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Finding Blind Orebodies with REGOLEACH

As the search for ore focuses more and more on blind or concealed deposits, so the exploration methods currently used for locating outcropping mineralisation are being replaced by methods developed to pinpoint hidden targets. This is clearly a more difficult geochemical exploration problem than seeking outcropping ore, and the search procedures for hidden ore deposits should be able to identify the alteration and trace mineralisation peripheral to a deposit to maximise success. A further prerequisite is the ability to detect subtle changes in elemental abundance, as the surface signature of ore at depth is likely to be weak. These subtle anomalies are largely masked by the variations in background levels found with 'total' analyses.

Selective extractions are proved finders of deep or covered deposits, as shown by case studies in Russia, China, South America and elsewhere. Some of these studies and a comprehensive bibliography on partial extractions are available from Hall and Bonham-Carter (1998).

REGOLEACH is a proprietary partial-extraction technique, developed by ALS and Rutherford Mineral Resource Consultants, to find hidden orebodies and their halos. It was designed to measure levels of mobile ions to a low limit of detection. As with all geochemical survey methods, REGOLEACH will detect many examples of sub-economic mineralisation, but all of the 'scientific successes and economic failures' will increase understanding of the environment being prospected.

The REGOLEACH technique has now been extensively tested in the Lachlan Fold Belt of NSW, NW Qld, NT and WA, by the collection of tens of thousands of exploration samples and interpretation of the results. The technique is described herein, followed by examples that illustrate results that can be achieved.

SUITABLE EXPLORATION ENVIRONMENTS

REGOLEACH can be used to identify and map outcropping and near surface mineralisation and ore-related alteration in areas with thin residual soil, but comes into its own when applied to the weaker anomalies arising from ore features obscured by thick cover.

Ore and pathfinder elements can occur in soil and drainage samples as:

- **Minor constituents of organic material;**
- **Major constituents of secondary ore minerals, such as lead in cerussite, zinc in smithsonite, etc;**
- **Elements 'captured' by secondary carbonates and sulphates;**
- **High background values in the weathered products of particular rock types, such as nickel in ultramafics; and**
- **Ions adsorbed on the surfaces of clay minerals, or 'collected' by amorphous iron oxide and manganese oxide coatings.**

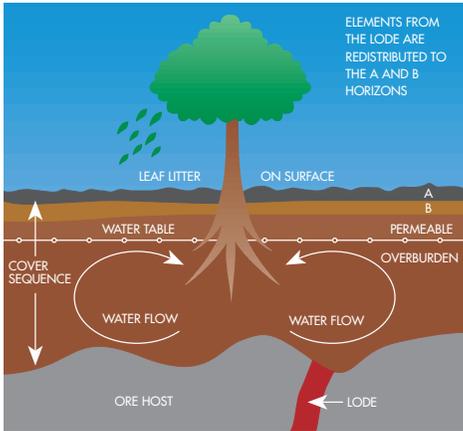
Practically all ore and pathfinder elements are dissolved with the standard geochemical analyses, that apply a strong solvent such as aqua regia to a finely ground sample to determine a 'total' element value. Thus a total element anomaly, that appears to be an exploration target, may be due to:

- **A rock type with a high elemental abundance, such as copper in basalt;**
- **A difference in the material sampled (e.g. between residual and transported soil);**
- **Areas of hydrothermal alteration; or**
- **Ore mineralisation.**

Discriminating between an ore-related and a spurious total element anomaly is frequently difficult, and often requires intensive, expensive and unrewarding field work.

The REGOLEACH technique is particularly suitable for detection of ore and pathfinder elements that have migrated to surface sites by a combination of ground water flow, capillary action and transpiration of volatile compounds.

Figure 1



Schematic movement of elements from concealed mineralisation to near surface sites. Elements in the basement are dissolved by oxidising ground water, then moved by convective circulation to the near surface zone. Here they may be concentrated by collector materials such as vegetation, and organic matter in the A soil horizon, or by carbonates, clay minerals and amorphous iron and manganese oxides in the A and B horizons.

Surface organic material, carbonates, sulphates and coatings rich in iron and manganese oxides are the most common efficient collectors of these transported elements. The organic material is concentrated in the uppermost, A soil horizon, whereas the carbonates and iron and manganese oxide coatings occur in both A and B horizons. A horizon material is very easy to sample, and the adsorbed ions are readily detectable with weak extractions. However, the distribution of organic material may be very irregular, and digestion of some organic material is incomplete, forming a 'crud' in the digestion stage of an analysis. There are also numerous problems with re-adsorption of trace elements by organic matter. The A horizon is relatively unstable, as it is subject to leaching by rain and to sheetwash erosion. Thus REGOLEACH sampling is focused on the more stable B horizon materials. This is discussed in more detail under 'Optimum Survey Procedures', below.

THE REGOLEACH SYSTEM

REGOLEACH is a selective leach technology coupled with ICP-AES and ICP-MS determination of a large range of elements. It applies the simultaneous multi-element analysis of regolith, soil and drainage samples to the search for a wide variety of mineralisation styles, including gold, base metals, the nickel-PGE association and uranium.

ICP-MS determinations allow the precise measurement of traces of ore and pathfinder elements in the REGOLEACH solute, to detection limits that are several orders of magnitude lower than those available with AAS or ICP methods. This is illustrated in the table below, which is an abbreviated version of the tables of detection limits in the ALS Schedule of Services and Charges.

Table 1 LOWER LIMITS OF DETECTION ACHIEVABLE WITH AAS, ICP AND REGOLEACH ANALYSES, IN PPM

Element	Technique*/Code			
	AAS/G103	ICP-AES/IC587	ICP-MS/MS587	REGOLEACH/PEO10
Cu, Pb, Zn, Ni	5	5	1	0.01-0.05
As, Bi, Sb	5-20	5	0.2	0.01-0.1
Pt	NA	NA	NA	0.001
Au	NA	NA	NA	0.001
Ag	1	1	0.2	0.01

*In order to provide a meaningful basis for comparison, the LOD for the first three methods is with the same solution procedure - digestion in hydrofluoric, nitric and perchloric acids, then leaching by hydrochloric acid. Lower detection limits are available for some elements by a different digestion procedure or minor equipment changes. NA indicates not available with this code.

The digestion procedure uses a 'moderate' sample attack, using a dilute acid and an oxidant at controlled temperature that aids in dissolving gold and other pathfinders. The procedure dissolves more of an element than most of the common partial-extraction solvents that lack an oxidant. It will dissolve metal ions adsorbed onto clay particles, those attached to organic materials, and those combined with amorphous iron and manganese oxides. The moderate attack has the following advantages when compared with weaker extractants:

- **As some of the weak extractants are unstable with time, major batch background shifts can occur;**
- **Re-adsorption of ions, from solution back onto soil or organic material, is more likely with weaker extractants. The problem can be partly managed by separating materials with differing adsorption characteristics, i.e. by recognising and not compositing organic poor with organic rich materials, clay poor and clay rich soils, etc;**
- **Some weak extractants are sensitive to soil pH, and will not dissolve all of the available, weakly bound elements in alkaline soils. Variations in solution buffering are described in Smee (1999);**
- **Some gold and base metal pathfinders, such as tungsten, uranium and rare earths, are not dissolved by the weaker extractants; and**
- **Gold is partially extracted by REGOLEACH (Table 2), but not by many of the weaker solvents.**

Table 2 ELEMENTS AVAILABLE BY REGOLEACH AND THE LOWER LIMIT OF REPORTING (LOR)

Element LOR(ppb)	Element LOR(ppb)	Element LOR(ppb)	Element LOR(ppb)
Ag 5	As 5	Au 1	Ba 1000
Bi 5	Cd 5	Ce 100	Co 10
Cr 10	Cu 10	Fe 5000	Hg 5
K 1000	La 1000	Mg 1000	Mn 1000
Mo 10	Na 1000	Nb 10	Ni 10
Pb 10	Pt* 1	S 1000	Sb 5
Se 5	Sn 5	Sr 1000	Te 5
U 10	W 5	Zn 50	

* Note that Pd is not available due to isotopic interferences during ICP-MS determination.

The sample is not pulverised prior to leaching by the REGOLEACH solvent, so that only grain surfaces are exposed to the leaching process. This maximises extraction of adsorbed or coating elements, whereas dissolution of pulverised samples (as in the total analysis procedures) allows digestion of all of the sample components.

OPTIMUM SURVEY PROCEDURES

As in all geochemical programs, an orientation survey over known mineralisation is recommended as a starting point. The survey should determine the response to REGOLEACH analyses of mineralisation at depth, in samples of a variety of surface materials of different origin, including residual and transported soil. A comprehensive suite of the elements available by REGOLEACH should be determined on the orientation samples, to identify co-anomalous elements and alteration signatures.

A REGOLEACH analysis requires digestion of 50 grams of the minus 2 mm fraction. The field sample is generally about 300 grams (to allow for several analyses), sieved from stream sediment or from the uppermost metre of the soil profile using a steel or nylon screen, and stored in a Kraft paper bag. The sieving is intended to remove larger rock fragments, quartz grains and ferruginous nodules that may carry higher values. The sampler should not wear any gold jewellery.

The preferred material for REGOLEACH soil samples is a near-surface layer of fixed substrate composition, that has had time to accumulate sufficient mobile ions and reach equilibrium with the total soil profile. The best indication of this material is the presence of iron oxide spotting or ferruginous nodules.

The soil profile should be examined at each site before the sample is taken, to make sure that the optimum material is collected. In general, soil samples are taken after removing the upper 10-20 centimetres of the profile and placing it well clear of the hole. This discarded material is typically a loose soil, dominated by biological activity, rich in organic material and subject to sheetwash erosion, winnowing and flushing. Values in this layer are seasonal, being subject to movement of salts by rainwater, and re-deposition of the salts by evaporation of groundwater during dry periods. Seasonal variation in soil composition continues below the surface layer, and B horizon samples are more repeatable if they are collected after a long dry period, when the chemical composition of the soil has stabilised.

The B horizon is generally a well-bound soil, weakly cemented by silt, clay, incipient calcrete or ferricrete. This is the zone of superficial iron enrichment due to evaporation of ground water, and the profile below this often becomes progressively depleted in iron and other ore elements. In deeply weathered terrains the mottled and pallid saprolite zones may be considerably depleted in ore and pathfinder elements, and are of little value for any geochemical survey procedure. In areas of thin soils, where the B horizon is absent, the top layer of the C horizon may be sampled.

The samples should be air dried if they are damp, at a contamination-free site.

Regional soil sample traverses should be between 200 and 800 metres apart, ideally 400 - 500 metres, but traverses up

to a kilometre apart may be useful as a 'first pass' scan of an unknown area. Regional survey sample spacing on the lines is commonly 50 metres. Results for individual traverses may not be comparable with those from the adjacent traverses in regional surveys, due to the broad line spacing. Significant anomalies may only report on a single line. A survey may be closed up to 100 by 25 metre sample spacing around co-anomalous sites; closer sample spacing than this is not expected to provide further useful information. Coherent anomalies may be checked by a second analytical procedure, such as ZARG analyses for gold anomalies and multiple element checks by Method IC588 for base metal targets. Confirmed anomalies should be appraised by drilling.

REGOLEACH soil samples are best collected along traverses across the regional formation, structural or mineralisation trend. Changes in elemental levels can then be related to changes in these features.

Proper documentation of each sample site is an essential input to effective anomaly assessment in all geochemical surveys, but the poor site data problem is more significant with partial extraction programs. These surveys can't be carried out by someone hired at the last minute from the local pub - accurate documentation of site geology and geomorphology is essential. For stream sediment samples the stream size, material sampled, organic content, plus presence and quantity of quartz vein and ferruginous materials should be recorded.

Attributes recorded for soil samples should include ground slope, presence and rock type of outcrop, geomorphic domain (residual, transported or depositional), sample depth and soil colour, plus estimates of organic, ironstone, calcrete and quartz fragment content. These data are most effectively collected digitally at each site and entered into a PC. For soil samples the data can be used to produce a geomorphic or geological sketch of the sample traverse on which to plot the geochemical analyses. With a little off-line inspection of outcrops a geological base map can be produced for the area sampled, and the area has been systematically prospected for signs of outcropping mineralisation or alteration.

It is advantageous to maximise the number of samples along the line, as this is most likely to detect subtle anomalies. This provides a similar benefit to the better resolution obtained by taking closely spaced magnetometer readings along magnetic survey traverses. Collecting a large number of samples need not cause a high assay cost. The high sensitivity available with ICP-MS allows detection of an anomaly in a composite of two or more adjacent samples, even if the anomaly arises from a high value in only one of the combined samples. The compositing procedure should be:

- ***Design the compositing instructions when all the samples have been taken, and all the site data are available. The compositing can then be based on sample type, which simplifies calculation of background values and comparison of anomaly intensity. It also provides a check to make sure that all the site data have been recorded;***

- Do not composite samples from different soil types or from different geomorphic or geological domains (combine apples with apples);
- Combine the samples at the laboratory, where accurate weighing is easier and cheaper, and individual samples are available for follow up analysis of the members of anomalous composite samples; and
- Plot the analysis on the plan and profile at the mid point of the composited sample sites.

PRESENTATION OF REGOLEACH DATA

The analyses should be presented in plan and profile formats. With the plan view, a plot of REGOLEACH values should be overlaid on a magnetic image base if the basement geology is unknown. The REGOLEACH data will frequently reflect the geology of the underlying formations, by a pattern of values that is specific for each rock type or formation. A plan view illustrating this correspondence of values with rock type is shown in Figure 2.

If there is some outcrop information, the plan presentation should show the REGOLEACH values on an outcrop map and a TMI image, as depicted on Figure 3. Samples collected from different programs, such as an initial reconnaissance and an infill program, are best shown by different symbols. This will highlight any change in values due to an area-batch shift in the two sets of analyses.

The values should also be shown as line profiles of single elements, stacked above each other, or as 'metal factor' profiles. Metal factors can be derived intuitively from knowledge of the metallogenic associations in the area being surveyed, or derived from correlation matrices or factor analyses. Although the elemental association of a metal factor will change from region to region, and for different types of mineralisation, there are many common associations.

Figure 2

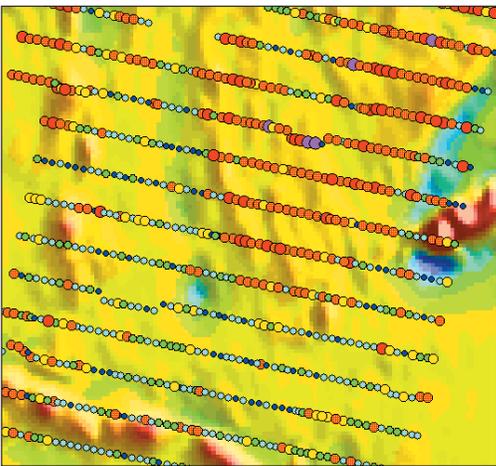


Figure 2. The combined Ba, Co, W and Bi 'metal factor' values, plotted on the airmagnetic TMI image, show high values associated with the Coomberg Formation in the top right hand part of the figure, and low values overlying Adaminaby Group elsewhere. Sample spacing is 500 x 100 metres. Data supplied by Hargraves Resources NL.

Figure 3a

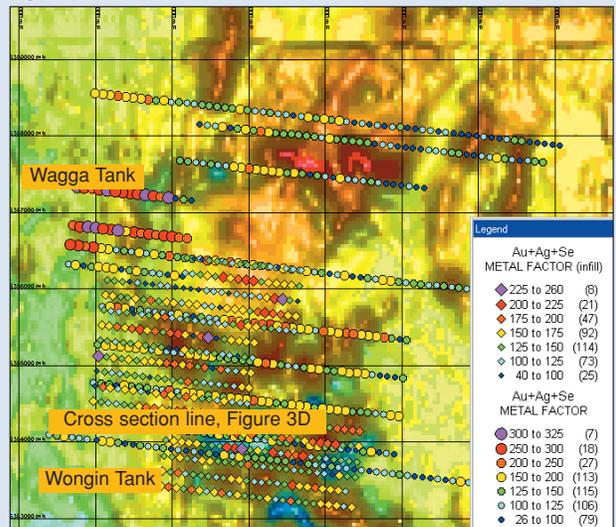


Figure 3b

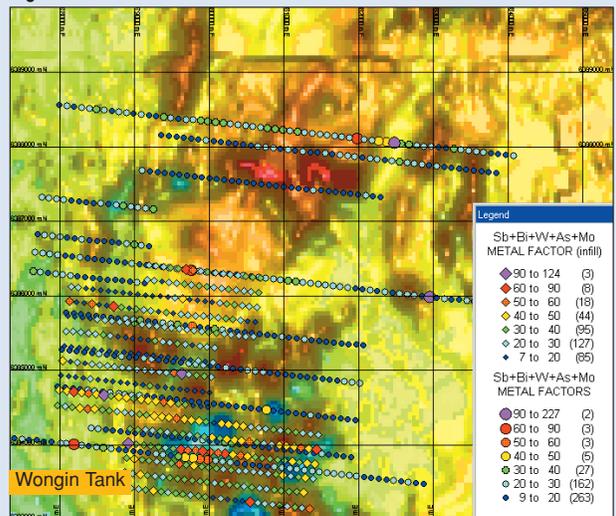


Figure 3c

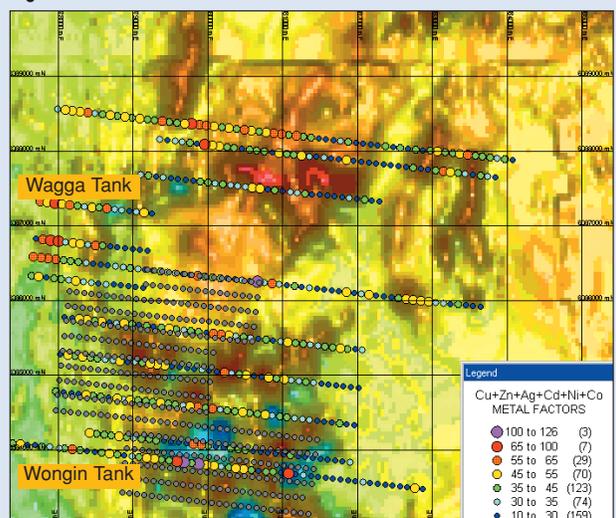


Figure 3a

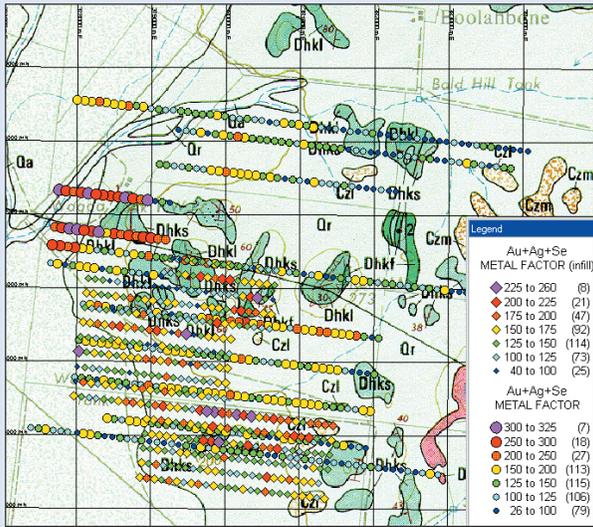


Figure 3b

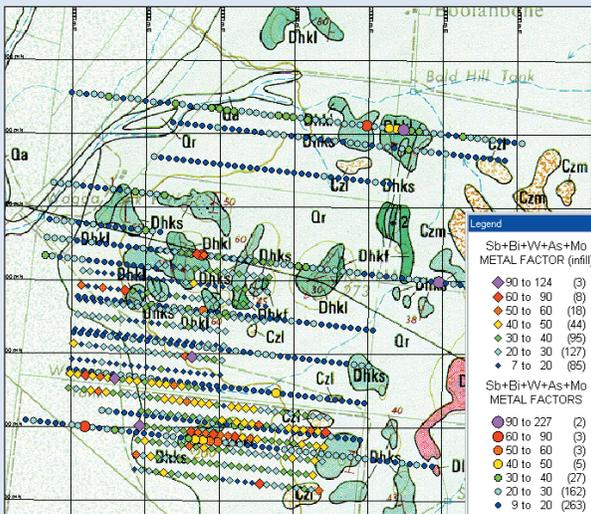


Figure 3c

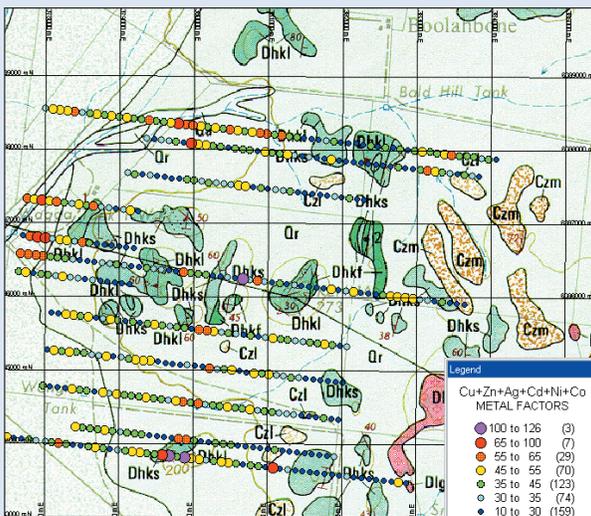


Figure 3d

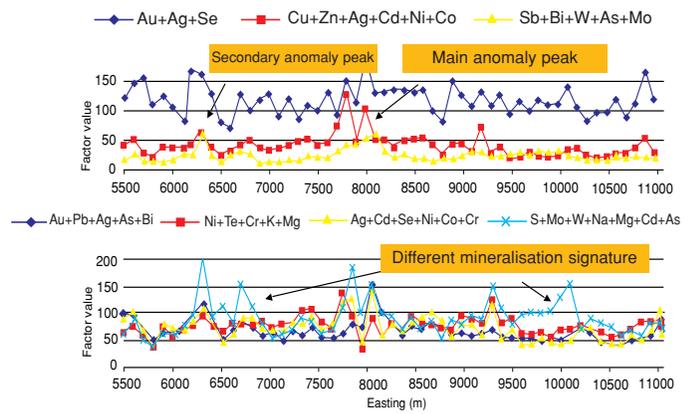


Figure 3. Three plan views (a, b, c) of REGOLEACH metal factor values at the Wagga Tank-Wongin Tank area, central western NSW, on a geology and magnetic image, and a typical cross section (d). Geological symbols are: Qa - Quaternary alluvium, Qr - Quaternary residual soil, Czl - Cainozoic laterite, Czm - Cainozoic sands and silts, Dhks, Dhkl and Dhkf - Devonian sediment and felsic volcanics intruded by granite. Graticule lines are on 1 km spacing. Data supplied by Golden Cross Resources NL.

Seven metal factors are illustrated in Figure 3d, to show the metal association in a variety of ore and rock types. The factors and their diagnostic purpose are:

- Au + Ag + Se - gold mineralisation;
- Cu + Zn + Ag + Cd + Ni + Co - a base metal indicator;
- Sb + Bi + W + As + Mo - contact hornfels or skarn effects;
- Au + Pb + Ag + As + Bi - quartz veining, shearing or porphyry effects;
- Ni + Te + Cr + K + Mg - basic rock types;
- Ag + Cd + Se + Ni + Co + Cr - a basic/ultrabasic indicator; and
- S + Mo + W + Na + Mg + Cd + As - skarn associated with chlorite alteration.

If a range of geomorphic types is present, it is useful to divide the area into source domains, and rescale the data for each domain. This approach is illustrated in Figure 4.

Figure 4a Geomorphic domains

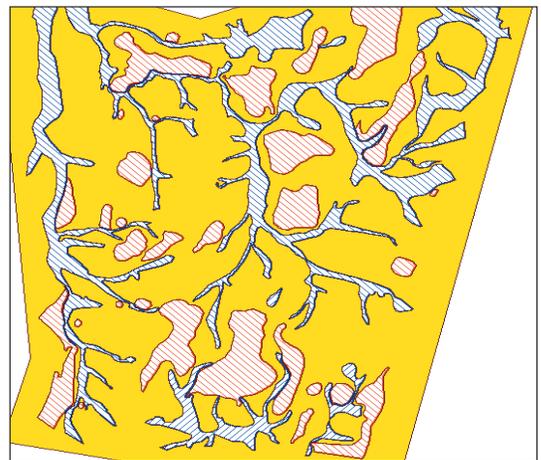


Figure 4a. Three geomorphic domains in a central NSW area; b, c, d - The same area divided into three domains with the REGOLEACH values for copper rescaled to suit individual domain ranges. Sample spacing is 50 metres, combined into 100 metre composites, on lines 500 metres apart. Data supplied by Hargraves Resources NL.

Figure 4b Depositional domain

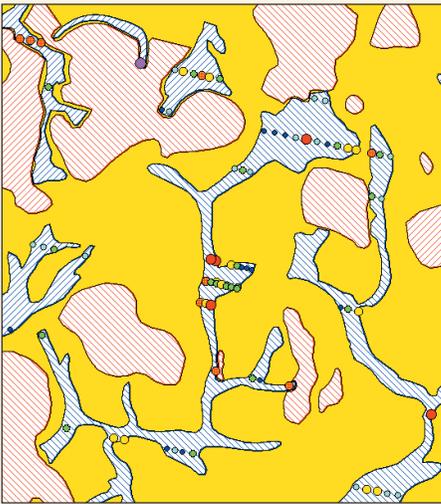


Figure 4c Transported domain

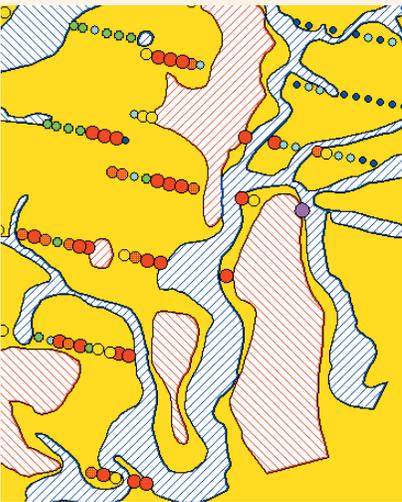


Figure 4d Residual domain

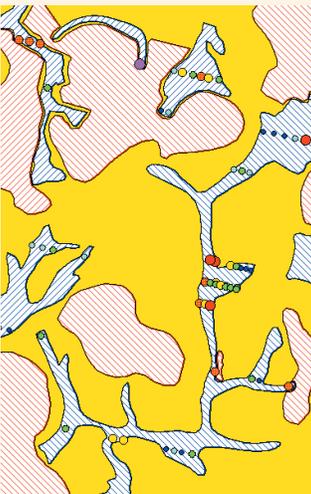


Figure 5

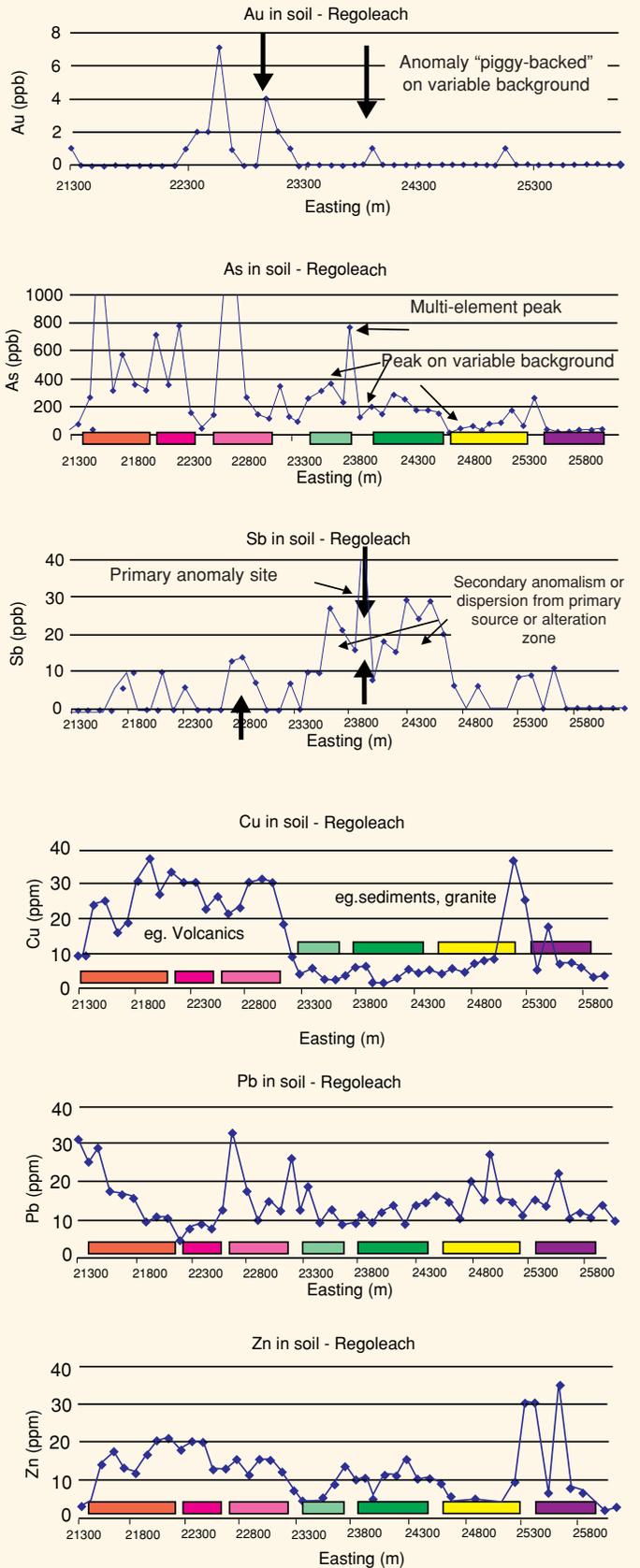
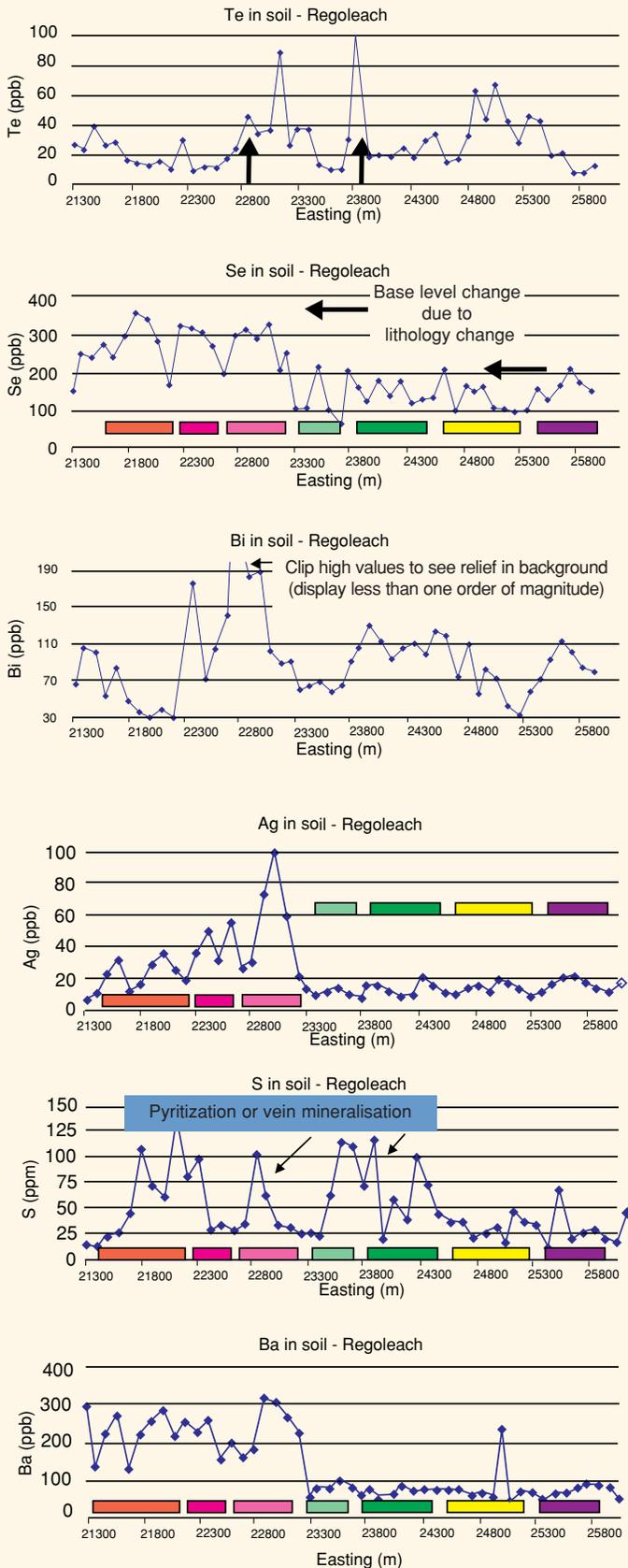


Figure 5



DATA INTERPRETATION

As REGOLEACH anomalies are essentially a record of the more easily leached mobile ions, it follows that the source of an anomaly may not always be vertically below an area of high soil values. Likewise the absolute value for a single element, single site anomaly is not particularly important, and follow up work should be directed at zones with anomalous values for a suite of associated pathfinder and ore elements. This 'co-anomalism' of the ore and pathfinder elements - the spatial association of anomalous elements - is the critical indicator of a specific type of deposit, not the absolute magnitude of a single element.

The co-anomalism approach also allows the identification of a halo to mineralisation, which may not be typified by anomalous levels of ore elements. The halo is more commonly indicated by high values for a suite of trace elements such as mercury, selenium, tellurium or tungsten, and elevated alteration indicators such as sodium, magnesium or potassium.

Anomaly selection begins by plotting the REGOLEACH value for each element on its own traverse profile - these are readily produced using the Chart Wizard in Excel. The traverse base should show ground slope, soil type and rock type, and any relevant comments. If the single element profiles are plotted on a geology base, this will enable recognition of background levels for each of the rock types in the survey area, as shown in Figure 5. The series of profiles drawn for each element on the traverse can then be compared, and multi-element anomaly sites selected.

Figure 5. REGOLEACH values from a soil profile in the Orange area of eastern NSW. The values for Cu, Ag, Ba and Se in the soils overlying volcanics strongly contrast with values for these elements in soils overlying a sediment-granite area. Values for S depict pyrite or vein mineralisation. A strong anomaly is defined by multi-element highs, for Au, Te, As, Sb and Bi. Coloured bars show changes in rock type. Data supplied by Hargraves Resources NL.

Figure 6a



Figure 6b

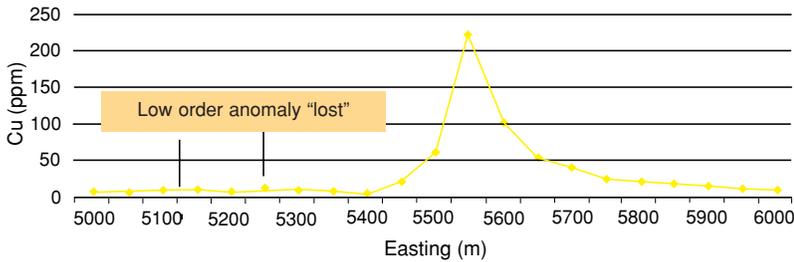


Figure 6c

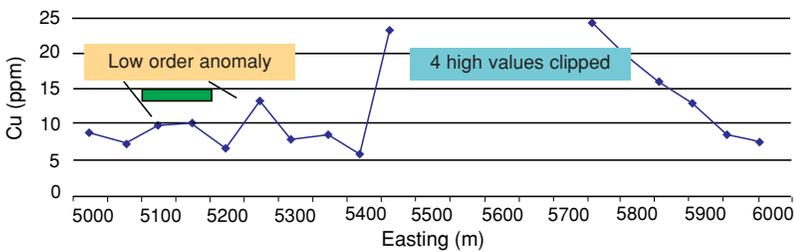


Figure 6d

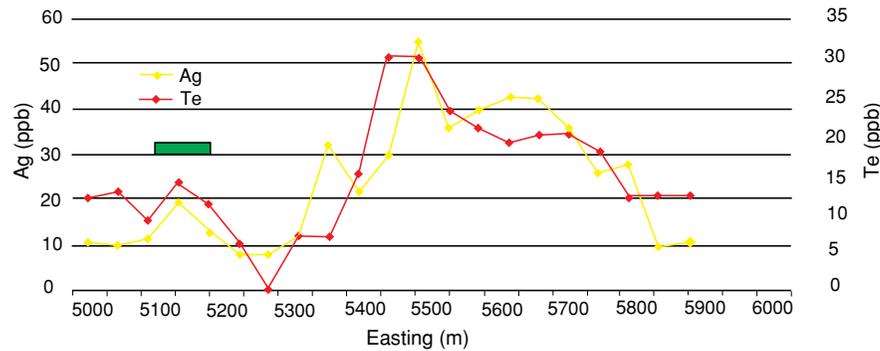


Figure 6e

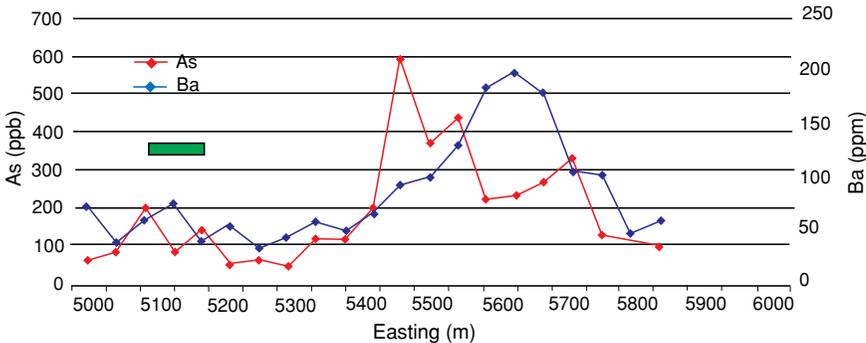


Figure 6a. A schematic geological cross section, and b-e, geochemical profiles of soil values, from the Blayney district of central NSW. Unclipped Cu (b) and REGOLEACH Cu (c) values are contrasted, demonstrating that the buried Cu anomaly is lost in the unclipped analyses. Clipping of the high REGOLEACH Cu values sourced from the outcropping mineralisation draws attention to the concealed multi-element Cu-Ag-Te-As-Ba anomaly (profiles c, d, e). Data supplied by Hargraves Resources NL.

'Clipping' of high values is recommended, to de-emphasise isolated, single element anomalies. This enables recognition of the lower intensity, multi-element anomalies that are 'lost' in analyses for total element content (Figure 6).

All Au values detected should be regarded as anomalous. If Au is not accompanied by common associate elements, such as As, Te, Sb, Ag or base metals, it can generally be considered to be alluvial and likely remote from source. Conversely very low values or lack of gold values in samples high in these associate species should not necessarily be regarded as negative for gold. In general gold derived by weathering of sulphide sources is well dispersed, often as atomic gold or sols etc, and is able to be readily detected by REGOLEACH (and BLEG). Repeat sampling generally repeats the gold anomalism. Repeat sampling in alluvial environments generally produces erratic results whether or not you are using REGOLEACH, BLEG, other selective leaches or total gold methods.

ALS Brisbane Office (see page 1), and Rutherford Mineral Resource Consultants (telephone and facsimile 02 9665 8263, e-mail rminres@zip.com.au) will be pleased to advise clients on optimum field and analytical procedures for REGOLEACH surveys.

ACKNOWLEDGEMENTS

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Neil Rutherford and Don Berkman, March 1999.

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