The Use of Airborne Gamma Ray Spectrometry by M.I.M. Exploration — A Case Study From the Mount Isa Inlier, North West Queensland, Australia

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ABSTRACT

This paper describes how airborne radiometrics has been used by M.I.M. Exploration Pty. Ltd. (MIMEX) to aid mineral exploration. The case study for this paper focuses on the Mount Isa airborne survey undertaken from 1990–92. During this survey both radiometrics and magnetics were recorded over 639 170 line kilometres. Due to the perceived value of the radiometric data, stringent calibration procedures, including the creation of a test range, were adopted. In addition to the newly flown areas, agreements were entered into to acquire existing data (76 760 line kilometres) from other companies. These were reprocessed and stitched in to give an overall 'seamless join' to images. The total area covered by the Mount Isa airborne survey was 1 513 000 km^2.

Over the last five years MIMEX has undertaken a number of projects and generated a number of products to maximise the in-house use of radiometrics for mineral exploration. This paper highlights these products, techniques, and results based on radiometric signatures of major mines in the Mount Isa Inlier; radioelement contour maps; geomagnetic/radiometric interpretation maps; lithological mapping; regolith mapping; geochemical sampling; and spatial modelling using geographical information systems (GIS).

Due to the recent introduction of GIS technology and better techniques for handling MIMEX's high quality digital data, there has been a revived interest in making more use of image data sets. The integration of raster and vector data sets for both spectral and spatial modelling has highlighted the vast potential that lies ahead.

INTRODUCTION

MIM Exploration Pty Ltd (previously Carpentaria Exploration Company) has been using airborne radiometric techniques to assist in mineral exploration since the late 1960s.

The initial work was largely for uranium exploration, but a gradual evolution to mapping using multichannel systems occurred. Unfortunately, the data quality often varied between surveys and companies, and thus the data was compromised and too often not interpreted properly.

In 1990, MIM Exploration Pty. Ltd. embarked upon a major airborne geophysical program in North West Queensland, Australia (Figure 1). A significant component of this program was the need to collect high quality, radiometric data, which would assist mapping and target generation in this highly prospective region (Figure 2).

To maintain radiometric data quality throughout the survey, which occurred over a 12-month span and used 4 different aircraft, stringent survey specification and calibration procedures were adopted. These specifications were established by MIMEX in conjunction with World Geoscience Corporation Ltd (WGC), the contractors. The adherence to these standards allowed the collection of 639 170 line kilometres of data converted to elemental concentrations. This allowed accurate comparison across areas and enabled the implementation of spatial modelling techniques using GIS for quantitative interpretation.

Survey procedures

The survey was largely flown east-west using 200 m line spacing, terrain clearance of 80 m, and a radiometric sampling interval of 60 m. Areas where the interpreted depth to magnetic basement was greater than 300–400 m were flown at 400 m. The wider spacing was chosen due to the reduced prospect of locating economic mineralisation at these depths.

The four spectrometers used were Geometrics Exploration GR800B units with crystal volumes of 33.56 litres. Two hundred and fifty-five

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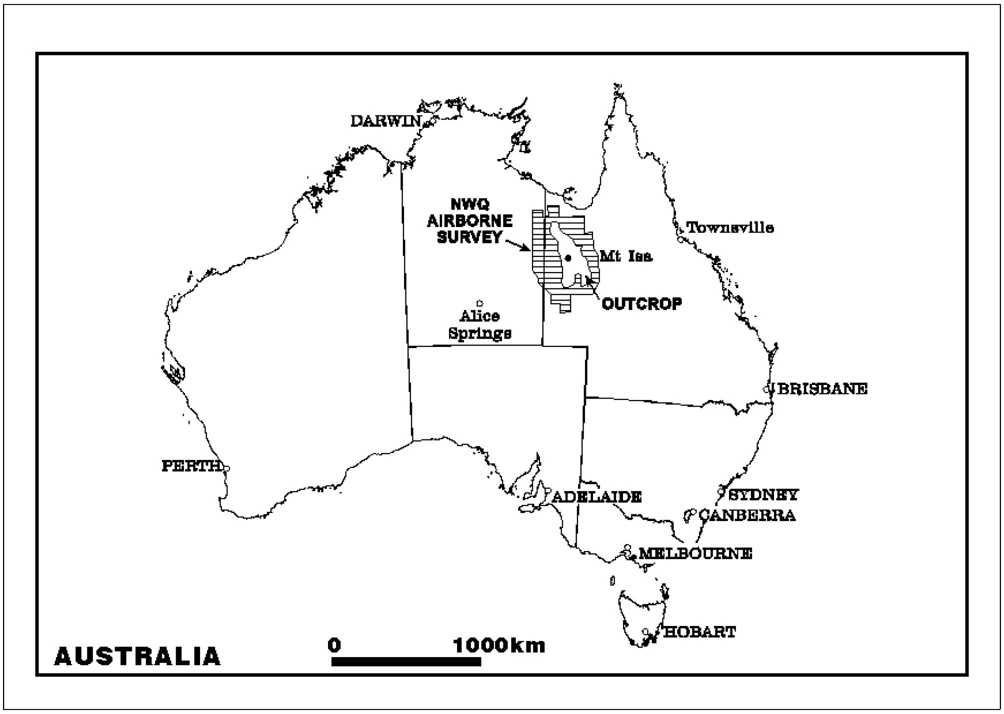

Figure 1: *Mount Isa Inlier radiometrics survey location diagram.*

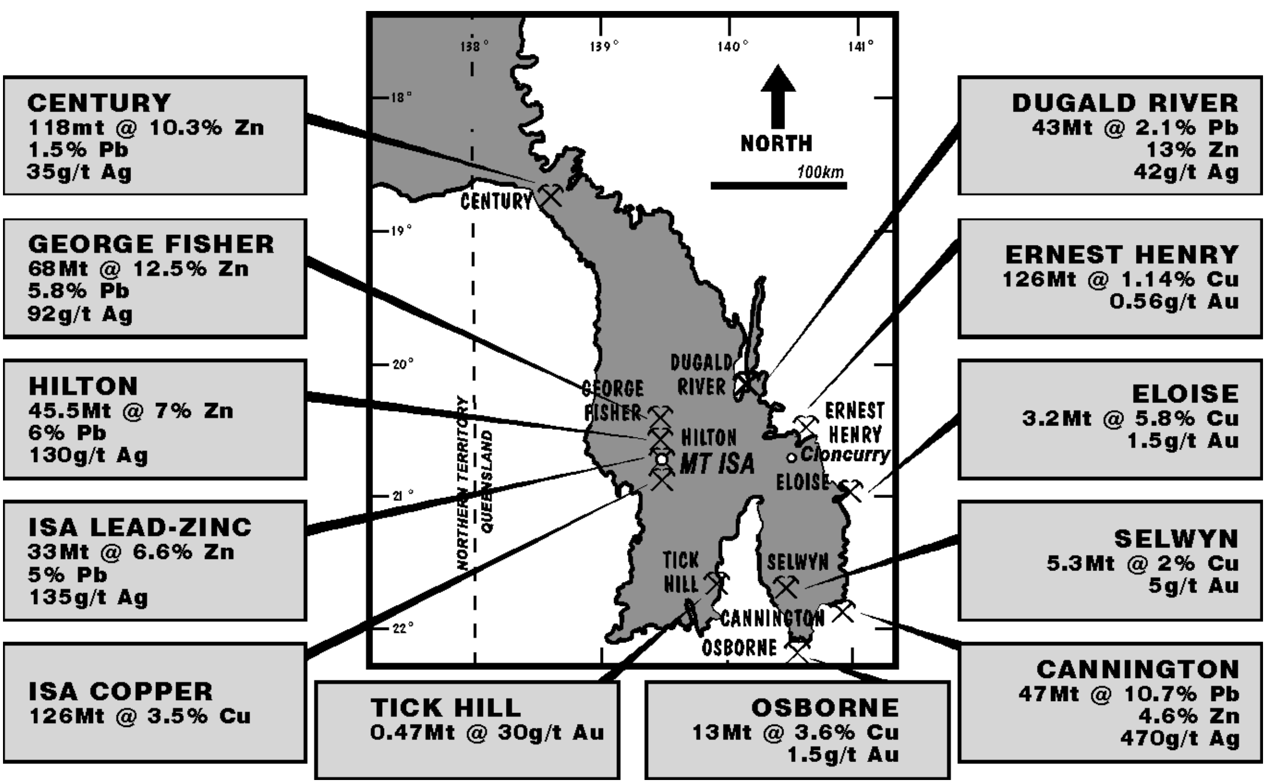

Figure 2: *Major deposits in the Mount Isa Inlier, North West Queensland.*

Table 1: ***Spectrometer energy ranges used for interpretation.***

Name	Energy (MeV) From		To
Total Count	0.402		3.000
Potassium - 40	1.373		1.562
Uranium	1.668		1.858
Thorium	2.414		2.804
CS137		0.662	
Cosmic	3.000		6.000

channels of data were measured from 0.006 MeV to 3.0 MeV, and one channel, the cosmic channel, from 3.0 to 6.0 MeV. All channels were recorded but only the counts in the following energy ranges were displayed and used for interpretation purposes (Table 1).

To maintain data quality the following routine procedures were adopted:

- Daily spectral plots using a standard cesium source to monitor crystal tuning and drift.
- Pre- and post-flight ground calibration in a pre-selected location. A thorium source, a uranium source and no source recordings were made. The thorium and uranium data were corrected for background noise and statistical analysis conducted for spectral stability.
- Weekly checks of each individual crystal using cesium and thorium sources. Also, a drift check and crystal resolution check was undertaken.
- At the commencement, two monthly intervals thereafter, at times of crystal changes, and at completion the following additional checks were undertaken:
  - — pad calibration to determine stripping ratios (Compton Scattering)
  - — high altitude stack to determine background coefficients
  - — test range to determine height attenuation coefficients and to determine sensitivity coefficients

The pads used for calibration were manufactured by Dr R.L. Grasty of the Geological Survey of Canada.

The test range established for this survey allowed accurate conversion of data to percent potassium, equivalent ppm uranium, and equivalent ppm thorium. An example of the results from an in-field calibration run is shown in Figure 3. Where the concentrations computed from surface geochemical sampling are plotted against ground and airborne counts.

It is considered that the rigorous implementation of the above procedures has resulted in a data base unique in Australia, which allows quantitative interpretation of the worlds largest continuous commercial airborne survey at the time. The collection of 256-channel data will allow reprocessing of data if and when required.

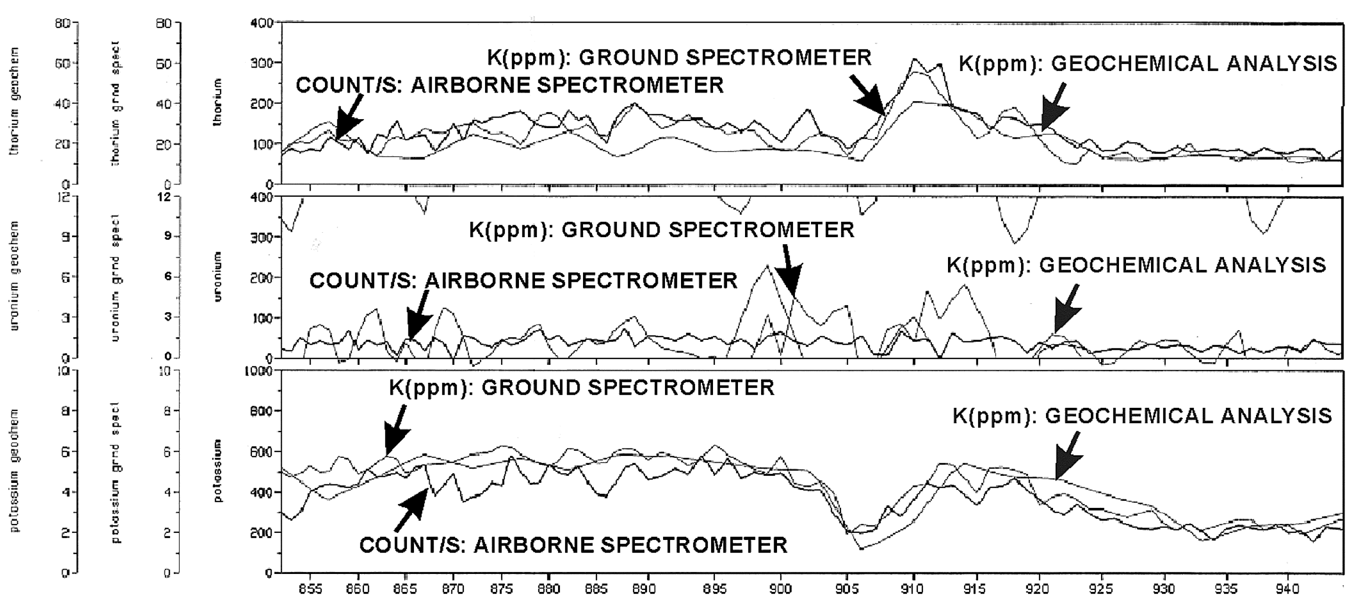

Figure 3: *Calibration ranges 20-Sept-1990 (field copy).*

RADIOMETRIC PROJECTS

This section describes products and techniques developed to maximise the use of radiometrics in MIMEX's exploration efforts.

Radiometric signatures for major deposits in the Mount Isa Inlier

Detailed visual analysis of the airborne radiometrics was carried out over eighty mineral deposits. An example from this compilation is the Dugald River deposit situated 300 km northwest of Mount Isa on the Quamby 1:100 000 scale map sheet. Dugald River is a zinc/lead/silver deposit with an estimated resource of 60 Mt at 10% Zn, 1% Pb and 30g/t Ag. The deposit type is a sheeted mineralisation of Proterozoic age. The host rock is the Dugald River Shale Member containing black, commonly carbonless shales. Mineralisation occurs in fine grained black slate with abundant sulphides. The primary mineralogy is pyrrhotite, sphalerite, pyrite and galena. The airborne radiometrics for this deposit (Figure 4) highlight the presence of a 2 km north-south lineament centred about the deposit and enriched in uranium (U) and potassium (K). The large K high to the west of the deposit is due to a Knapdale Quartzite ridge, which is dominated by potassium feldspar. The magnetics over this deposit (Figure 5) showed a prominent north-south magnetic lineament, 6 km long and with a peak amplitude of 660 nT, associated with a pyrrhotite enriched stratigraphy surrounding and including the mineralisation. This has been mapped as a steep synform in the Corella Formation.

Radioelement contour maps

Radioelement contour maps were generated by WGC at 1:100 000 and 1:25 000 scale over the survey area. The radiometric data was corrected for attenuation and stripping ratios and then gridded at 70 m. System parallax was removed and microlevelling was applied. The spectrometer sensitivity coefficients were: potassium 95.3 cps/% K; uranium 10.59 cps/eppm U; and thorium 6.97 cps/eppm thorium (Th). Figure 6 shows part of the Quamby 1:100 000 scale radioelement contour maps, over the Dugald River deposit. Contour maps were generated for total count (50 counts per second contour interval), potassium (0.1% contour interval), thorium (1.0 eppm contour interval) and uranium (0.5 eppm contour interval). These maps are used to aid in the visual interpretation of potential exploration areas. Hard copies of these maps are available to MIMEX staff at 1:100 000 and 1:25 000 scale, and form a very useful product when interpreting the airborne radiometric survey.

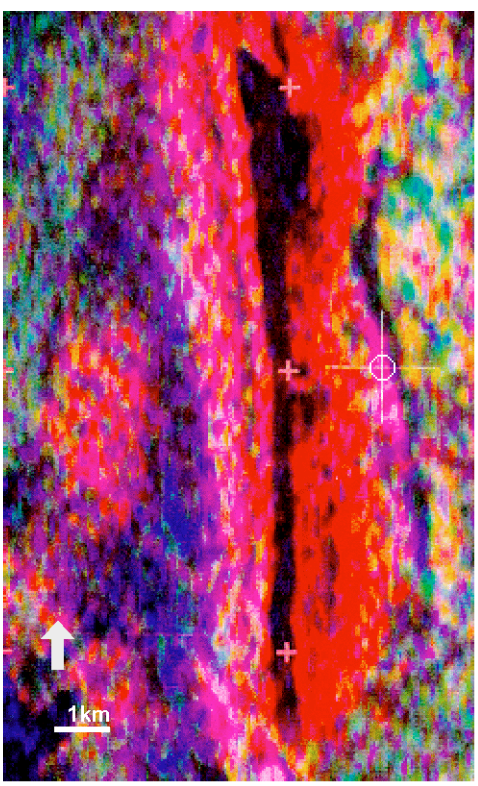

Figure 4: *The ternary image (K:Th:U = R:G:B) over the Dugald River deposit (white circle).*

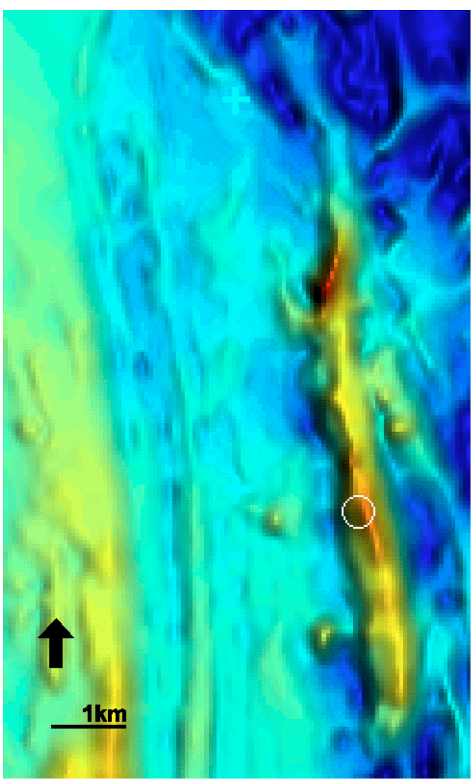

Figure 5: *Pseudo color magnetics image for the Dugald River deposit.*

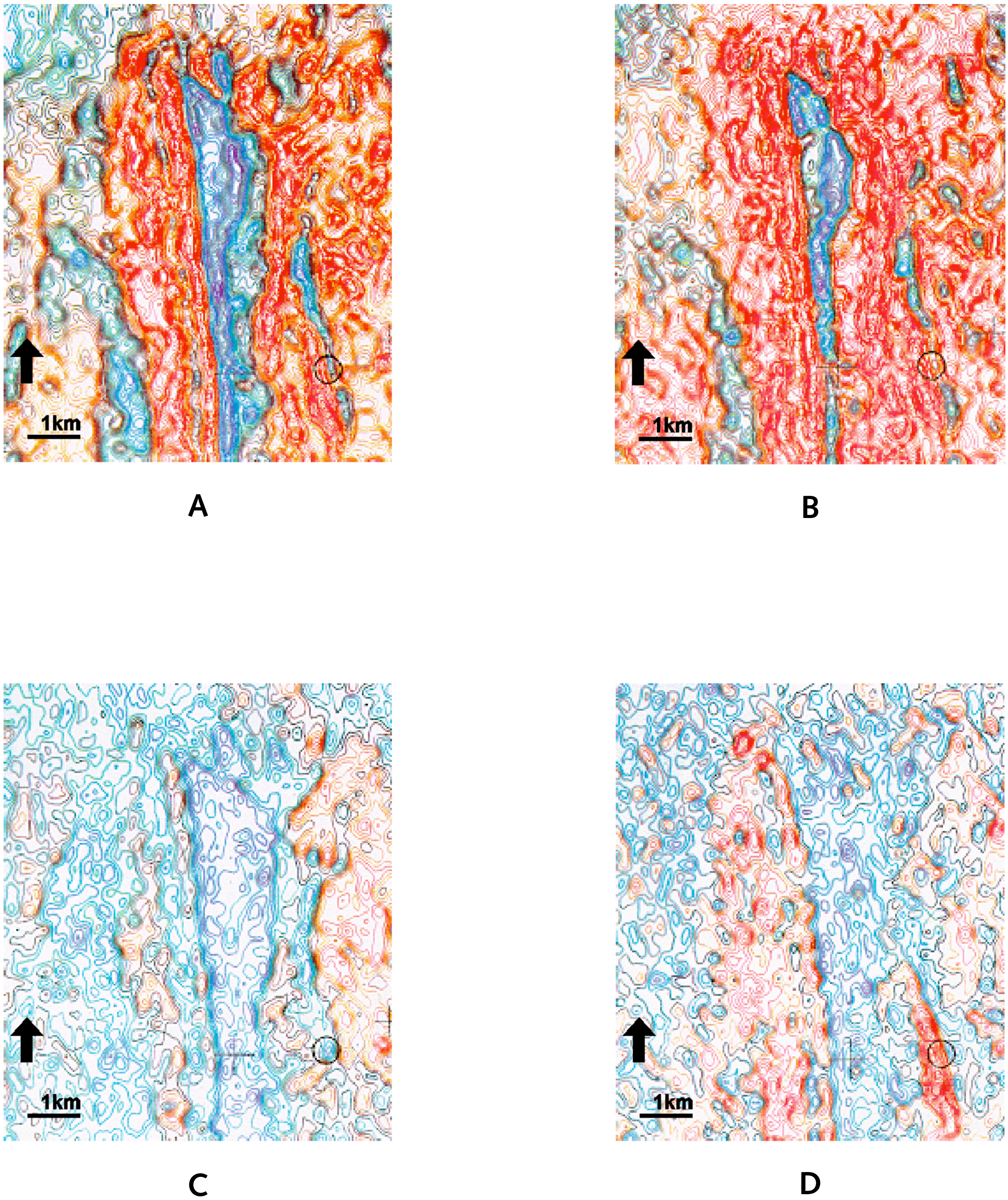

Figure 6: *Radioelement contour maps over the Dugald River deposit (black circle). (**A**) Total count with a contour interval of 50 counts per second. (**B**) Potassium with a contour interval of 0.1%. (**C**) Thorium with a contour interval of 1.0 eppm. (**D**) Uranium with a contour interval of 0.5 eppm.*

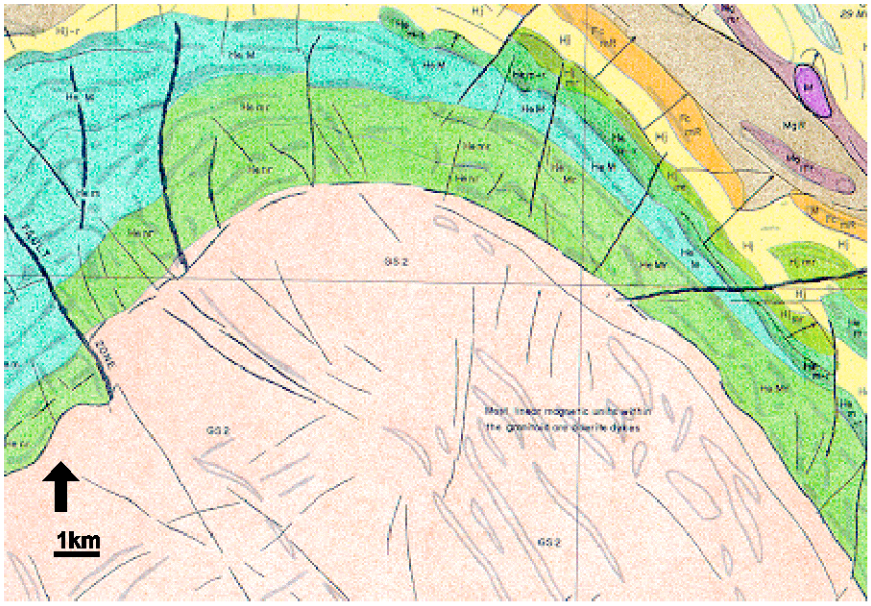

Figure 7: *An extract from the southern part of the Kennedy Gap 1:100 000 scale geomagnetic / radiometric interpretation map.*

Geomagnetic / Radiometric interpretation maps

Fifty-three 1:100 000 scale geomagnetic/radiometric interpretation maps were compiled from radiometric and magnetic contour maps and images by WGC and in-house interpretation teams. An example is shown in Figure 7. Geological control was from the Bureau of Mineral Resources mapping published at 1:100 000 scale and localised mapping from MIMEX. The area shown in Figure 7 is approximately 20 km nortwest of Mount Isa and on the southern part of the Kennedy Gap 1:100 000 scale map sheet. The large dome-shaped body in the centre is the Sybella Batholith and can be distinguished clearly in the radiometrics. The eastern and marginal parts of the batholith are non-magnetic and highly enriched in K. The west and central part of the batholith shows consistent weak, noisy magnetic patterns and variable radioelement response. Enrichment in U and Th is also common. These geomagnetic and radiometric interpretation maps have been very useful in MIMEX's first pass targeting.

Lithological mapping

Radiometrics has been very useful in delineation of lithological boundaries and geological mapping mismatches. This process involves overlaying of geology maps or traced geological boundaries onto radiometrics and Landsat Thematic Mapper images to highlight areas of variation and possible mismatch. While this can be achieved using hardcopy maps and images, recent improvements in computer hardware and software capabilities and the introduction of GIS technology has enabled the overlaying of data sets on the computer screen. Figure 8 shows the published Bureau of Mineral Resources geological boundaries (white) overlain on the radiometrics (K:Th:U = R:G:B). The area shown in Figure 8 is approximately 70 km north of Mount Isa and on the northeastern corner of the Kennedy Gap 1:100 000 sheet. The dark areas (low K, Th, and U) are part of the orthoquartzite component of the Leander Quartzite. The bright area (high K, Th, and U) in the lower left of Figure 8 differentiates the Gunpowder Creek Formation and, in particular, the micaceous siltstone and ferruginous siltstone components.

In areas of good outcrop, the radiometric data is very good at delineating the geology and is readily interpreted. Interpretation of the radiometrics for lithological mapping becomes more difficult in deep, transported soils. In these areas radiometrics have proven more useful for regolith mapping and planning geochemical surveys.

The use of radiometrics to aid lithological mapping has been further enhanced by the use of GIS based spatial modelling, discussed below.

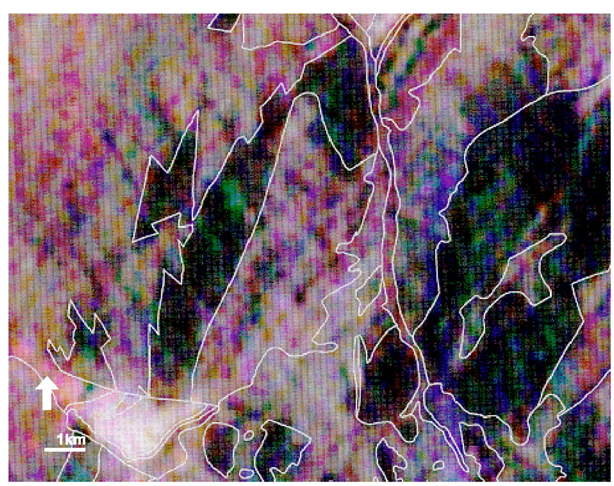

Figure 8: *Radiometric colour image (K:Th:U = R:G:B) overlaid with geological boundaries (white) from the northeastern corner of the Kennedy Gap 1:100 000 scale published mapping.*

Regolith mapping

The awareness of the value of regolith mapping in mineral exploration is rapidly increasing. By understanding the regolith, a better grip on the underlying geology can usually be attained and importantly, exploration techniques to explore below the regolith can be devised. When the radiometrics is combined with Landsat Thematic Mapper, aerial photography, and digital elevation models, a better understanding of the regolith landforms can be attained. An example of the use of the Mount Isa airborne radiometrics data set to identify depositional areas is shown in Figure 9. The various regolith boundaries are in grey and have been overlaid onto the ternary image (K:Th:U = R:G:B). The lighter coloured arcuate channel in the top centre of the figure highlights an area of alluvial clays and silts, within a depositional zone. By using the radiometrics these depositional zones can be very quickly identified in similar regolith settings elsewhere.

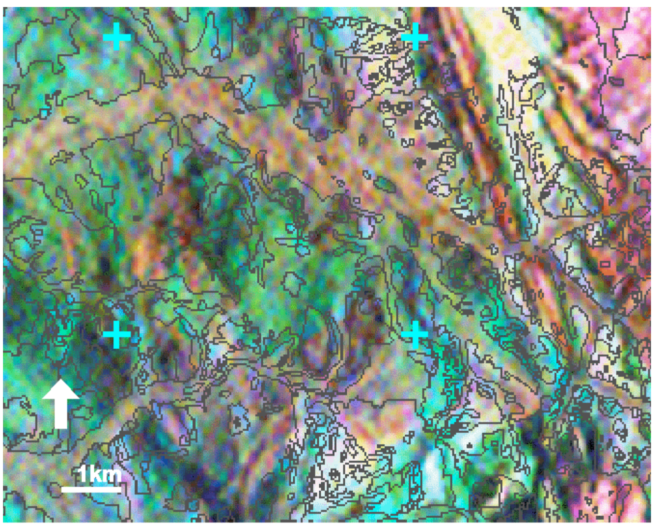

Figure 9: *Radiometrics ternary image (K:Th:U = R:G:B) with regolith boundaries overlaid in grey. The lighter coloured arcuate channel running across the top centre of the figure, is an area of alluvial clays and silts, within a depositional profile.*

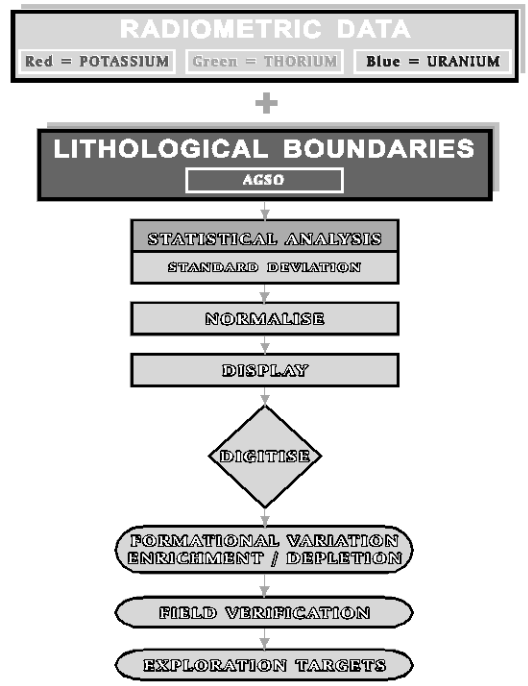

Figure 10: *Radiometric normalisation methodology.*

Geochemical sampling

Radiometric data has been recognised (but too often ignored) as useful in planning exploration geochemical surveys and in interpreting previous ill-constrained surveys. By recognising the context of regolith landforms—depositional, erosional or residual, the sample site significance can be better used in the interpretation.

Spatial modelling using GIS

The introduction of GIS technology into MIMEX's exploration effort has enabled the development of semi-automated spatial analysis models to aid in the interpretation and analysis of large quantities of the airborne radiometric data within a reasonable time frame. The techniques described below were developed as part of the data synthesis, regional interpretation and targeting for the Mount Isa block and involved MIMEX staff and Dr. B. Dickson (CSIRO, Exploration and Mining).

The aim was to identify anomalous radiometric (enrichment or depletion) responses within lithological units. Figure 10 shows the radiometric normalisation methodology adopted. The technique required the development of a GIS-based model to analyse and normalise the radiometric data within each lithological unit. Lithological boundaries were obtained from the 1:100 000 scale Australia Geological Survey Organisation (AGSO) published mapping.

The GIS model generated normalised images for a given 1:100 000 scale map sheet. The radioelement statistics for each lithological unit were also automatically generated. These included: gcode (unique number for each lithological unit), minimum, maximum, mean and standard deviation. Once normalised images were created, standard processing was carried out to stretch the images to highlight areas of enrichment (>= 3 std) and depletion (<= -2 std). Different cut-offs were chosen for enrichment and depletion as the normalised distribution showed a negative skew. The resulting new image contained nine bands, 1–3 containing K, Th, U from the original image; 4–6 containing areas of enriched K, Th, U; and 7–9 containing areas of depleted K, Th, U. The resulting nine band image was taken back to the GIS for second pass processing. In the second pass processing the enrichment and depletion areas from pass one were masked out of the radiometrics and the normalisation re-run to highlight the subtle highs and lows. The results from the second pass were combined with the first pass to create radiometric enrichment and depletion maps (Figures 11 and 12). Figure 11 shows an example of part of the Mount Isa 1:100 000 scale radiometric enrichment map around the Mount Isa deposit.

The Mount Isa deposit is a zinc/lead/silver/copper deposit in the Mount Isa Inlier mineral province. The estimated resource is 150 Mt at 7% Zn, 5–6% Pb and 140 g/t Ag and 255 Mt at 3.3% Cu. The deposit types are stratabound for Zn/Pb and discrete tabular bodies for Cu. The host rock for the Pb/Zn and Cu ore bodies is the Urquhart Shale, which contains dolomitic and variable carbonaceous siltstone rich in fine grained pyrite and numerous tuff beds. The Cu ore body has a silica dolomite alteration halo. In Figure 11, the lithological boundaries are in grey and the ternary image (K:Th:U = R:G:B) highlights areas of K, Th and U enrichment.

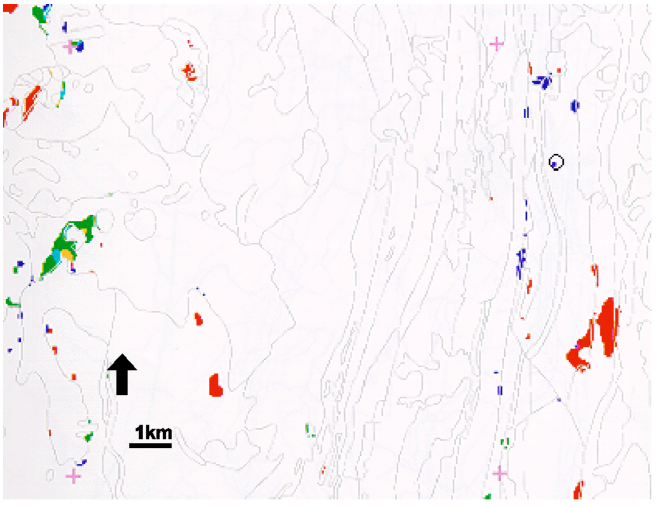

Figure 11: *An extract from the Mount Isa 1:100 000 scale radiometric enrichment map. The centre of the Mount Isa deposit is shown by a black circle. The lithological boundaries are in grey and the ternary image (K:Th:U = R:G:B) highlights areas of K, Th and U enrichment.*

An interesting finding from this technique is the large area of K enrichment to the south of Mount Isa. This occurs on the Native Bee Siltstone unit which is stratigraphically above the Urquhart Shales and composed of bedded dolomitic siltstone, laminated siltstone, minor tuff, and chert. Field assessment using a hand held spectrometer confirmed this area as an area of high K alteration. Which could be interpreted as a possible fluid channel for the ore bearing fluids of the Mount Isa deposit.

The technique has also highlighted lithological boundaries. For example, the area of Th enrichment on the western edge of Figure 11 was due to a mapped geological boundary mismatch between the Sybella Granite and Cainozoic cover in the AGSO database.

Figure 12 shows an example of part of the Mount Isa 1:100 000 scale radiometric depletion map around the Mount Isa deposit. The lithological boundaries are in grey, roads are in gold, and the ternary image (K:Th:U = R:G:B) highlights areas of K, Th, and U depletion. The depletion results identify a large area of Th depletion coincident with the surface projection of the lead/zinc ore body. The Th depletion is mainly within the Urquhart Shale and could not be due to geological boundary effects. At present, and at the time of the survey, the area was covered by mining infrastructure, thus the source has not been identified and could be geological or man made.

Another example of geological mismatch is the sliver of K depletion to the West of Mount Isa. This has resulted from a lithological boundary mismatch between the Eastern Creek Volcanics and the Mount Guide Quartzite.

This semi-automated spatial modelling technique has resulted in defining areas of enrichment/depletion and thus prospective for mineralisation. It has also assisted in more precise geological mapping of areas considered previously to be well mapped.

CONCLUSION

Each of the products and techniques described have provided invaluable information in helping MIMEX geoscientists better understand the complex environment in which they work. The overall compilation of the radiometric signatures for the eighty major mines in the Mount Isa Inlier was bound into a three volume set. This unpublished document provides a very useful resource for MIMEX geoscientists. Hard copies of the radioelement contour maps are available to MIMEX staff at 1:100 000 and 1:25 000 scale, and form a very handy supplement when interpreting the airborne radiometric survey. The geomagnetic/radiometric interpretation maps have been very useful in MIMEX's first pass targeting, as have the Mount Isa airborne survey data set in helping geologists with the delineation of lithological boundaries and geological mapping mismatches. When the radiometrics is combined with Landsat Thematic Mapper, aerial photography, and digital elevation models, a better understanding of the regolith landforms can be attained. In terms of geochemical sampling the radiometric data has been recognised (but too often ignored) as useful in planning exploration geochemical surveys and in interpreting previous ill-constrained surveys. GIS analysis has enabled the development of a semi-automated spatial modelling technique for defining areas of enrichment/depletion and thus pros-

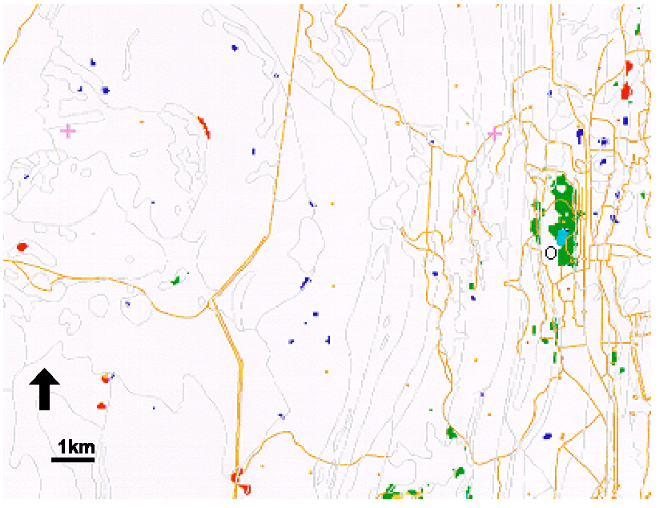

Figure 12: *An extract from the Mount Isa 1:100 000 scale radiometric depletion map. The lithological boundaries are in grey, roads in gold and the ternary image (K:Th:U = R:G:B) highlights areas of K, Th and U depletion.*

pects for mineralisation. It has also assisted in more precise geological mapping of areas considered previously to be well mapped.

The recent introduction of high powered personal computers and the improved spatial analysis capabilities through GIS has seen new emphasis placed on the airborne radiometrics and other raster data sets. MIMEX geoscientists now have the technology and capability to routinely overlay vector and raster data sets in real time on their computer screen. Image data can be spatially analysed or digitised on the screen.

By adopting internationally established airborne radiometric survey standards, the MIMEX airborne radiometric survey is of high quality and is timeless in its value for mineral exploration. Within a GIS, attribute (database) information associated with spatial features can be readily obtained and themes (data layers) can be colour coded and shaded based on their attributes. This vector information (points, lines and polygons) can be quickly and easily overlaid on the raster information (pixels) such as the radiometrics to help interpretation.

The improvements in data capture techniques, and the high quality spatial and spectral accuracy that will become available in the future, will mean a large increase in digital data.

It is through the analysis of good quality data (such as the airborne radiometrics) that will enable MIMEX to forge ahead in the future.

Although MIMEX has been working with airborne radiometrics since the late 1960s, it is only now that our computer hardware and software is equipped to maximise the benefits. There is still so much more information in the airborne radiometrics that we have not attained. The combination of radiometrics with new data and modern technology will certainly lead us closer to unlocking the earth's secrets.