
|---|---|---|---|---|---|---|
| Bengaccah (transported) | 138462 | 32.9 | 30.0 | 15.1 | 3.9 | 30.9 |
| | 138464 | 23.7 | 25.7 | 13.9 | 3.7 | 25.3 |
| Poon Boon | 138466 | 20.0 | 22.9 | 15.0 | 8.8 | 20.9 |
| | 138468 | 35.3 | 31.3 | 14.9 | 3.4 | 32.2 |
| Northern Pods | 138538 | 42.8 | 32.0 | 23.8 | 10.1 | 41.3 |
| | 138539 | 39.9 | 31.2 | 24.2 | 9.0 | 38.5 |
| | 138540 | 37.2 | 36.8 | 27.0 | 8.8 | 37.1 |
| | 138541 | 27.8 | 31.8 | 23.8 | 5.8 | 30.0 |

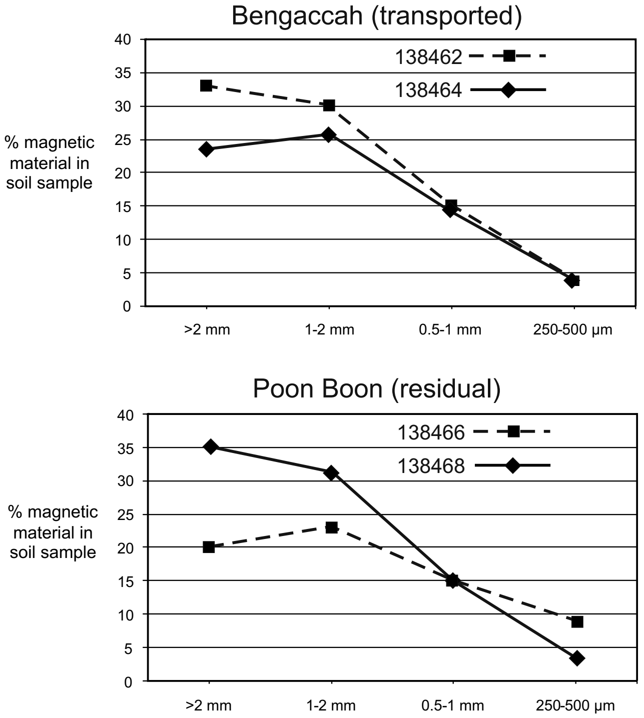

**Fig. 4.** Distribution of magnetic material in different size fractions of soils, Endeavor Mine area.

## DISCUSSION

### Distribution of elements in the soils

Maximum concentrations of As, Fe, Pb, Sb, Zr (and commonly Ag) occur in the coarse and magnetic soil fractions whereas Al, Ca, Cu, Na, Ti, Zn (and probably Cd) are concentrated in the fine (<63 µm) soil fraction (Tables 5 & 6). Phosphorus (and S) have bimodal distributions, tending to be elevated in both the coarse/magnetic and fine soil fractions. Thus these three soil fractions appear to provide the maximum amount of geochemical information about their parental soils. Dunlop *et al.* (1983) also observed that maximum Pb and Zn contents in soil fractions varied with particle size in drainage channels about the Endeavor Mine site.

Iron within the coarse and magnetic fractions is distributed between hematite, maghemite and goethite whereas, in the fine (more clay-rich) soil fraction, maghemite is not present and goethite is the dominant Fe oxide (Table 4; see also Scott & Dickson 1991). Thus the elevated As and Pb in the coarse and magnetic fractions probably occur within hematite and maghemite whereas the elevated Cu and Zn in the fine clay-rich fraction is probably associated with goethite (cf. similar concentration of Cu and Zn into goethite and Pb into hematite observed elsewhere; Scott 1986, 1992, 2008). Phosphorus and S may be associated with both hematite and goethite, with P particularly associated with the latter (Scott 2008). The very high S (>600 ppm) associated with elevated Ca in the coarse fraction in the Bengaccah area reflects the presence of gypsum there (see Results; Tables 4 & 5).

Titanium and Zr abundances determined by dissolution methods should be interpreted cautiously due to the possibility of incomplete digestion (see Methods). However, the consistent concentration of Ti in fine soil fractions and Zr in the Fe-rich coarse and magnetic fractions (Table 5) may suggest that non-resistate Ti is concentrated in the clay and goethite whereas Zr (probably as zircon) is not.

### Features of soils – Endeavor Mine area

This study suggests that Pb is generally ≥70 ppm in the coarse or magnetic portion of the soils from the Bengaccah and Northern Pods areas and only marginally lower (50–70 ppm) in the equivalent fractions of the Poon Boon soils (Table 6). However, because Pb>50 ppm defines the magnetic lag anomaly at the Endeavor Mine and at other deposits in the region (Table 1), it is likely that the Pb in coarse and magnetic soil fractions at Poon Boon may still be anomalous rather than representing 'background'. If this is so, Pb in these soil fractions may actually define a larger anomaly (*c.* 4 km long and of unknown width) than the 2.5 × 1.6 km Pb >50 ppm in magnetic lag anomaly above the Elura orebodies (Fig. 2). Further sampling may be warranted to confirm this.

Although there is drainage Zn anomalism (>400 ppm) to the SW of the Elura orebodies (Fig. 2), Zn in soils above the mineralization is low (40–50 ppm: Taylor *et al.* 1984; Govett *et al.* 1984). This study indicates that Zn >150 ppm can be found in the fine fraction of the soils in the Bengaccah and mineralized Northern Pods samples but samples only 250 m away from the latter location contain <70 ppm (Table 6), i.e. Zn anomalism is quite restricted within the broad Pb anomalous area. Elevated Cd also occurs in the high Zn samples (Table 6).

Sulphur is >300 ppm in the fine fraction of all four Northern Pods soils, *c.* 250 ppm at Bengaccah but only 200 ppm at Poon Boon (Table 6). This may suggest an association of elevated S with mineralization in the fine portion of soils but the presence of gypsum in the coarse fraction of some of these soils (Table 4) indicates such an association needs independent verification (e.g. by use of S isotopes: cf. Taylor *et al.* 1984). The occurrence of As >60 ppm in coarse and As>50 ppm in magnetic soil fractions of all four Northern Pods samples compared to As ≤50 ppm elsewhere (Table 6)

**Table 4.** *Mineralogy of fine and coarse fractions of surficial soils (determined by X-ray Diffraction: 6 = very abundant, 1 = trace. Note these abundances determined from peak heights are only semi-quantitative)*

| | Quartz | Hematite | Maghem | Goethite | Rutile | Musc/illite | Kaolinite | Gypsum |
|---|---|---|---|---|---|---|---|---|
| 138462 (Bengaccah: transported) | | | | | | | | |
| >2 mm | 6 | 3 | 2 | 3 | 3 | 4 | 3 | ? |
| >2 mm (non-magnetic) | 6 | 4 | | 2 | 1 | 4 | 3 | |
| 1–2 mm | 6 | 4 | 4 | | 1 | 2 | 2 | 2* |
| <63 µm | 6 | | | 2 | 4 | 4 | 4 | |
| 138540 (Northern Pods: residual) | | | | | | | | |
| >2 mm | 6 | 5 | 4 | | | 4 | 4 | |
| <63 µm | 6 | | | 2 | 2 | 5 | 5 | |

Note: * some calcite may also be present in this sample.

**Table 5.** *Chemical composition of different fractions of representative surficial soils, Endeavor Mine area*

| Location | Sample | Fraction | Ag ppm | Al % | As ppm | Ca ppm | Cd ppm | Cu ppm | Fe % | K ppm | Mn ppm | Na ppm | P ppm | Pb ppm | S ppm | Sb ppm | Ti ppm | Zn ppm | Zr ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bengaccah transported | 138462 | >2 mm | 0.5 | 4.65 | 35 | 5520 | 0.4 | 27 | 27.00 | 6250 | 320 | 475 | 420 | 72 | 3400 | 8.3 | 4410 | 220 | 180 |
| | | 1–2 mm | 0.3 | 3.45 | 34 | 735 | 0.2 | 27 | 26.60 | 4150 | 250 | 225 | 400 | 66 | 325 | 7.2 | 4050 | 67 | 150 |
| | | 0.5–1 mm | 0.2 | 2.50 | 16 | 1000 | 0.2 | 21 | 10.60 | 3250 | 265 | 170 | 240 | 42 | 470 | 3.1 | 3420 | 61 | 94 |
| | | 250–500 µm | <0.1 | 2.10 | 6 | 875 | 0.1 | 21 | 3.00 | 2900 | 295 | 150 | 140 | 24 | 345 | 1.2 | 2250 | 58 | 58 |
| | | 125–250 µm | <0.1 | 2.60 | 5 | 540 | <0.1 | 24 | 1.69 | 3800 | 110 | 160 | 145 | 17 | 115 | 0.7 | 2020 | 48 | 54 |
| | | 63–125 µm | <0.1 | 3.20 | 4 | 610 | <0.1 | 26 | 1.67 | 6050 | 83 | 395 | 170 | 16 | 87 | 0.7 | 2380 | 56 | 57 |
| | | <63 µm | 0.3 | 9.05 | 11 | 1760 | 0.3 | 47 | 3.95 | 15000 | 255 | 1390 | 515 | 37 | 260 | 1.6 | 6420 | 220 | 150 |
| | | Magnetic | 0.4 | 3.50 | 44 | 560 | 0.2 | 26 | 39.80 | 4900 | 140 | 160 | 565 | 84 | 250 | 10.4 | 4880 | 59 | 200 |
| Poon Boon | 138466 | >2 mm | 0.3 | 7.45 | 50 | 470 | <0.1 | 25 | 23.20 | 17500 | 95 | 305 | 365 | 50 | 100 | 7.7 | 3650 | 42 | 170 |
| | | 1–2 mm | 0.3 | 8.25 | 36 | 840 | <0.1 | 28 | 17.50 | 19600 | 155 | 375 | 365 | 45 | 110 | 4.4 | 3820 | 51 | 160 |
| | | 0.5–1 mm | 0.2 | 7.90 | 27 | 1080 | 0.1 | 32 | 11.00 | 17400 | 450 | 460 | 325 | 49 | 140 | 2.8 | 3970 | 54 | 140 |
| | | 250–500 µm | <0.1 | 4.80 | 12 | 740 | <0.1 | 26 | 5.25 | 9050 | 315 | 280 | 205 | 33 | 110 | 1.5 | 2920 | 36 | 94 |
| | | 125–250 µm | <0.1 | 3.35 | 4 | 525 | <0.1 | 18 | 2.50 | 5450 | 90 | 165 | 140 | 18 | 85 | 0.6 | 1760 | 46 | 57 |
| | | 63–125 µm | <0.1 | 4.35 | 4 | 755 | <0.1 | 21 | 2.05 | 7500 | 100 | 505 | 170 | 17 | 80 | 0.5 | 2750 | 54 | 70 |
| | | <63 µm | 0.2 | 10.20 | 11 | 1890 | <0.1 | 42 | 4.05 | 15000 | 400 | 1160 | 430 | 33 | 200 | 1.3 | 6090 | 79 | 150 |
| | | Magnetic | 0.3 | 6.55 | 43 | 540 | <0.1 | 24 | 30.70 | 15000 | 120 | 235 | 425 | 52 | 100 | 8.2 | 4200 | 36 | 200 |
| Northern Pods | 138540 | >2 mm | 0.2 | 6.75 | 66 | 500 | 0.2 | 20 | 36.80 | 18300 | 75 | 610 | 400 | 68 | 200 | 7.8 | 3680 | 66 | 190 |
| | | 1–2 mm | 0.2 | 7.95 | 59 | 670 | 0.4 | 24 | 31.60 | 22000 | 120 | 715 | 435 | 65 | 215 | 5.1 | 3520 | 120 | 180 |
| | | 0.5–1 mm | 0.2 | 6.45 | 36 | 700 | 0.5 | 22 | 18.40 | 16600 | 200 | 550 | 365 | 52 | 200 | 3.0 | 3540 | 110 | 140 |
| | | 250–500 µm | 0.1 | 5.80 | 14 | 905 | 0.5 | 30 | 6.35 | 11100 | 250 | 610 | 265 | 41 | 150 | 1.3 | 3770 | 220 | 100 |
| | | 125–250 µm | 0.1 | 6.30 | 7 | 945 | 0.4 | 26 | 3.00 | 11100 | 140 | 695 | 255 | 23 | 130 | 0.8 | 3950 | 240 | 100 |
| | | 63–125 µm | 0.4 | 6.70 | 6 | 970 | 0.4 | 26 | 2.75 | 12600 | 115 | 890 | 270 | 20 | 120 | 0.7 | 4360 | 250 | 110 |
| | | <63 µm | 0.2 | 11.70 | 11 | 1610 | 0.8 | 43 | 4.40 | 21000 | 175 | 1340 | 510 | 36 | 385 | 1.2 | 6570 | 460 | 160 |
| | | Magnetic | 0.3 | 5.80 | 58 | 610 | 0.2 | 24 | 44.10 | 14800 | 105 | 495 | 485 | 81 | 170 | 7.5 | 3960 | 87 | 210 |
| Detection Limit | | | 0.1 | 0.01 | 1 | 50 | 0.1 | 5 | 0.01 | 500 | 10 | 50 | 30 | 1 | 10 | 0.1 | 10 | 5 | 5 |

**Table 6.** *Anomalism within the coarse, fine and magnetic fractions of surficial soils, Endeavor Mine area*

| Location | Sample | Fraction | Ca ppm | Cd ppm | Cu ppm | Fe % | P ppm | Pb ppm | S ppm | Zn ppm |
|---|---|---|---|---|---|---|---|---|---|---|
| Bengaccah (transported) | 138462 | >2 mm | 5520 | 0.4 | 27 | 27.00 | 420 | 72 | 3400 | 220 |
| | | <63 µm | 1760 | 0.3 | 47 | 3.95 | 515 | 37 | 260 | 220 |
| | | Magnetic | 560 | 0.2 | 26 | 39.80 | 565 | 84 | 250 | 59 |
| | 138464 | >2 mm | 1270 | 0.1 | 21 | 29.60 | 405 | 71 | 685 | 43 |
| | | <63 µm | 1330 | 0.2 | 41 | 4.10 | 470 | 39 | 255 | 150 |
| | | Magnetic | 410 | <0.1 | 27 | 41.70 | 545 | 91 | 195 | 39 |
| Poon Boon | 138466 | >2 mm | 470 | <0.1 | 25 | 23.20 | 365 | 50 | 100 | 42 |
| | | <63 µm | 1890 | <0.1 | 42 | 4.05 | 430 | 33 | 200 | 79 |
| | | Magnetic | 540 | <0.1 | 24 | 30.70 | 425 | 52 | 100 | 36 |
| | 138468 | >2 mm | 735 | <0.1 | 18 | 36.20 | 455 | 61 | 140 | 23 |
| | | <63 µm | 2140 | <0.1 | 48 | 4.40 | 460 | 29 | 225 | 73 |
| | | Magnetic | 640 | 0.1 | 22 | 43.70 | 605 | 72 | 105 | 36 |
| Northern Pods (barren) | 138538 | >2 mm | 465 | <0.1 | 17 | 46.00 | 370 | 84 | 305 | 13 |
| | | <63 µm | 2660 | <0.1 | 52 | 4.10 | 445 | 40 | 415 | 72 |
| | | Magnetic | 445 | <0.1 | 19 | 51.30 | 405 | 97 | 290 | 12 |
| | 138539 | >2 mm | 480 | <0.1 | 16 | 38.90 | 340 | 86 | 275 | 12 |
| | | <63 µm | 1790 | <0.1 | 44 | 3.85 | 420 | 41 | 405 | 59 |
| | | Magnetic | 405 | <0.1 | 19 | 51.80 | 420 | 89 | 250 | 13 |
| Northern Pods (mineralised) | 138540 | >2 mm | 500 | 0.2 | 20 | 36.80 | 400 | 68 | 200 | 66 |
| | | <63 µm | 1610 | 0.8 | 43 | 4.40 | 510 | 36 | 385 | 460 |
| | | Magnetic | 610 | 0.2 | 24 | 44.10 | 485 | 81 | 170 | 87 |
| | 138541 | >2 mm | 1370 | 0.1 | 25 | 35.20 | 430 | 62 | 230 | 69 |
| | | <63 µm | 2970 | 0.3 | 48 | 4.40 | 545 | 36 | 330 | 200 |
| | | Magnetic | 850 | <0.1 | 21 | 38.80 | 515 | 68 | 150 | 77 |

**Table 7.** *pH and EC for fine soil fractions, Endeavor Mine area*

| Location | Sample | pH | EC (dS/m) |
|---|---|---|---|
| Bengaccah (transported) | 138462 | 5.8 | 0.15 |
| | 138464 | 5.1 | 0.16 |
| Poon Boon | 138466 | 5.4 | 0.09 |
| | 138468 | 6.1 | 0.10 |
| Northern Pods (barren) | 138538 | 5.1 | 0.68 |
| | 138539 | 5.0 | 0.88 |
| Northern Pods (mineralized) | 138540 | 4.9 | 0.71 |
| | 138541 | 6.6 | 0.83 |

may also suggest that As reflects a sulphide association in the Northern Pods soils.

Most of the fine soil fraction pH values in the Endeavor Mine area are <6 and, although such development of acidity could reflect the weathering of sulphides, the presence of calcrete in soils of the region (Chan *et al.* 2004) may affect the usefulness of pH as an indicator of weathering sulphides. However, electrical conductivity in soils is much higher above the Northern Pods than at other locations. Such increased conductance and evidence of increased acidity has been observed during earlier work in the drainage anomaly area (Govett *et al.* 1984). Thus systematic determination of electrical conductivity (EC) and soil pH (relative to calcrete development) should be done to better evaluate their potential as additional exploration tools.

The fine soil fraction in the Northern Pods area appears to be characterized by high electrical conductivity and S in a zone at least 250 m wide with high Zn (and Cd) within a smaller subzone (see Fig. 5) which is directly above the Northern Pods mineralization *c.* 400 m below. Arsenic in the coarse and magnetic fractions of the soils is also elevated here (as seen above). These features may suggest that the As, Cd, Zn and S are derived from sulphide mineralization and that the Zn and Cd are not as laterally dispersed as As and S. The presence of Zn anomalism directly above the deep Northern Pods mineralization and the absence of strong Zn anomalism directly above the Elura orebody could suggest that the Zn above the former is recently derived (i.e. subsequent to the time that Zn was leached from the Elura orebody), possibly by leakage up vertical shears. It is possible that such Zn anomalism could represent post-mining contamination (Lorrigan 2005) but restriction of the Zn anomalism to within a more extensive As, S and EC anomaly (and the occurrence of the As anomalism within the coarse and magnetic soil fractions rather than in the fine soil component) may imply that the anomalism is bedrock-related *via* vertical shears. A much more extensive study, specifically characterizing vertical profiles above deep mineralization would be needed to completely understand the significance of the Zn anomalism.

Despite some questions about the genetic significance of the Northern Pods Zn anomaly, the fact that the Zn anomalism in soil at Bengaccah is not associated with high S or high EC in its fine fraction, nor anomalous As in its coarse or magnetic fraction, suggests that it not sulphide-derived. Possibly the anomaly could be derived from the weathering of a non-suphide Zn-rich interval (where the Zn is present in siderite and, to a lesser extent, chlorite and muscovite; Scott 2009) or it could simply be a southerly extension of the mapped transported Zn soil anomaly (see Fig. 2). Whatever the mechanism for formation of the Zn anomalies in the Endeavor Mine area, the association of Zn with elevated S, EC and As above the Northern Pods mineralization and the absence of these probable sulphide-associated features at Bengaccah allow ranking of Zn anomalies in soils.

## Implications for soil sampling

As indicated above, Pb and As are preferentially concentrated in coarse and magnetic soil fractions and this study suggests

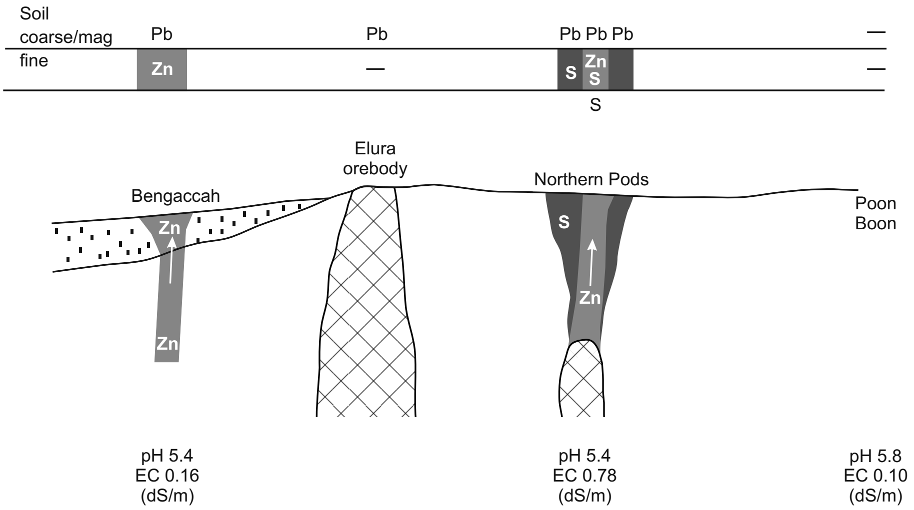

**Fig. 5.** Features of soil fractions relative to underlying mineralization, Endeavor Mine area.

**Table 8.** *Zn contents (ppm) in different soil fractions, Endeavour Mine area*

| Location | Sample | >2 mm (% in whole soil) | Zn (ppm) | | | <63 μm (% of <2 mm material) |
|---|---|---|---|---|---|---|
| | | | Whole soil | <2 mm fraction (calculated) | <63 μm fraction | |
| Bengaccah (transported) | 138462 | 0.9 | 140* | 140 | 220 | 50.6 |
| | 138464 | 0.9 | 86* | 86 | 150 | 42.7 |
| Poon Boon | 138466 | 4.3 | 61* | 62 | 79 | 40.9 |
| | 138468 | 1.5 | 50* | 50 | 73 | 37.6 |
| Northern Pods (barren) | 138538 | 20.9 | 35 | 50 | 72 | 44.1 |
| | 138539 | 16.4 | 28 | 41 | 59 | 44.3 |
| Northern Pods (min) | 138540 | 4.6 | 280 | 330 | 460 | 41.2 |
| | 138541 | 2.0 | 150 | 160 | 200 | 44.5 |

Note: whole soil Zn values marked with * are calculated rather than being directly determined.

that Pb >50 ppm in the coarse or magnetic fraction of soils may define a larger anomaly (*c.* 4 km long and of unknown width) than the previously identified 2.5 × 1.6 km Pb >50 ppm in magnetic lag anomaly above the Elura orebodies. Arsenic >50 ppm in the coarse soil fraction might also be expected to confirm such anomalism.

In the Endeavor Mine area, Zn (and Cd) anomalism (best seen in the fine soil fraction) occurring within a larger elevated S and high electrical conductivity halo, appears to identify sulphide-related mineralization within a broad Pb anomaly in coarse and magnetic soil fractions (Fig. 5). However, the time needed to prepare a fine soil fraction makes its use during routine regional exploration impractical. Fortunately, the fine fraction of the soil generally makes up 40–50 % of the <2 mm fraction of the soil in the Endeavour Mine area (Table 8; as well as elsewhere in the Cobar region; Scott 2006), so use of the <2 mm soil fraction to determine Zn concentrations during the initial exploration stages appears feasible. Thus in the Endeavour Mine area, mineralized Northern Pods <2 mm soils contain ≥150 ppm Zn *v.* ≤ 65 ppm Zn in the equivalent soil from the barren Northern Pods and Poon Boon samples (Table 8). Such results suggest that the mine area threshold (400 ppm Zn) reported by Lorrigan (see Table 1) may be unduly conservative and values of *c.* 50 ppm Zn (as estimated from small sample sets; Table 1) may be obtained when sufficient regional samples are analysed.

Because whole soil Zn contents are similar to <2 mm fraction values (Table 8), whole soils could also be used as surrogates for fine soil fractions provided that the >2 mm component of the soil is not greater than *c.* 20%. However, as indicated by Scott (2006), variable amounts of aeolian material may be present in the fine fraction of soils from the Cobar region and so examination of the nature of soils should be undertaken in local areas prior to relying on the whole soil or its <2 mm fraction as a surrogate for the fine (<63 μm) fraction.

## CONCLUSIONS AND IMPLICATIONS FOR EXPLORATION

This study suggests that the coarse (>2 mm) and magnetic fractions of surficial soils, originally chosen to represent background, may still be within the anomalous Pb area. Thus Pb and As anomalism in the coarse or magnetic fraction of soils may produce a even larger anomaly than the known lag anomaly in the Endeavor Mine area. Where the fine (<63 μm) soil fraction is enriched in Zn and S and EC is high, derivation from sulphides appears likely and such anomalies should be considered more prospective than Zn anomalies without those associations. Preparation of this fine soil fraction is time-consuming but this study suggests that because the fine fraction forms a relatively constant 40–50% of the total soil in Cobar region, the <2 mm portion of the soil may be used to obtain similar results provided the coarse component of the soil is <20%. Thus cost effective exploration for base metal mineralization in the Cobar region could utilize the >2 mm soil fraction for determining Pb and As and the <2 mm soil fraction for S, Zn and EC. The latter discriminants (in the <2 mm soil fraction) may be particularly useful to improve the chances of detecting Zn-only mineralization.

Soil pH, determined on the <2mm soil fraction regionally, may have potential as an indicator of weathering sulphides but the influence of calcrete development in such semi-arid regions needs further investigation.

This study was conducted as a collaborative project between Pasminco Exploration (a forerunner of Minerals and Metals Group Ltd) and CRC LEME (Co-operative Research Centre for Landscape Environments and Mineral Exploration). The encouragement of Prof. G. Govett (the Visitor to the CRC) and I. Mackenzie (formerly Regional Exploration Manager, CBH Resources) encouraged publication of the study. Comments by M. Leybourne, A. Rate and D. Cohen on earlier drafts have significantly improved this paper.

Samples were sieved and crushed (where necessary) by J. Davis (Mineral Investigators Pty. Ltd.). Chemical analyses were done by Analabs, Perth and X-ray diffractometry was done in the North Ryde laboratories of CSIRO. Conductivity and pH of soils were determined by R. Greene (Fenner School of Environment and Society, ANU).

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Received 18 September 2009; revised typescript accepted 3 February 2010.