Regional Geophysical Exploration in Arid Terrain

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INTRODUCTION

A significant part of the world in which we frequently search for minerals can be defined as arid. This mainly refers to a sub-equatorial belt or belts occupying large parts of Australia, Africa, North and South America and Asia (Figure 1). The regional geology of these areas varies from relatively flat and often deeply weathered Precambrian Shield (for example, in Australia) to steeply mountainous, younger regions like the Andes in Chile and Peru.

Arid terrain usually results in a lack of vegetation or at least relatively low and sparse vegetation. This paper is mainly concerned with areas which are also flat or gently undulating and often deeply weathered. Of course, many people are currently working in arid and mountainous parts of the world, for example in the Andes in South America. These are rather special conditions which rarely occur in Australia where the authors are primarily working and consequently they will not be specifically addressed.

Poorly developed drainage is often a consequence of arid conditions, particularly in flat terrain, and this may limit the application of drainage geochemistry in such areas. Arid conditions combined with relatively flat terrain result in good conditions for low flying and consequently, a range of low-level, detailed airborne geophysical methods are widely used. Deep weathering or cover is often present but its severity is quite variable. Even in deeply weathered areas, it is possible to use most geophysical methods to advantage.

Traditionally, airborne geophysical methods were developed for the detection of anomalies (magnetic, conductive, or radioactive sources), however they soon became even more useful as aids to geological mapping, particularly beneath cover. As understanding of economic geology has grown, and models of ore genesis have developed, the ability to use the available data has also increased.

The most commonly used method is airborne magnetics, usually accompanied by radiometrics, but improvements in both hardware and software are resulting in increased usage of airborne EM, often combined with other methods (e.g., magnetics). Interpretation makes increasing use of combinations of these methods in geographical information systems (GIS) and automated processing, inversion and anomaly picking using the computer power which is now readily available in the field. Additional data from geochemical sampling, satellite imagery and digital terrain can also be combined with the geophysical data

Gravity data is also used where it is available, but ground gravity data is expensive and slow to collect. The authors anticipate that, in the future, airborne gravity or airborne gravity gradiometry will be added to the exploration toolbox, both for regional mapping and even for direct detection of major mineral deposits.

An excellent recent compilation of techniques for data collection, processing and interpretation for airborne magnetics, radiometrics and, to a lesser extent, gravity data was produced by the Australian Geological Survey Organisation (AGSO, 1997).

NAVIGATION AND DIGITAL TERRAIN MODELS

The use of low level, detailed airborne geophysics places severe demands on navigation. While the lack of vegetation or drainage patterns has often made visual navigation difficult in the past, this is no longer a limitation. Modern navigation with the global positioning system (GPS) does not rely on visual landmarks and is proving far more efficient and accurate than previously used methods. Navigation with differential GPS (either post-processed or real-time) generally provides x and y locations correct to ±5 metres. The regularity of the pattern of flight lines of modern surveys located using GPS was demonstrated by Reeves (1996).

A digital terrain model, correct to a few metres, is a valuable by-product of airborne geophysical surveys and is also useful in quantitative interpretation of magnetic anomalies. In forested and rugged areas, there may be major errors in the radar altimeter data and GPS heights. On the other hand, in areas of gentle topography and sparse vegetation, radar altimeter data provide a good measure of the height of the aircraft above the ground. With improved post-processing algorithms, the position of the aircraft relative to a reference spheroid can now be determined correct to ±10 metres. With some processing, the difference between the radar altimeter height and the GPS height yields the height of the topography beneath the plane with respect to the spheroid.

MAGNETICS

In Australia, the principal geophysical method in common use in mineral exploration has been airborne magnetics for many years. In practice it is usually combined with gamma ray spectrometry, but magnetics is

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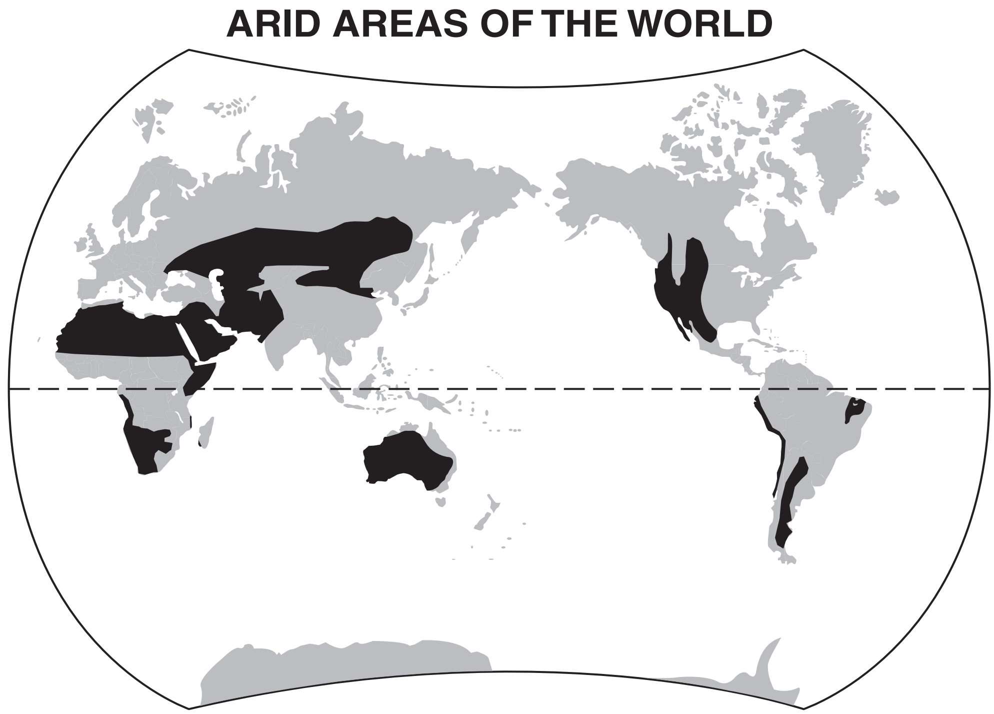

Figure 1: *World map showing semi-arid and arid regions in yellow (after Times World Atlas, 1994).*

the main tool. The arid climate makes flying possible at all times of the year, although low flying can be uncomfortable in the warmer months. These conditions have contributed to the development of very cost-effective methods and efficient contract services.

Arid weathering conditions often result in the formation of maghemite at the surface and an increase in the depth to geological sources of interest. To minimise the effect of geological noise arising from the presence of maghemite, and also for simple cost effectiveness, low-level aeromagnetic surveys are often preferred to ground surveys. In these circumstances the effectiveness of the method is enhanced rather than degraded by the arid conditions. Maghemite is not always a problem; the accumulation of maghemite in the upper horizons of Tertiary palaeodrainage channels can also be used to map the regolith and thus improve the design of geochemical surveys, as Dauth (1997) has demonstrated.

In recent years, the magnetic method has been used extensively in the search for gold in the Precambrian cratons of Australia. The Gawler Craton in South Australia was relatively unexplored till recently as explorers were deterred by Quaternary and Recent sediments which effectively blanket the underlying Archaean and Proterozoic geology. The level of exploration activity was significantly increased by the state government sponsored South Australian Exploration Initiative (SAEI). This program, which began in 1992, included high-resolution aeromagnetic surveys over much of the Gawler Craton and drilling programmes to test bedrock geology. This has led to the recent gold discoveries described below.

The Yilgarn Craton of Western Australia is characterised by gold deposits ranging from less than 1t Au to more that 1200t Au at grades between 40 and 2g Au/t. The most obvious control on the distribution of Archaean gold deposits is structure (Groves *et al*., 1990). Gold deposits are usually located in or adjacent to high-strain zones within low-strain, magnetic greenstone successions. Applying geological concepts for targeting structural settings favourable for gold deposits, exploration companies have used detailed magnetic images to locate prospective terrain in regions where outcrop is typically scarce.

It is the identification of these favourable structural settings which has led to the increased use of aeromagnetic data in gold exploration. In the past, aeromagnetic data were commonly used for regional-scale geological mapping or in the search for mineral deposits directly associated with magnetic minerals. The advent of high-resolution surveys, where the sensor is typically 60 m above the ground, the line spacing is often 200 m (but always less than 500 m), the field is sampled every tenth of a second (this translates to a 6–10 m sample spacing) and the survey accuracy is 0.5 nT; and the technology to transform and image large data sets has resulted in the ability to map, what was till recently, an unimaginable degree of structural detail.

Little exploration had been carried out on the Gawler Craton prior to the SAEI. High-resolution aeromagnetic data (typically 200 to 400 m line spacing and 80 m flying height) combined with successful, cheap and rapid calcrete sampling has played a significant role in increasing exploration activity and in the discovery of new gold deposits. A compilation of the SAEI aeromagnetic map for the northwest Gawler Craton is shown in Figure 2.

The high-resolution aeromagnetic and aeroradiometric data together with drilling results were released to exploration companies for a nominal charge. Mines and Energy South Australia (MESA) also released a sophisticated GIS package in ARCVIEW and MAPINFO format in 1993, initially on tape and later on CD-ROMs. They provided a detailed and extensive multi-layered GIS database which included solid geology, outcrop geology, images of gravity and aeromagnetic data, topographic detail (roads, railways, etc.), locations and simplified descriptions of exploration and stratigraphic drill-holes together with the most interesting geochemical intersections, and exploration licenses (including historical licenses). Free, regular updates are provided and abstracts from open-file reports have recently been incorporated.

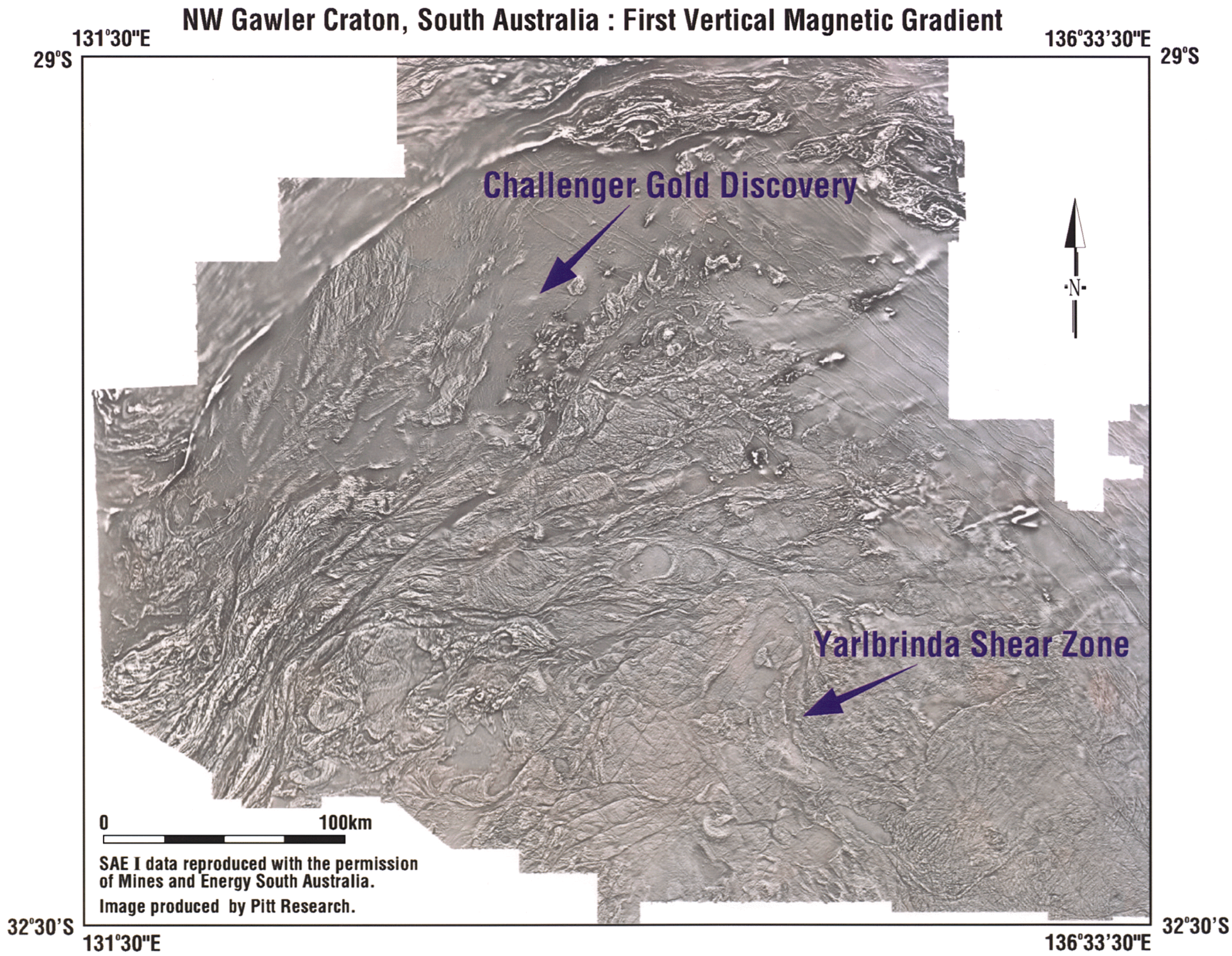

Figure 2: *Aeromagnetic map of the north west Gawler Craton, South Australia, (compilation of SAEI surveys) showing total magnetic intensity. Survey specifications: 200 to 400 m line spacing, nominal sample spacing of 7 m, nominal terrain clearance of 80 m, tie line spacing of 4000 m. There is very little outcrop in the area but the aeromagnetic image clearly shows shear zones and granites. The Yarlbrinda Shear Zone and the site of the Challenger discovery are marked on the map. The surveys were commissioned by the South Australian Department of Mines and Energy (image courtesy Pitt Research).*

The new magnetic maps indicated the kind of structural complexity which had previously been associated with the Yilgarn Craton and interpreters identified areas which fitted the classic structural settings considered favourable for gold. Within an extremely short period after the release of the data, exploration companies moved into the area and acquired exploration tenements. Sampling of the calcrete revealed that calcrete fixes copper, gold and nickel and cheap and rapid methods of calcrete sampling (using a spade or hand-operated auger) on a 1 km grid or thereabouts was successfully demonstrated by Dominion Mining Ltd. in their discovery of gold mineralisation at Challenger (see Figure 2). Successful calcrete sampling has led to a number of significant discoveries in the last 12 months, for example, South Hilga, Golf Bore etc. by the Resolute/Samantha Ltd.–Dominion Mining Ltd. Gawler Joint Venture (Daly, 1996). The north-south trending Yarlbrinda Shear Zone was defined as a result of the interpretation of the aeromagnetic data and the intersection of this shear zone with a granite (see Figure 2) is host to another gold discovery.

RADIOMETRICS

The radiometric method is also widely used although it is not often given the recognition it deserves. Lack of thick vegetation and dry surface conditions generally result in good radiometric responses, but until recently results often suffered from a lack of attention to careful field procedures and calibrations. Improvements in stabilisation of the scintillation spectrometers have led to more reliable instruments and, in combination with the development of calibration and test facilities and a technical review by AGSO (Grasty and Minty, 1995), have resulted in better radiometric data. There have also been a number of recent developments in spectral processing which appear to offer great promise for significant further improvements in airborne radiometric data quality (WGC, 1997; Hovgaard and Grasty, 1997; Minty, 1996). No doubt more improvements will be possible in both instrumentation and processing, leading to data which can truly be treated as airborne geochemistry.

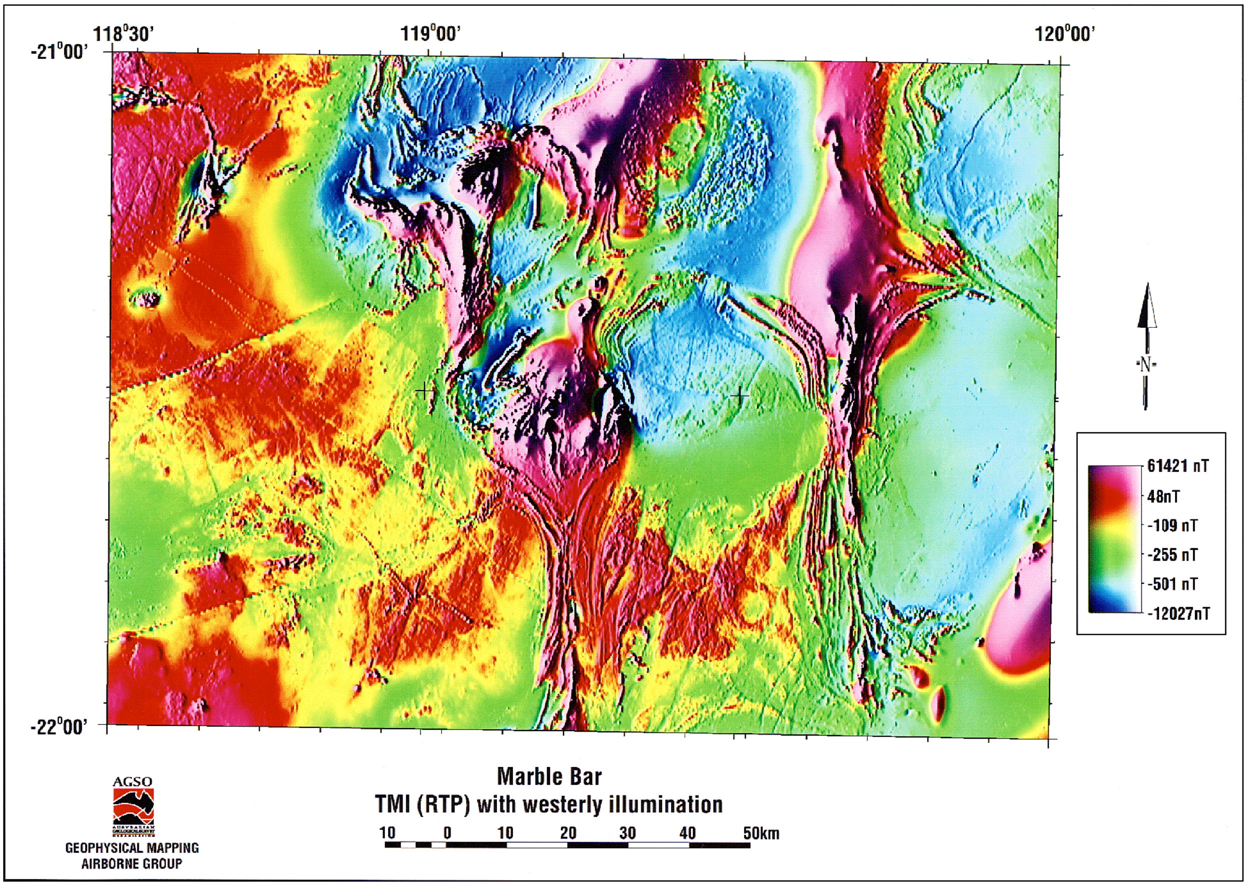

Figure 3: *The total magnetic intensity, reduced to the pole, with a westerly "illumination" for the Marble Bar, 1:250 000 map sheet in Western Australia. This map was prepared and released by the "Geophysical Mapping Airborne Group" of the Australian Geological Survey Organization (AGSO). The data were collected by AGSO in 1996 on east-west lines flown 400 m apart and 80 m above terrain.*

Combined with magnetics, airborne radiometrics is a powerful aid to geological mapping, providing a basic framework for mineral exploration. This combination of more than one method, measuring totally different geophysical (or geochemical) properties, is now a commonly used approach to regional exploration. Regional maps of magnetics and radiometrics, together with derived regional geological maps are often provided, relatively cheaply, by governments as an incentive to attract mineral exploration activity.

Figures 3 and 4 above are clearly both responding primarily to bedrock geology. The geology of this map sheet has been mapped and interpreted at 1:250 000 scale by the Geological Survey of Western Australia from numerous traverses aided by air photo interpretation. There is good outcrop and weathering is not severe. Nevertheless a geological framework could have been easily interpreted from either the magnetic map or the radiometric map and additional detail can still be interpreted. Compositional variations within the large ovoid granite bodies are clearly reflected in the radiometric response and even within the volcanics, additional unmapped structure and lithology can be interpreted. Quaternary cover is present in the North West corner of the map sheet and around the drainage channels evident near the Central part of the Western boundary, obscuring detail in the radiometric image which is still apparent in the magnetic image.

In addition to the mapping applications airborne radiometric data can also assist in the detection of alteration haloes superimposed on the primary signatures of lithology and thickness of cover. In some cases these signatures are obvious, in others it may be necessary to apply some normalization process to remove or suppress the lithological component before the anomalous alteration signature can be recognized. In the former case, potassic alteration will be visible as red or pink areas on the standard radiometric ternary image which maps the potassium, uranium and thorium signals to red, blue and green bands. Often this alteration is associated with a magnetic intrusive and the potassically altered areas may correspond with strong nearly circular magnetic features on the magnetic image.

ELECTROMAGNETICS

Airborne electromagnetic methods have rarely been as successful in Australian arid terrain as they have been in, say, Canada. This has mainly been due to deep weathering obscuring the responses from sulphide mineralisation, and simultaneously creating spurious anomalies in the regolith. In recent years, however, there have been major improvements in airborne EM methods (GEOTEM, QUESTEM) to improve

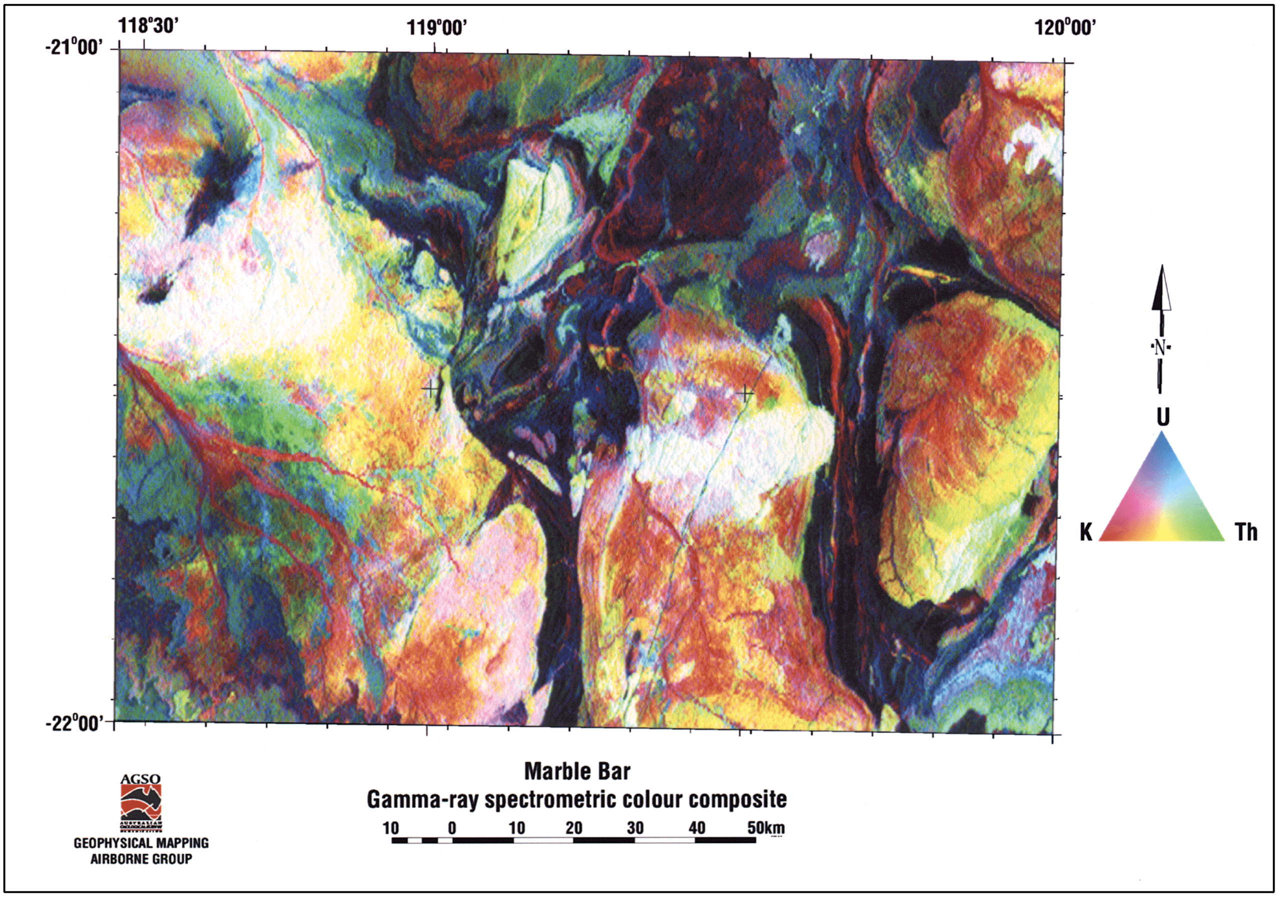

Figure 4: *A three-color composite of airborne gamma ray spectrometry for the Marble Bar, 1:250 000 map sheet in Western Australia. This map was prepared and released by the "Geophysical Mapping Airborne Group" of the Australian Geological Survey Organization (AGSO).*

effective depth penetration and, hopefully, improve discrimination or anomaly interpretation. Concurrently, new methods of automatic anomaly picking and interpretation are under development (McNae, J., 1997) and these, together with improved data, should help to sort out the numerous anomalies which are anticipated as a consequence of hardware improvements.

Strictly speaking, airborne electromagnetics is not yet a regional tool but there is a growing push within the industry to move in that direction so that conductivity maps can join magnetic, radiometric and gravity maps as standard geophysical tools.

GRAVITY

Airborne gravity has been the dream of geophysicists for many years and it may be close to realization. Of course, airborne gravity is available now but with a sensitivity and resolution which offers little benefit to mineral explorers. Even with projected improvements it seems unlikely that airborne gravity will ever offer the sensitivity and resolution necessary for direct detection and recognition of an ore body. It seems however that airborne gravity gradiometry may indeed do so and several systems are currently under development. At least arid conditions and flat terrain assist low flying and minimize terrain effects. Terrain effects will still be significant however and careful corrections will be necessary, made possible by high quality digital terrain models which may be produced as a byproduct of the airborne survey. Arid conditions and a consequent lack of vegetation make such digital terrain models possible from a combination of GPS for absolute height and altimeters for aircraft height above terrain.

Figure 5 shows an image of a simulated airborne gravity gradient survey over a three dimensional finite mesh model of the Century ore body and its immediate surrounds. The model was constructed from a CRA Exploration ore body model based on the extensive drilling results up to 1993 and includes a detailed digital terrain model. Terrain effect noise was modelled by subtracting the effect of a constant density terrain model calculated at aircraft positions differing from those of the simulated survey by a random Gaussian field with a standard deviation of 1 m. Instrument noise was simulated by an independent Gaussian field with a standard deviation of 1 Eö.

This demonstrates the potential power of airborne gravity gradiometry in detecting world class ore bodies, particularly when one considers that neither Century nor the structures that control its position have any recognizable magnetic signature.

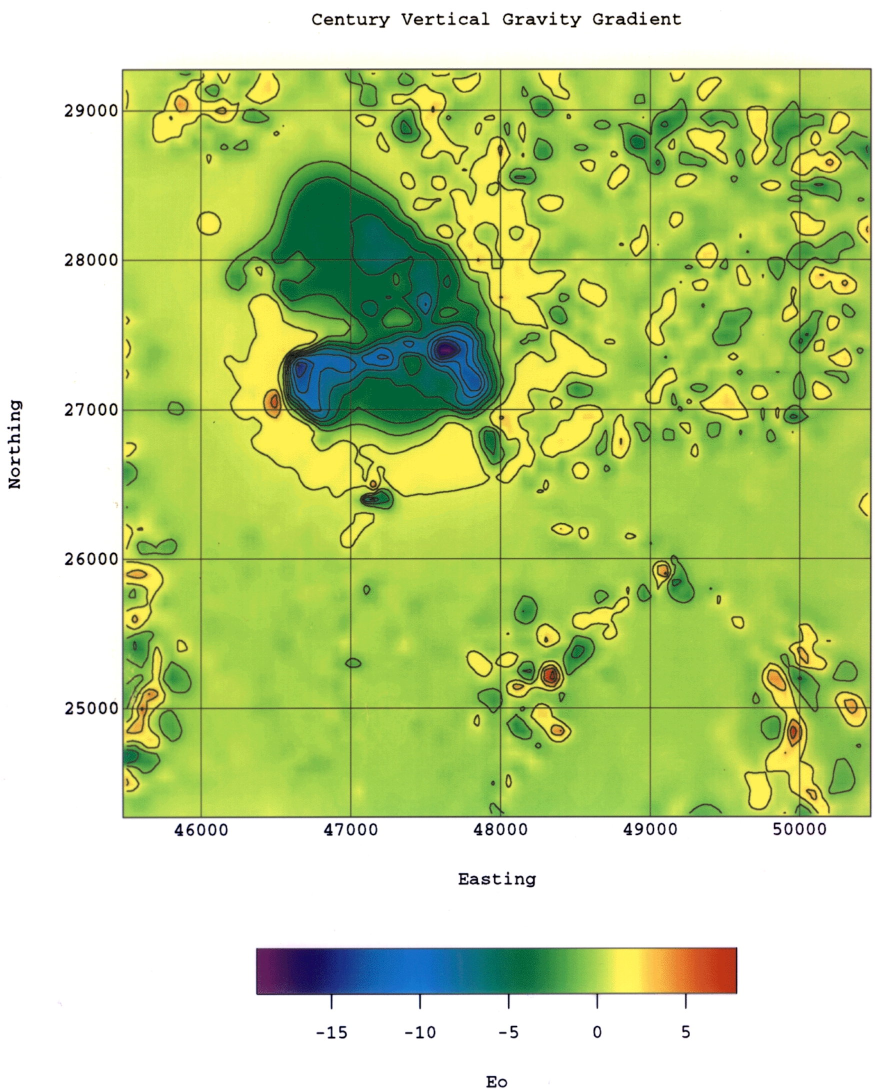

Figure 5: *The terrain-corrected vertical gravity gradient calculated for a simulated airborne gravity gradient survey over a 3-D finite mesh model of the Century ore body and its surrounds in northwest Queensland, Australia.*

INTEGRATION FOR INTERPRETATION

The ease with which large detailed regional geophysical data sets can be collected in the arid terrain of Australia has the potential to lead to data overload. Fortunately, in parallel with the developments that have made the data acquisition possible, there have been developments in computing hardware and software that have made it possible for the geoscientist to readily use this data. Geophysical data sets come as located, gridded and imaged data and all three forms can be utilized on the computer desktop with the capacity to readily switch from one to the other. With desktop mapping tools, various data sets can be assimilated to create interpretations and guide exploration.

Integration of the available data is at its most powerful when the data are well matched. Digital terrain data integrated with radiometric data helps in developing an understanding of how drainage is affecting the radiometrics. The combination of magnetics and gravity can be very powerful in mapping deeper sources. Alteration zones around magnetic intrusives can be mapped by the integration of radiometric and magnetic data. In the conductive overburden of the Australian arid zones, integrating airborne electromagnetics with radiometrics can be very powerful for discriminating different styles of conductor. An example of this is shown in Figure 6.

As well as the geophysical data, there are a variety of other types of information that can aid in the interpretation. Geographical information systems and desktop mapping tools allow the interpreter to include vector information and geo-referenced databases such as digital geology, tenement information, drillhole and surface samples and known mineralisation occurrences in the interpretation. The interpretation itself can be drawn as a digital layer on the computer.

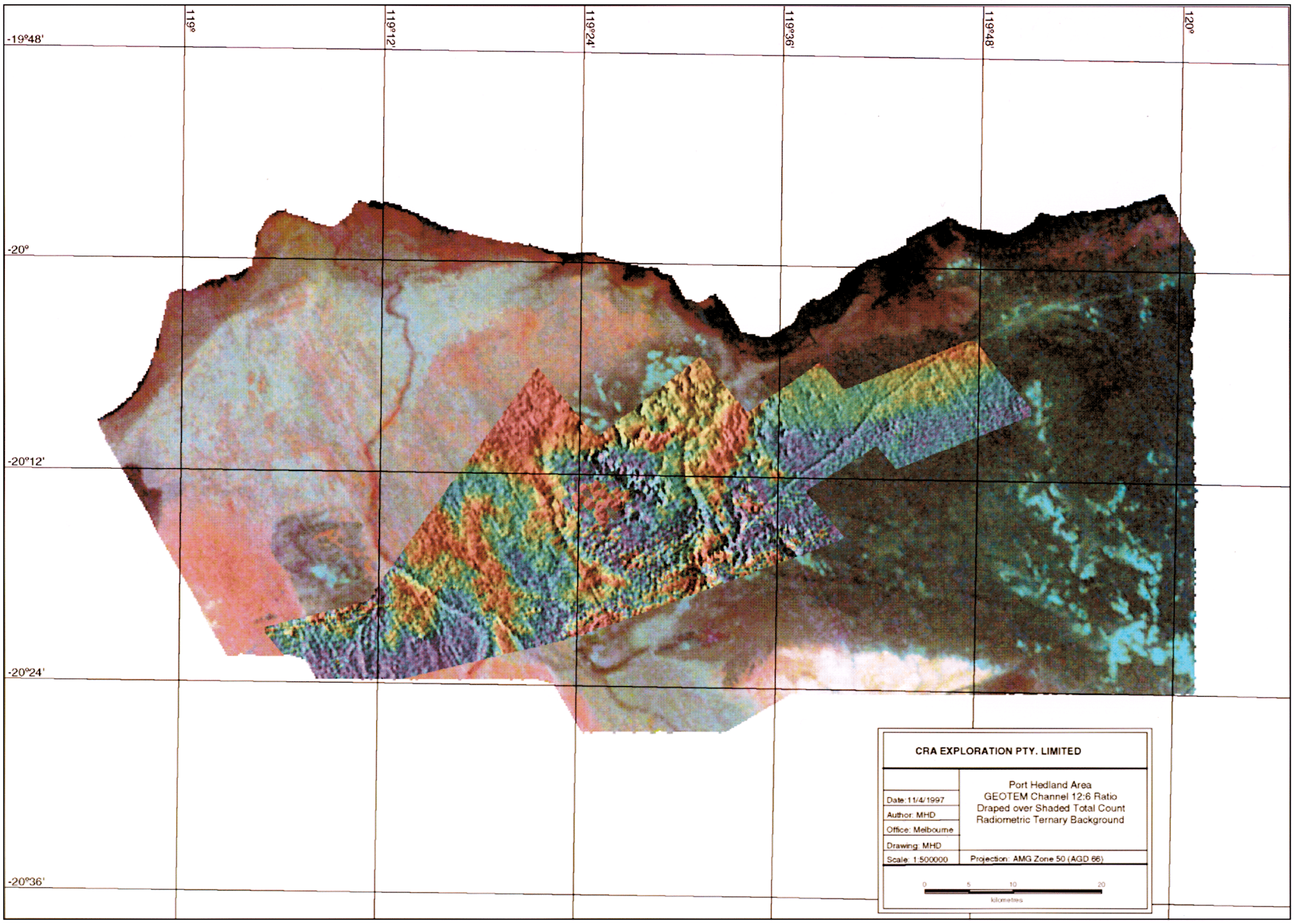

Figure 6: *The large regional image (the backdrop) is a ternary radiometric image over part of the Port Hedland 1:250 000 map sheet in north west Australia. Overlying this is a pseudo color ratio of GEOTEM channels 12 to 6 draped over a shadowed relief of the radiometric total count. The GEOTEM ratio is a useful indicator of conductivity. The nearly linear feature running in a WNW direction in the eastern end of the total count relief data is a road. The three more sinuous features in the west and center of the total count data are present-day drainage features heading towards the coast at the north of the image. There are clearly related but not entirely coincident conductive trends in the GEOTEM data. These latter are interpreted to indicate palaeo-drainage channels (image courtesy CRA Exploration Pty. Limited).*

REGIONAL DATA AVAILABILITY

In the modern world many countries are now recognizing the value of mineral development and often competing for exploration expenditure. Even individual states within Australia do this by undertaking regional airborne surveys and making the data available at low cost to exploration companies. In the south eastern states of Australia, over one third of the land area has been flown for magnetics and radiometrics in the last ten years at line spacings of 100, 250 and 400 m. In addition, the states provide regional geological interpretations and a compilation of most other regional data relevant to exploration.

The fact that such large areas can be surveyed easily and at relatively low cost is due in part to the flat arid nature of the terrain. As a result more regional data is available than ever before and many new tools are becoming available to help geophysicists integrate and interpret these data.

The availability of such regional data sets is of great value to exploration companies, and it can certainly influence the geographical distribution of exploration expenditure. In addition to direct data acquisition by exploration companies there are significant opportunities for governments to invest in such data acquisition to attract exploration dollars and for service companies to acquire it via multi-client surveys with or without underwriters. A great deal of existing data can be also be retrieved, checked, upgraded or recompiled and made available to exploration

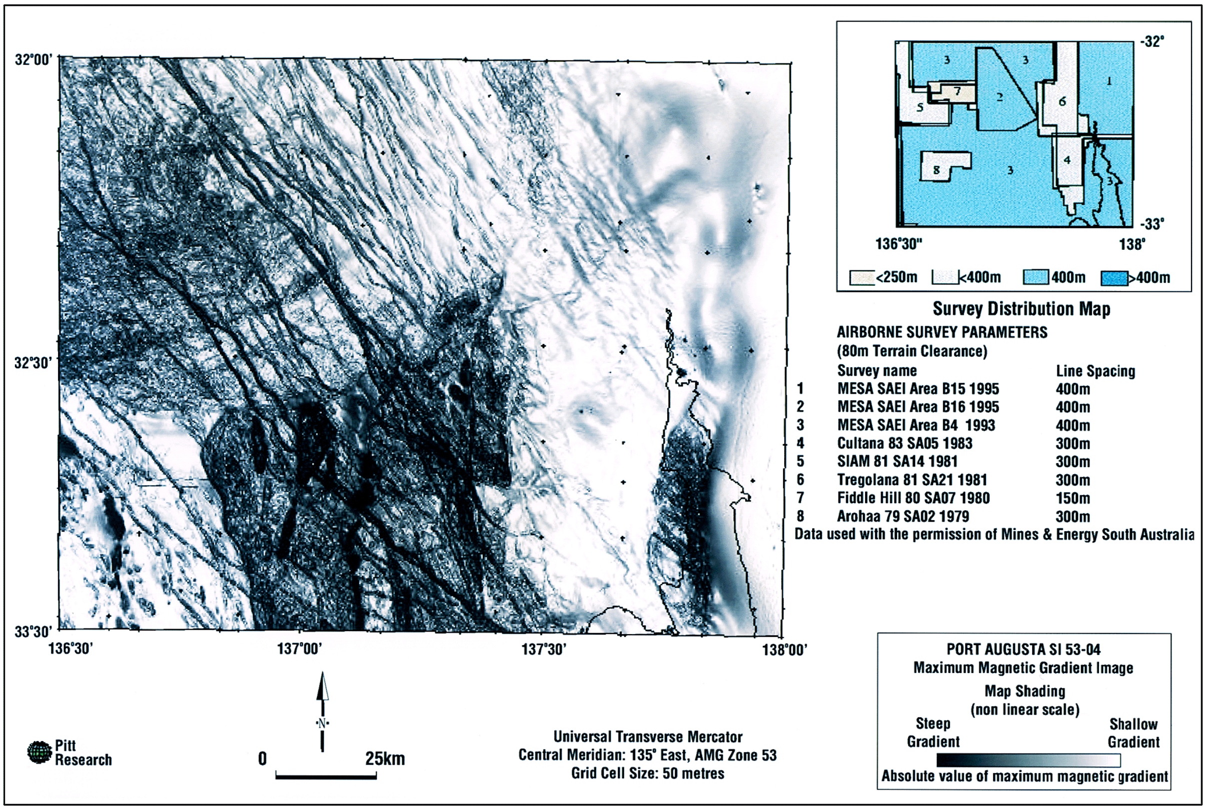

Figure 7: *Aeromagnetic map of the Port Augusta 1:250 000 map sheet, South Australia, showing maximum magnetic gradient of the total magnetic intensity and representing a compilation of company and government surveys (image courtesy Pitt Research).*

companies, as shown in Figure 7. These activities are already a significant part of the business for a number of service companies and they are expected to continue.

CONCLUSIONS

Arid terrains have a range of characteristics which can lend themselves to regional exploration with, principally, airborne geophysical methods. There are many new developments in hardware, processing and in interpretation tools which offer improvements in the way the data is used, if it is available or if it can be acquired. If regional data sets are available to explorers at reasonable cost then this will assist in area selection and encourage exploration.

ACKNOWLEDGEMENTS

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