Regional Geophysics and Geochemistry as an Exploration Initiative in New South Wales, Australia

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ABSTRACT

The level of mineral exploration within Australia and in particular within the state of New South Wales has significantly increased over the past five years. In New South Wales, the level of private company exploration expenditure has nearly doubled and has been led by the state's Discovery 2000 Exploration Initiative Program.

The New South Wales government began its six-year Discovery 2000 Exploration Initiative budget in 1994. Approximately $9 million has now been spent on the direct acquisition and processing of over 850 000 line kilometres of airborne magnetic and radiometric data, and over 14 000 gravity stations. Both mineral- and petroleum-prospective areas were targeted, covering an area of over 200 000 square kilometres—equivalent to 26% of the state.

Government participation in research in Australia on geochemical exploration, and subsequent conferences in Brisbane and Sydney, have focussed on the problems of the regolith. As a majority of New South Wales geology is covered by a thin veneer of sediments and regolith, the landscape and evolution of landforms is now considered before a decision as to whether geochemical exploration programs are directed at stream sediments, soils, lag, saprolite or bedrock sampling. The use of models from lead isotope studies can now assist the explorer on the geological age of a geochemical anomaly and can provide clues about whether the response is due, for example, to hydrothermal activity, volcanic-hosted massive sulphides (VHMS), or to granitoid intrusions.

With new high resolution geophysical data sets and a much greater knowledge of regolith, exploration within New South Wales can now be more effective over sediment-covered areas. These data releases and research have assisted, and will continue to assist selection of new exploration project areas which, in due course, should lead to new discoveries.

INTRODUCTION

The state of New South Wales covers over 800 000 km² with nearly two-thirds of the state having an annual rainfall of less than 500 millimetres (20 inches). Apart from the Great Dividing Range, the state is relatively flat and is typically covered with dry grasses, shrubs and trees. Most areas are lightly settled, with reasonable access for exploration and mine development. Annual exploration expenditure for minerals is now over $80 million, which predominantly involves the use of airborne magnetic and electromagnetic surveying, and geochemistry. Current mining activities in New South Wales directly employ a workforce of over 23 000 and the state receives royalties of over $170 million annually.

The Discovery 2000 program began in 1994 and is planned to finish in the year 2000. The New South Wales Government have provided, and proposes to continue, funding for accelerating the compilation and acquisition of regional geological, geochemical and geophysical information for use by the mining and petroleum industries. Discovery 2000 has provided and will continue to give a major boost to the exploration industry. The government anticipates a substantial return in due course—with new discoveries, development of new mines and, perhaps, the first major (conventional) oil or gas discovery in New South Wales.

Results of geophysical surveys have been progressively released in digital and hardcopy format. Airborne surveys have been flown at low altitudes (typically 60 m) at a close interline spacing (typically 250 m) together with a much improved density of gravity stations over all areas. Collection of seismic reflection data over specific areas and recent drilling by the Department of Mineral Resources have assisted with the 3-D view of sedimentary basins.

As much of the Australian continent has been emergent for over 2000 million years, with many landscapes originating over 300 million years ago, the modern explorationist needs to know where geochemical prospecting is going to be effective.

To help discriminate and understand these issues, the Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRCLEME) was established in Australia in July 1995. CRCLEME

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focuses on landscape evolution by integrating geomorphic, geological and geochemical processes and concepts. The New South Wales Department of Mineral Resources is an active participant of this seven-year, $37 million program.

Researchers have recently presented their initial results on the studies of the regolith at conferences such as the International Geochemical Exploration Symposium in Townsville (1995) and in Brisbane (Regolith '96).

The resurgence in geochemical exploration is partly due to the success of research into sampling techniques in defining gold mineralisation over deeply weathered terrains in Western Australia (Butt, 1995). Procedures testing for different regolith—landform settings have now been developed, using a variety of source materials including soil, lag, surficial or buried lateritic residuum, ferruginous saprolite, saprolite and groundwater.

EXPLORING WITH GEOPHYSICS

Methodology

During the first two years of Discovery 2000, nine areas were covered by high resolution geophysical surveys (Figure 1). This included acquisition of combined aeromagnetic and radiometric surveys and the upgrade of the existing gravity network from a grid at 11 km × 11 km to a new 4 km × 4 km grid.

Each major release of low priced geophysical data has led to a significant increase in the exploration licence applications. As value is added to these products, the higher level of exploration should be maintained.

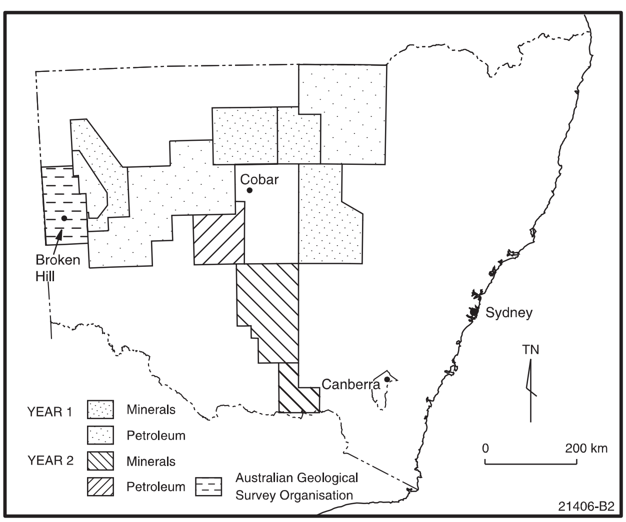

Figure 1: *Outline of Discovery 2000 geophysical coverage.*

Airborne geophysics

For dominantly mineral-prospective areas, the interline spacing for airborne surveys was 250 m, with a ground clearance of 60 m. In petroleum-prospective areas, the interline spacing was 400 m, with a clearance of 80 m. Because strike directions vary over the petroleum-prospective areas, the tie line/survey line ratio was kept to 1:5 compared to the industry standard ratio of 1:10. The additional tie lines also helped to ensure a very low noise level in the final data sets (Robson, 1996).

Navigation of the fixed-wing airborne surveys was controlled by global positioning (GPS) satellites, and 95% of the flightline locations and survey altitudes were respectively, within 2 m and 10 m of planned positions.

Gravity

To assist in the overall understanding of the different lithologies and regional structure, the gravity station readings over all survey areas were read on a 4 km × 4 km grid. To minimise impact on landholders a helicopter was used to travel between stations.

To ensure the availability of accurate heights necessary for high-accuracy gravity surveys, the Discovery 2000 program completed the largest GPS survey ever undertaken anywhere in the world with state-of-the-art dual frequency, real-time differential GPS receivers. Such hardware and software capabilities have revolutionised the positional accuracy of gravity surveys. Further, the results have now formed a strong network to facilitate future infill.

Seismic surveying

Over 250 line kilometres of high resolution seismic surveys were undertaken over three sedimentary basins. A total of four traverses were recorded with vibroseis, using either 120-fold or 240-fold stacking with a 3-second or 5-second recording interval.

Results

The new high resolution geophysical data sets have provided industry with a world-class product—to extend understanding of the resource potential of an area with extensive cover but which has proven deposits supporting major mines.

For example, in the mineral-prospective area of Northern Parkes, (250 000 km^2) which hosts the Northparkes cluster of porphyry copper—gold deposits (reserves of over 70 million tonnes averaging approximately 1.3% copper and 0.6 g/t gold), the new 1995 airborne data (250 m interline spacing) represent a tenfold increase in resolution over the previously available data. Except for a 1960 reconnaissance aeromagnetic survey (1.5 km interline spacing), barely 10% of the area was covered with company surveys. Extracts of the new and the old data set for the Northparkes and Peak Hill area (Robson and Spencer, 1997) is shown in Figures 2, 3 and 4. Figure 2 shows regional aeromagnetic data flown in 1960; Figure 3 shows the higher resolution aeromagnetic data obtained with the recent Discovery 2000 survey (displayed as an equivalent colour stretch range to the regional data on Figure 2); and Figure 4 shows the Discovery 2000 radiometric data (no such data were acquired with the 1960 regional survey), with the K/Th/U radioelements shown as a red/green/blue ternary image.

The department has completed a first pass interpretation of this data set using a synthesis of the known geology with colour images of the total magnetic intensity (TMI), grey-tone images of the 1st and 2nd vertical derivatives, and colour images and contours of the radiometric and gravity data. To encourage the explorer further, the department

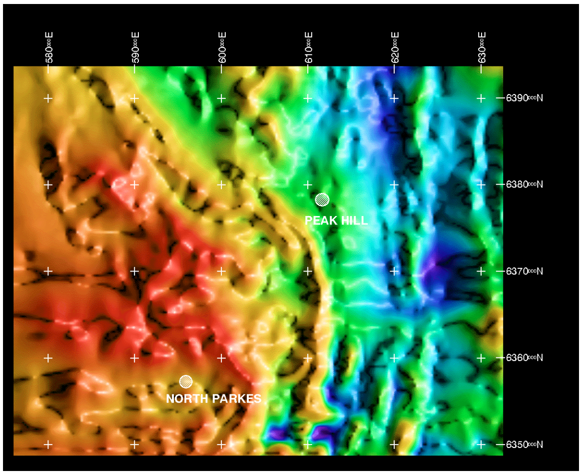

Figure 2: *Previous regional aeromagnetic coverage over Northparkes/ Peak Hill.*

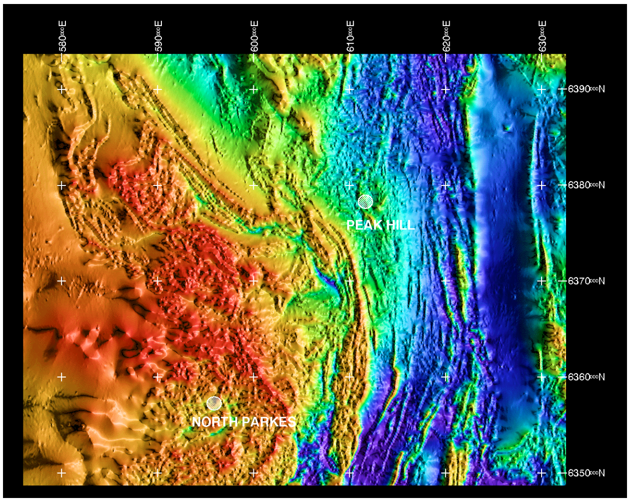

Figure 3: *Discovery 2000 aeromagnetic coverage over Northparkes/ Peak Hill.*

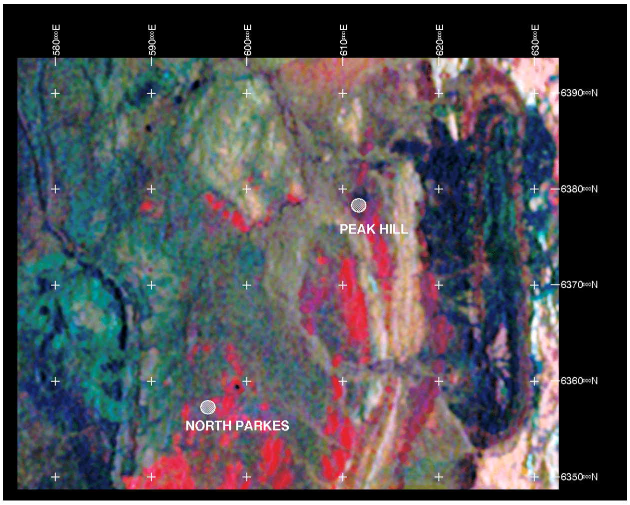

Figure 4: *Discovery 2000 radiometric coverage over Northparkes/ Peak Hill.*

completed computer-depth analyses, potential-field computer modelling, downhole logging and a physical property database.

The second project flown in 1995 with high resolution geophysics was the Bourke Project Area (220 000 km^2). Most of the geology in this area is masked by relatively thin (10 m to 50 m) cover, and Palaeozoic sequences with significant mineral potential are now interpreted to extend into this area. To the south of the Project area lies the Early Devonian Cobar Basin, which hosts the Cobar group of mines (e.g., Elura, CSA, The Peak, McKinnons Tank, etc.) which had a pre-mine resource of well over 150 million tonnes of gold, copper, lead, zinc and silver mineralisation. Other mineralisation styles are present to the southeast of the project area include platinum-rich Alaskan style ultramafic intrusive complexes and copper-rich Ordovician sedimentary rocks. Together they had a pre-mining resource of over 26 million tonnes of significant mineralisation. The new generation geophysics now strongly indicates that much of the Ordovician through to Devonian stratigraphy continues well into the Bourke Project Area. This understanding has led to a ten-fold increase in exploration activity.

CD-ROM packages have now been released for the three survey areas (each approximately 25 000 km^2). The CD-ROM package includes outcrop geology, bedrock interpretation, depth to basement, rock chip and groundwater geochemical data, location of mineral occurrences, and a large collection of geophysical images (e.g., TMI, ternary radiometric and digital terrain model images, together with gravity and TMI colour contour plots).

In other areas which already receive a significant level of exploration, the department has collaborated with industry in the acquisition of new regional data. At the request and financial support of explorers in the Cobar area, the department, with some assistance from the Australian Geological Survey Organisation, proceeded to cover most of the Cobar Basin (30 000 km^2) with a network grid of 2 km × 2 km gravity stations. This involved the reading of over 2000 heli-gravity and 2000 detailed road gravity stations. Results which were released in early 1997 have assisted in delineating structures within and along the margin of the basin, particularly the non-magnetic features. Images of gravity gradients have been particularly helpful in further delineating these structures which are in part associated with mineralisation.

Each of the major geophysical releases over project areas have shown a significant surge in the number of Exploration Licence Applications within the Lachlan Fold Belt (Figure 5). Over the past two years the level of new exploration predominantly within the Discovery 2000 areas has increased the exploration expenditure within the state from \$65 million to over \$80 million.

Besides the mineral-prospective areas, analysis of the high resolution aeromagnetic and gravity data sets has revealed many new geological features in the sedimentary basins. Combined with recently acquired seismic data, and the reinterpretation of existing seismic data, new structures within the basins have been located—and even the basin shapes have been redefined. Tectonic features that can be identified include normal and thrust faults, and large horsts and rifted blocks.

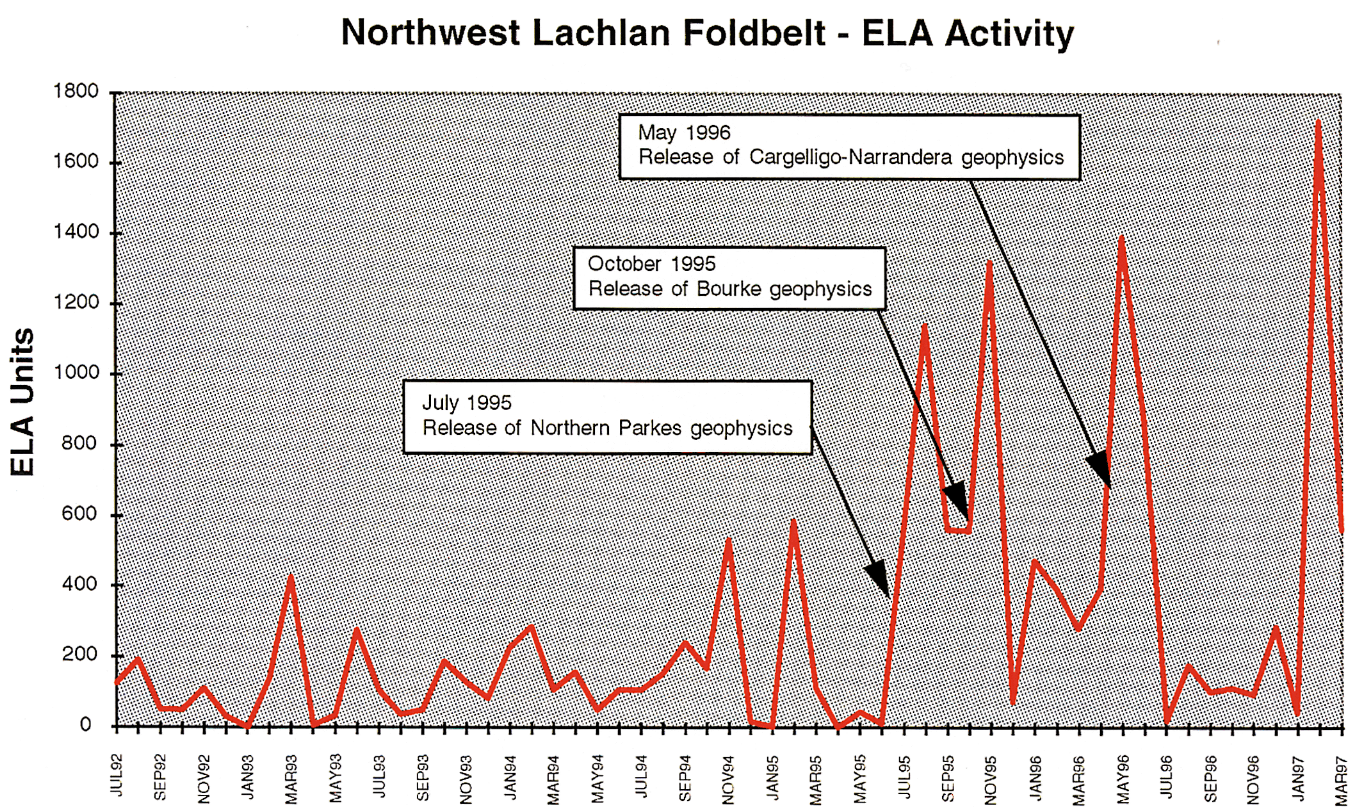

Figure 5: *Northwestern Lachlan Fold Belt—Exploration Licence Activity (ELA) activity.*

Such tectonic features could provide suitable structures for the entrapment of petroleum. Both large and small structural features have now been mapped over large regional areas. Combined with the recent but limited seismic refraction surveys, the mapping has directly led to a greater understanding of the basins.

The Darling Basin, for example, appears to contain proven reservoir and seal rocks, large structural and stratigraphic traps, but lacks definitive information on source rocks. Early Devonian marine sequences are regarded as the best potential source rock interval and although this unit is known to be widespread there are few subsurface intersections. Those wells with intersections are located on structural highs and have unacceptable seismic data which cannot be integrated into existing seismic data sets and extrapolated into deeper, more prospective parts of the basin.

Acquisition by the department of new high quality seismic data using vibroseis (240-fold, 12.5 m group interval and 12.5 m source interval) represents the first modern high-fold seismic data to be recorded within the Darling Basin. Using the interpretation of the aeromagnetic and gravity data, the seismic lines were positioned over structural highs where Early Devonian sedimentary rocks occur at the surface, or are near-surface. The aim was to position relatively shallow (1000 m) stratigraphic wells to penetrate areas with minimum overburden so that the source rock potential and thermal maturity of the complete Early Devonian sequence could be assessed. The department has recently completed an 1100 m stratigraphic drillhole and the results have already provoked new ideas of the regional stratigraphy.

Impact on regional geological mapping

The department has already began Second Edition geological mapping. As this requires high resolution geophysics, the Discovery 2000 program is already facilitating the re-mapping of the state.

The integration of geophysical data sets with geology is a collaborative process and is now mandatory for efficient geological mapping. The department follows three distinct stages in regional geological mapping. They are — pre-mapping interpretation of the geophysical data (includeing the existing geology); on-going consultation and interpretation of the geophysics with the field mapping; and post-mapping GIS synthesis of the new geology with the geophysical data. To achieve a high professional mapping product, the following is required:

1. processing a variety of images at various scales — filtering, ratioing and merging of data sets.
2. accessing different data sets. Regional gravity data normally acquired on a 4 km grid are useful in defining major structural features.
3. a variety of imaging techniques. The use of 3-D graphics with views in real-time rotation and “fly throughs”. The draping of the radioelement data over a 3-D perspective of the terrain has proved to be of great assistance in the understanding of the regolith.
4. potential field modelling can infer fault dips and depths to intrusive bodies.
5. collection and modelling of ground surveys to resolve specific problems.

To achieve a good degree of collaborative mapping, the department allocates one geophysicist between four or five geologists.

Other exploration initiatives

Besides the Discovery 2000 Exploration Initiative in New South Wales, other states in Australia have similar programs. All of the initiatives have involved the acquisition of high resolution geophysics. As detailed in Table 1 (Hone *et al.*, 1997), the individual states over the last three years have collectively acquired over 3.5 million kilometres of aeromagnetic and radiometric data. This data has been collected on interline spacings of between 200 and 400 m at a survey flying height of either 60 or 80 m.

In addition to the states completing their own surveys, the Australian Geological Survey Organisation (AGSO) in joint ventures with the states, flew over 700 000 kilometres of aeromagnetic and radiometric data. This wealth of high resolution airborne data has greatly encouraged further exploration, especially in covered terrains. For instance, explorationists use the aeromagnetic information to outline the area required for an exploration licence. In turn, this has controlled the extent of geochemical sampling programs to a particular magnetic unit or structure. Explorationists have used this strategy on the Gawler Craton in South Australia (covered by the SAEI program), where geochemical sampling has recently defined several significant gold deposits.

Table 1: ***Summary of recent airborne geophysical data acquired by state governments (Hone et al., 1997).***

State	Period	Km	Comments
New South Wales	1994–1996	800 000	DISCOVERY 2000
Northern Territory	–1996	930 000	Long term program
Queensland	1994–1996	290 000	Geomap 2005
South Australia	1993–1995	930 000	South Australian Exploration Initiative (SAEI)
Tasmania		70 000	
Victoria	1994–1997	360 000	Victorian Initiative for Minerals and Petroleum (VIMP)
Western Australia	1994–1995	120 000	

EXPLORING WITH GEOCHEMISTRY

Methodology

Landscapes over the Australian continent can be traced back from 300 million years ago to the present. With the need to explore under the regolith cover, a range of collaborative research projects between research agencies, government and industry have now been developed.

In July 1995, the Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRCLEME) was established in Australia. CRCLEME focuses on landscape evolution on the Australian shield (principal cratons), the Tasman Fold Belt (eastern Australia) and on major sedimentary basins. Although the project is still in its infancy, much understanding and problem solving have been completed. The 17th International Geochemical Exploration Symposium (May 1995) in Townsville, and the CRCLEME Regolith '96 Conference (November 1996) in Brisbane, discussed the evolution of regoliths and landscapes in deeply weathered terrain, together with case studies on the genesis and classifications of the regolith.

At project level, there have been several research projects developed by AMIRA (Australian Mineral Industries Research Association Ltd.). This has included research on such projects as "Deep penetration EM systems and interpretation tools for exploration in regolith-dominated terrain" and "Geochemical exploration in areas of transported overburden, Yilgarn and environs, WA" (CSIRO, 1994).

Early outputs from CRCLEME include the publishing of regolith—landform maps at 1:500 000 scale over the Cobar region (McQueen, 1996) of central New South Wales, and for the Broken Hill and Curnamona districts (Pain *et al.*, 1996). This included an evaluation of aerial photography, Landsat TM, existing information on landscapes and regolith, and reconnaissance field work. The study has shown the coexistence of a variety of duricrusts, and that the relationships of those duricrusts to geochemical differentiation and palaeo-environmental change requires further explanation. Explanatory notes on the regolith units are about to be published.

Preparation has now begun by CRCLEME on the regolith—landform framework for the northern Lachlan Fold Belt extends through central New South Wales. Once completed, the study will fill large gaps in the knowledge of surficial deposits in southeastern Australia.

Procedures have now been developed for different regolith—landforms by using a variety of sampling media including soil, lag, surficial or buried lateritic residuum, ferruginous saprolite, saprolite and groundwater. Figure 6 illustrates the model of geochemical dispersion expected in the regolith horizon.

Lag

Lag is a term used to described the residual products of surface weathering. Generally they are iron-rich nodules which can be either magnetic or non-magnetic. Because ferruginous materials accumulate gold and base metals, they are an excellent medium to sample. Although the anomalies are less intense than can be obtained directly over an ore body, they are broad and facilitate a wider sample interval. Provided that subtle lag anomalies can be effectively interpreted, the technique can lead to a higher probability for an exploration success.

The most important ferruginous sample media are duricrusts and loose nodules and pisoliths (collectively described as lateritic residuum), ferruginous saprolite and mottles. They are generally referred to as a lag sample and occur at or near the surface and have been sampled beneath transported cover. As surface maghemite accumulations are generally not associated with primary mineralisation, the effectiveness of lag sampling is dependent on the environment. For example, sampling by some companies in the Cobar area has been restricted to ero-

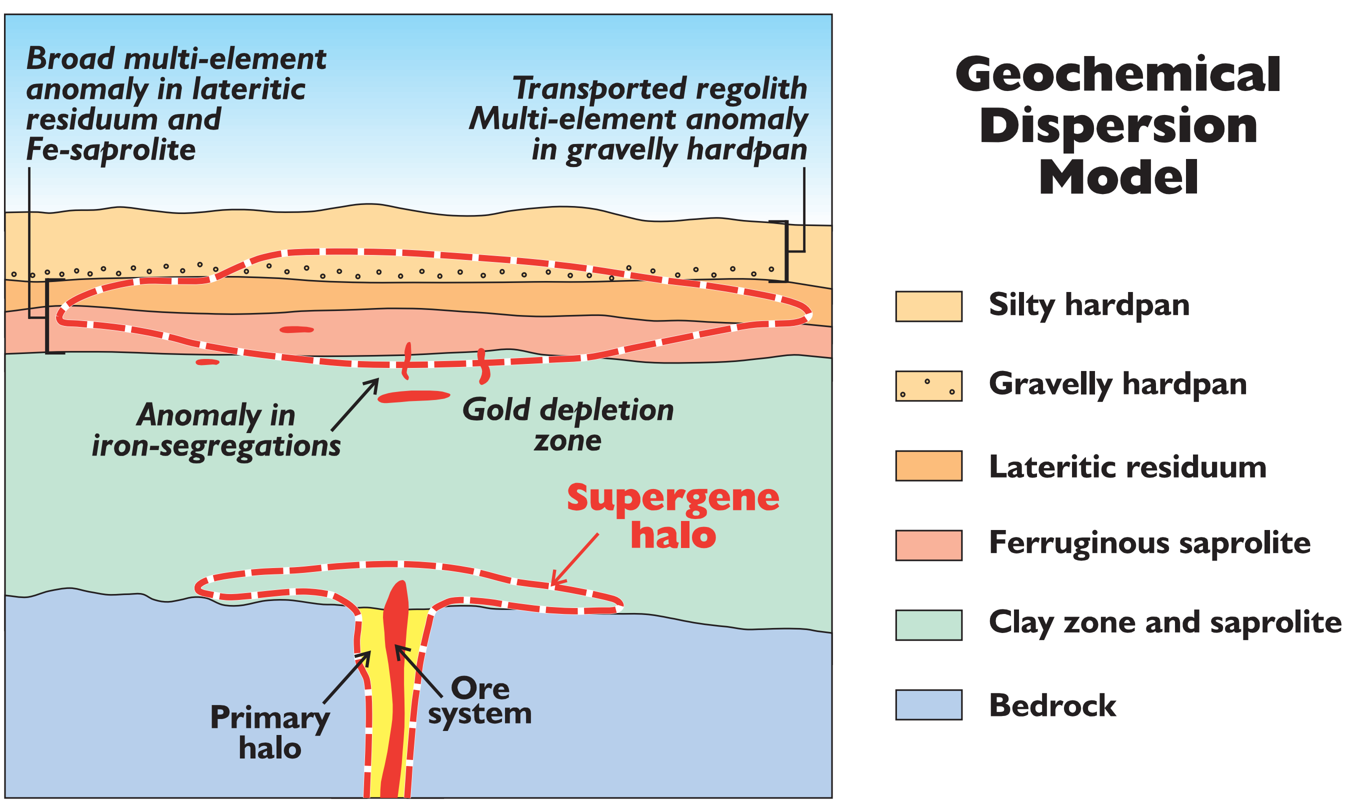

Figure 6: *Geochemical dispersion model of the regolith—Australia (modified from Anand and Robertson, 1996).*

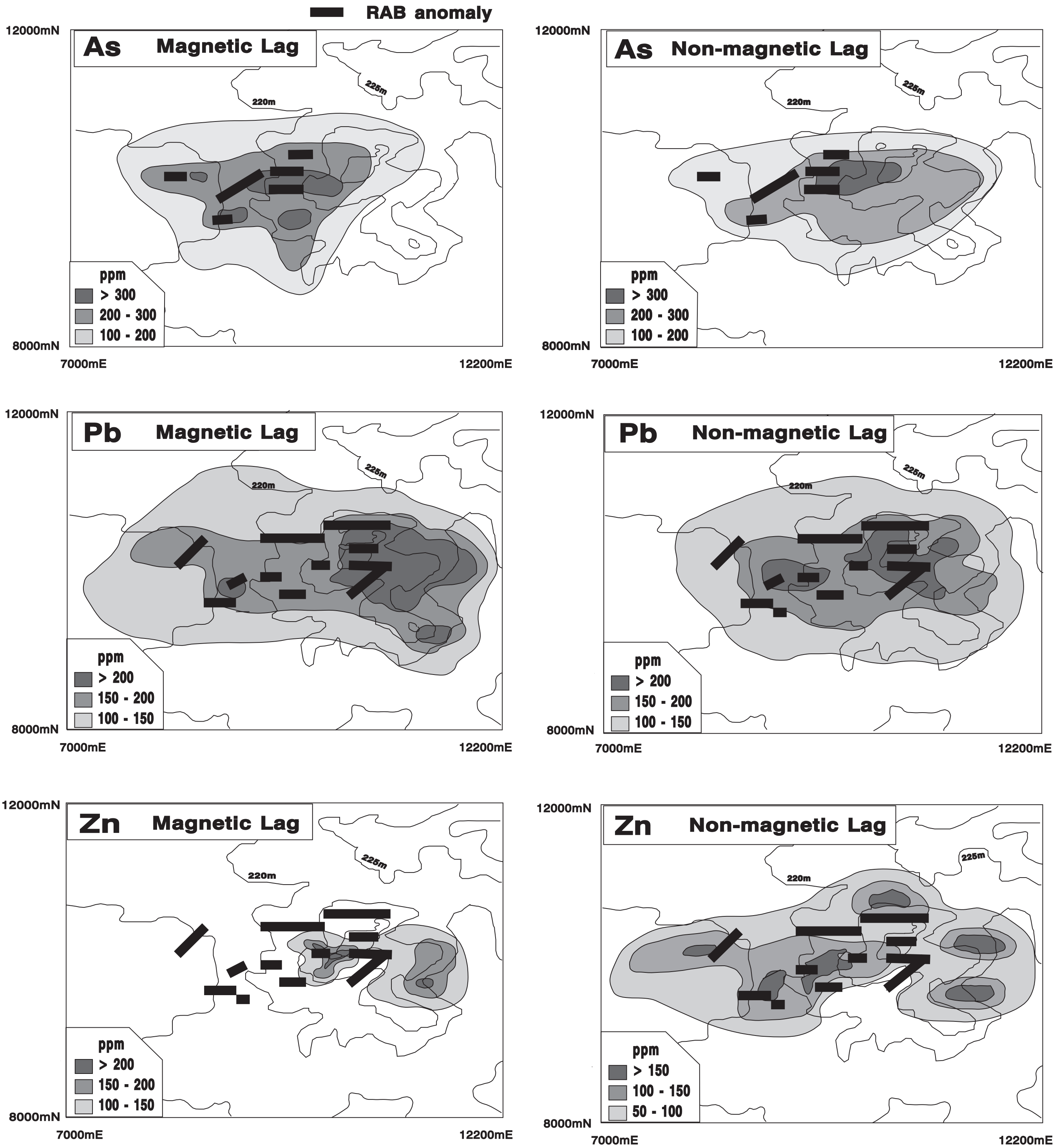

Figure 7: *Comparison between geochemical patterns of Zn, Pb, and As in magnetic and non-magnetic lag fractions, Mrangelli prospect, Cobar, New South Wales, (Cohen et al., 1996).*

sional and depositional landforms (no sampling of transported material). The pisoid-type lag in the Cobar area has approximately 90% magnetic fraction which is represented by haematite and maghemite. The non-magnetic fraction is dominated by vein quartz. Geochemical patterns in the magnetic and non-magnetic fractions have been investigated at the Mrangelli prospect in the Cobar area by Alipour *et al.* (1995). As shown in Figure 7, the lead and arsenic results in the magnetic fraction, show broad, generally low order (100–200 ppm) anomalies, with lead in the non-magnetic fraction forming local spot highs (+300 ppm). However, zinc and copper in the non-magnetic fraction show a more coherent and anomalous response with the Rotary Air Blast (RAB) drill sample results.

A detailed investigation of the regolith was recently completed at the McKinnons Gold Mine near Cobar. The study defined a strong arsenic response to be closely associated with mineralisation (Cohen *et al.*, 1996). The peak arsenic values (10 ppm) in the non-magnetic lag lay directly over the mineralisation, whereas the arsenic peak values (100–120 ppm) in the magnetic fraction, are slightly displaced downslope. The gold response shows erratic lag values, with peak values (20 ppb) over the mineralisation.

Soils

In regolith areas, soils have been used when there is a lack of ferruginous material. Calcareous soils (calcrete) are particularly important as they can be enriched in gold from concealed mineralisation. No longer is surface soil sampling or sampling at a particular depth appropriate because the material hosting gold anomalies may be missed. Pedogenic carbonate (calcrete) dominantly consisting of calcite and dolomite (Lintern and Butt, 1996), has been shown to be an excellent sample medium—even through 20 m of leached saprolite. It is also generally widespread, readily identifiable and inexpensive to collect. In conjunction with CRCLEME and AMIRA, this technique has already been successfully used within the Eastern Goldfields of Western Australia, and the Gawler Craton area of South Australia.

Saprolite

Intense leaching of the saprolite zone generally implies that these products are unsuitable for prospecting with geochemistry. However, this is not always the case and sampling of saprolite material may be used as a follow-up tool. The limited lateral extent of anomalies in saprolites increases the costs associated with sampling and drilling. Conversely, sampling of ferruginous saprolite can be very effective on mafic and ultramafic lithologies.

Groundwater

The New South Wales Department of Mineral Resources recently released the results of a groundwater geochemistry database and interpretation over the Narromine-Nyngan region in central western New South Wales (Giblin, 1996). This is one of the department's Discovery 2000 Exploration Initiative areas (Figure 1), and was conducted by the Commonwealth Scientific and Research Organisation (CSIRO).

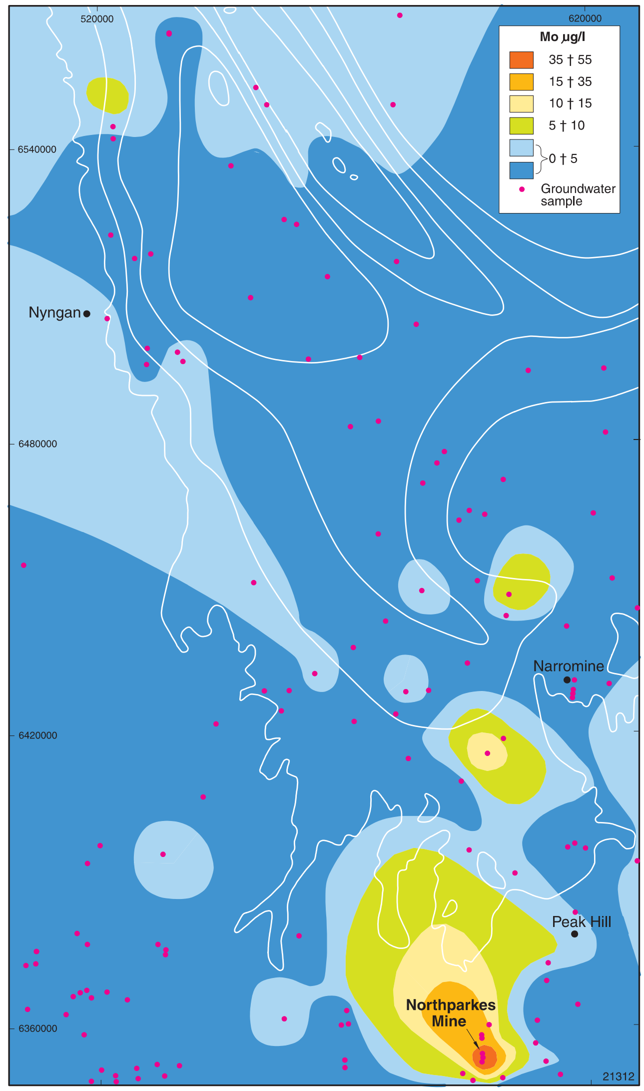

Figure 8: *Molybdenum in groundwaters across the Narromine-Nyngan groundwater study area. The white contour lines indicate increasing thickness of cover sediments to the northeast, (Giblin, 1996).*

This groundwater program successfully tested the concept that groundwater can define basement rock types under cover sediments. Groundwater samples from 152 stock bores and company drillholes were assayed for 52 chemical elements. Results were interpreted in terms of their bulk rock composition and exploration significance. Both gold and copper results show a number of anomalous values comparable to those obtained over the copper—gold deposits at Northparkes. The molybdenum results are shown as Figure 8 and may relate to the porphyry-style of this mineralisation. This is one of the first published reports on groundwater geochemical survey used as a regional low-cost indicator for potentially economic mineralisation.

Biogeochemistry

The application of biogeochemical prospecting is new to Australia. The biochemical characteristics of most Australian plant species are relatively unknown. A study needs to be specific to the same climatic condition and species. Sampling must be restricted to the same plant part, the same state of growth and collected in the same season.

As part of a survey in the Drake area in northern New South Wales during late 1994 (Cohen *et al.*, 1995), sampling was focussed on casuarina and wattle trees. Results showed highly anomalous cobalt around granites, but very subdued cobalt responses around the basalts. More recent sampling (Cohen *et al.*, 1996) over the McKinnons Tank gold mine near Cobar, has indicated anomalous gold and arsenic contained in the leaves of white cypress pine (Callitris columellaris) trees. There was limited within-site variability and a strong geochemical contrast between mineralised and background sites. The results show a consistent 500 m wide zone of anomalies directly over mineralisation.

Lead isotopes

Lead isotope studies over the Palaeozoic Lachlan Fold Belt in New South Wales (Carr *et al.*, 1995), have defined hydrothermal activity to be associated with mineralising events from the Ordovician to the Carboniferous. As part of that study by the CSIRO in conjunction with the department and industry, the lead isotope signatures of 100 deposits and prospects involving close to 500 determinations considered to represent initial ratios were obtained. Results clearly show that lead isotope analysis can target copper—gold rich Ordovician volcanic and intrusive rocks. Typically deposits in these rocks have a distinct lead isotope signature where isotopic compositions plot on or close to a mantle mixing line. They can be discriminated from crustal lead-dominated systems such as Silurian and Devonian volcanic-hosted massive sulphide (VHMS) mineralisation and Devonian and Carboniferous granitoid intrusions. A big advantage of studying lead isotopes is that results are independent of whether the sampling is taken from weathered material or rock. The model defined for the Lachlan Fold Belt can evaluate new prospects with just moderate levels of lead (about 100 ppm), and the appropriate exploration strategy developed.

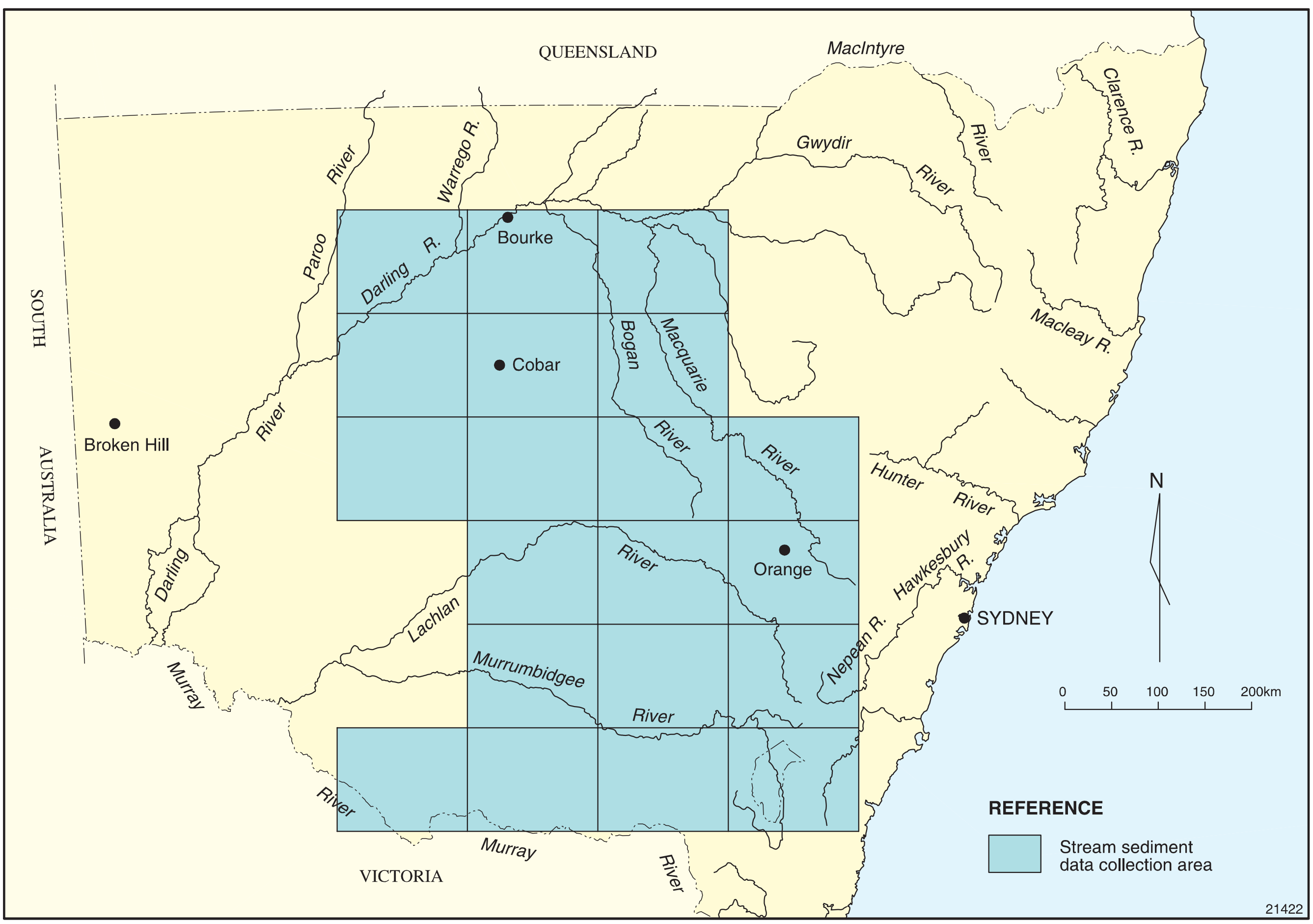

Figure 9: *The twenty 1:250 000 map sheet areas from which data was drawn for the stream sediment database.*

Stream sediment

Explorationists within New South Wales have routinely used stream sediment geochemistry as a first pass in evaluation. The department has released a compilation of over 170 000 samples held in numerous open-file company reports. The data were accumulated on more than twenty 1:250 000 scale map sheet areas (Figure 9) and cover most of the active drainage proximal to mineralisation within the Lachlan Fold Belt.

Stream sediment sampling can be conducted with a variety of methods. To help overcome sampling problems, explorationists may initially take bulk sediment samples from either the stream sediment or from the stream bank. After bulk leaching for extractable gold (BLEG), the sieved (–180 μm), magnetic/non-magnetic lag, siliceous or heavy mineral separate may be analysed. Nearly half of the state is attractive for stream sediment sampling.

In many areas of the state the drainage of low order river systems are broad and the effectiveness of stream sediment geochemistry is questionable. Many have ephemeral waterways filled by silts derived from the local deflation of soils, and aeolian influx. The silts generally show no geochemical equilibrium with the catchment bedrock. Hence the use in these areas with the conventional stream sediment using the –180 μm fraction is ineffective.

In low order systems such as in the Cobar area of central New South Wales, drainage from a small topographic high may still be effective. For instance, the area around the Elura ore body has shown a possible dispersion of lead of more than 5 kilometres into the drainage system (Cohen *et al.*, 1996).

Airborne electromagnetic data

Areas which have substantial regolith cover impose a serious limitation on direct exploration techniques. While many advances have been achieved in understanding the regolith, there are still many unknowns. Airborne electromagnetic surveys (AEM) may now have the potential to provide better understanding of the regolith and to determine bedrock structure below the regolith. An AMIRA project on EM systems is in part examining the effect of the relative conductive sediment cover.

Many regolith materials are conductive (Munday and Worrall, 1996), and where they are laterally extensive they will produce a coherent AEM anomaly. Hence EM techniques have the capability to map weathered zones and provide additional information to complement regolith and geological mapping. EM data can provide a depth perspective which is critical in unravelling the development of a landscape and may indicate possible bedrock conductors requiring follow up with geochemical surveys. With the display of multichannel, multicomponent AEM data, conductivity variations may map the alluvium and colluvium, and the technique may also assist in the mapping of the bedrock. EM also has great potential in the understanding of groundwater flow, and could assist in the understanding of hydromorphic dispersion of pathfinder elements through the regolith profile (Munday and Worrall, 1996).

Airborne radiometric and magnetic data

Radiometric data can greatly assist in the mapping of the regolith. As with the geological map, images of radiometric data provide another supplementary data set. However, unlike geology maps, the data can be manipulated to highlight domains, boundaries and structures. As the radiometric data is predominantly from the measurement of gamma-rays in the top 10 cm of the surface, the radioelement data provides the geochemical expression of a wide variety of surface materials. It provides information on the geochemistry of the regolith, the composition of materials and can provide clues to the length of time of weathering.

Over the Bathurst area in eastern New South Wales, a combined image of the radiometrics and Landsat has been particularly helpful for regolith mapping. This is achieved with a HSI (hue/saturation/intensity) image by representing the radiometric data (typically the potassium channel) as the hue and the saturation, and the Landsat TM band 5 represented as the intensity. This style of image together with the radioelement red/green/blue ternary image, has very clearly shown geochemical boundaries — especially depicting weatherable granites that form erosional bowls (e.g., Bathurst Granite). In depositional areas immediately west of Bathurst, the radioelements have been helpful in delineating regolith changes on subtle relief with low regolith visibility, and in determining the provenance of sediments, especially where the signal of the sediments contrasted with that of the surrounding regolith. In volcanic areas, lava flows commonly occur as sinuous lava plateaus with the more weathered flows showing a high thorium signal (Chan, 1995) — highlighted by ratioing the Th/U data.

Aeromagnetic data has also played an important role in regolith mapping. For instance, in the Cobar area high resolution aeromagnetic data is a valuable tool for identifying areas of deep fluvial deposits. The identification of magnetite filled palaeodrainages during the planning stage of an exploration program will allow the areas to be suitably sampled by various methods.

CONCLUSIONS

The New South Wales Government's Discovery 2000 Exploration Initiative for minerals and petroleum, and the consequent release of high resolution geophysics at affordable prices, have provided industry with a once-in-a-generation opportunity for major discoveries. The high number of new exploration licences over Discovery 2000 survey areas is a direct outcome of the release of high resolution geophysical data.

Exploration geologists now use the new high resolution geophysics to select new areas for exploration. As many of the Discovery 2000 areas are covered with regolith, existing geology maps have been of limited use. Once an exploration licence area is defined, geologists use the high resolution airborne geophysics — especially the aeromagnetic data — to restrict geochemical sampling to a particular magnetic unit or structure.

The modern explorationist is no longer satisfied with conducting geochemical sampling by simply collecting stream and soil samples. Depending on the environment and landscape, much thought is now being given to whether the crushed, sieved or sized sample is siliceous, ferruginous, magnetic/non-magnetic and whether or not it will be leached as a bulk sample. Based on results from case histories collected of exploration throughout Australia, a lag or duricrust sample is now known to give a much broader but lower order anomaly than that obtained directly over an ore body. This in turn has led to wider and cost-effective sample intervals. Gone are the days when samples were collected at the surface or from a certain depth. Sampling of the carbonates within a weathered horizon has been effective as they are generally widespread, easily recognised and relatively cheap to analyse. Biogeochemical sampling has also been effective in certain areas, but more case histories are required to confirm and consolidate its usefulness. From a detailed lead isotope study of over 100 deposits/occurrences within the Lachlan Fold Belt of New South Wales, a model for mineralisation was generated. Thus, as an anomaly is defined within this region, it is now possible to categorise the likely sources as either due to hydrothermal, VMS or granitoid. As many parts of the regolith/cover can be conductive, airborne EM may be an effective and quick way to better understand the regolith horizon.

Effective application of spatially-based data in a GIS, the use of multivariate statistics to isolate geochemically anomalous samples and the integration of geology, geophysics, geochemistry and geomorphology continue to improve the reliability of exploration programs.

The Discovery 2000 exploration initiative in New South Wales has led to a major boost in the level of exploration. Combined with the progressive release of value added products, a series of new discoveries is anticipated.

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