Developments in airborne gamma-ray spectrometry to aid the search for strategic minerals

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Summary

We review recent developments in the processing of airborne gamma-ray spectrometric data that facilitate the detection of ever more subtle radioelement anomalies. These have application to the search for strategic minerals, often after the primary geological feature has been identified from airborne magnetics.

The recent developments include improved noise-reduction for multichannel spectra, the automatic detection of various types of radioelement anomalies, the correction of airborne data for topographic effects and the full 3D inversion of airborne gamma-ray spectrometric data to elemental concentrations on the ground. All these contribute to the utility of the gamma-ray spectrometric method for the search for strategic minerals, and are demonstrated here together with carbonatite hosted deposits.

Introduction

The airborne gamma-ray spectrometric method is an important tool in the search for strategic minerals. The strategic fission elements uranium and thorium can be detected directly, as daughters in their respective radioactive decay series produce gamma-rays that are readily detected at airborne survey heights. Rare earth elements are often found in placer deposits or residual deposits due to weathering. These deposits may also contain significant resistate minerals, such as monazite and zircon, which are rich in uranium and thorium, and thus detectable using gamma-ray spectrometry. Some deposits may have been leached near surface with significant signal now reporting in the surrounding drainage systems.

Recent developments include the following:

- the reduction of noise in multichannel airborne gamma-ray spectra using principal component–type analyses: Both the NASVD (Noise Adjusted Singular Value Decomposition) and MNF (Maximum Noise Fraction) methods can be improved by first sorting the raw spectra into clusters based on spectral shapes, and then applying the noise-reduction methods to these clusters;
- automatic detection of radioelement anomalies from 3-channel gamma-ray spectrometric data: two types of radioelement anomalies are identified – the classical "point" anomalies, and "spectral" anomalies that have rare spectral response signatures. In addition, the method for detecting spectral anomalies can be tuned to target both potassic alteration (high potassium relative to thorium) and hydrocarbon seepage alteration (low potassium relative to thorium);
- correction of airborne gamma-ray spectrometric data for topographic effects in areas of rugged terrain; and
- the 3D inversion of airborne gamma-ray spectrometric data to elemental concentrations on the ground.

Noise Reduction

The random nature of radioactive decay ensures that noise levels are a significant limitation of the gamma-ray spectrometric method. Fortunately, much of this noise can be removed using the NASVD method or the MNF method.

For large surveys, the implementation of either of these methods can be improved by first sorting the raw spectra into clusters on the basis of similarity in spectral shape. The NASVD or MNF method is then applied to each cluster of spectra in turn. This typically further reduces the random noise by a factor of two. Accuracy can be improved by incorporating spatial information into the analysis. The reduced noise enables smaller radioelement anomalies to be resolved.

Automatic Radioelement Anomaly Detection

We recognize two types of radioelement anomalies (Figure 1). The value of the anomaly A occurs only once in the dataset – its value is rare. We call this a "spectral anomaly". In the case of 3-component radioelement data (K, U and Th), spectral anomalies are those areas of the map or profiles where the 3-component radioelement signature (K, U and Th concentrations) are rare. They are calculated using a Principle Component type analysis where the aim is to search for the minor (rare) spectral components in the data. The technique can also be tuned to target potassic alteration (high potassium relative to thorium) and hydrocarbon seepage alteration (low potassium relative to thorium). Note that spectral anomalies do not necessarily have anomalous amplitudes - rather, it is the relative concentrations of K, U and Th (i.e. the ratios between the radioelement concentrations) that is anomalous.

The value at anomaly B, on the other hand (Figure 1), occurs at several places in the dataset. But it is anomalous with respect to the local background. These are the classical geophysical "point" anomalies.

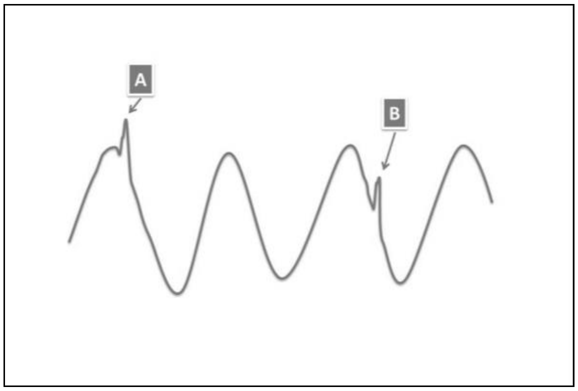


Figure 1: Hypothetical single-band signal showing 2 different types of anomalies – a spectral anomaly (A), and point anomaly (B).

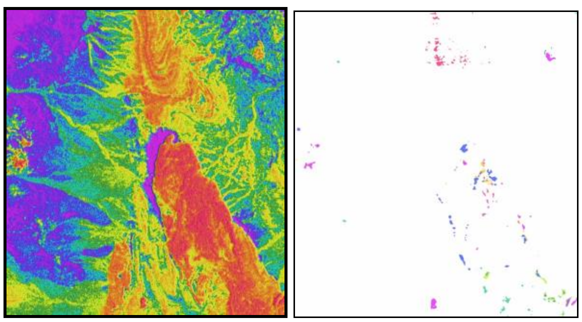


Figure 2: Detection of spectral anomalies from gridded data. The anomalies are colour-coded according to their type. Data courtesy Geoscience Australia.

Point anomalies are contextual anomalies – i.e. they are anomalous within a local context. Point anomalies are detected using a matched filter.

The methods can be applied to either line or grid data. Figure 2 shows an example of the detection of spectral anomalies from gridded data. The spectral anomalies are color-coded according to anomaly type (K, U, Th, U+Th etc).

Topographic Correction

The standard processing of airborne gamma-ray spectrometric data is based on the assumption of flat-earth topography. The effect of topography is usually minor - for gently undulating topography, the effect is generally less than 10% and within the noise envelope of the data. For rugged topography, the effect can be much larger – sometimes exceeding 30%.

We use the method of Schwarz et al. (1992), to correct line data for topography. This is a point-by-point correction applied to stripped 3-channel data prior to the height correction. It is based on the assumption that the earth has uniform concentrations of the radioelements within the field of view of the spectrometer. The correction is essentially a scaling of the data at each point by the ratio of the counts that would be detected at that point from a flat earth (with uniform concentration of a radioelement) with the counts that would be detected from the actual undulating topography (with the same uniform concentration of the radioelement). An example of the application of the method is shown later in Figure 5.

3D Inversion of Airborne Gamma-ray Data

A more rigorous way to correct for topographic effects is to invert the processed airborne radioelement line data (processed without a topographic correction) to a regular grid of radioelement concentrations on the ground in a way that incorporates the 3D topography within the field of view of the detector (Minty and Brodie, 2015).

We use a source model comprising vertical rectangular prisms of uniform radioactivity and with the same horizontal dimensions as the required grid cell size. The top of each prism is a planar surface derived from a best-fit plane to the digital elevation model of the earth's surface within each grid cell area (Figure 3). The source-detector response for a 50 m grid cell size (and hence prism size) is shown in Figure 4 for a 60 m flying height. This shows that the response due to a rectangular prism extends well beyond the source, and its effects are measureable on several airborne samples, as well as on at least one adjacent flight line on either side of the cell. The response is also corrected for the directional sensitivity of the detector and the velocity of the detector. The estimated errors in the line data are used to weight the data inversely as their variances during the inversion.

The method inverts the line data directly to a regular grid of concentrations - so there is no need for gridding. It gives superior interpolation between flight lines and better anomaly definition. It also eliminates terrain effects.

An example of the application of the method is shown in Figure 5. The images are from the South-East Lachlan survey, New South Wales. The survey was flown at 60 m height over an area that is quite mountainous in parts. Figure 5a shows the digital elevation model over part of the survey area, which shows elevation changes of up to 900 m. Both the topographic correction grid and the 3D

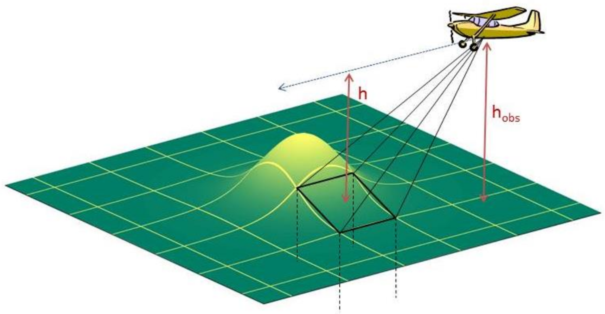


Figure 3: Schematic showing the parameterization of the topography using prism sources with slanted top surfaces relative to the detector.

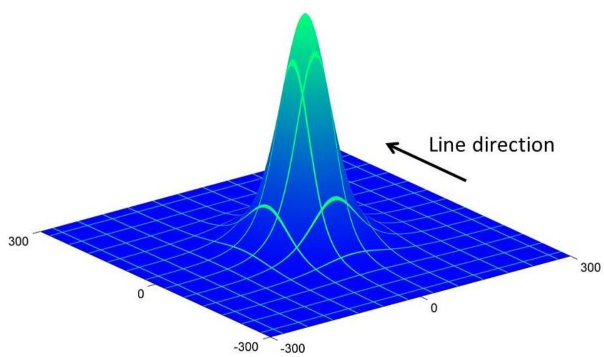


Figure 4: Source-detector response for a slab detector at 60 m height above a vertical rectangular prism source centred at (0,0) with dimensions 50×50 m. The figure is 600 m wide in the x and y dimensions.

inversion grid show the effects of correcting for topography. However, the 3D inversion grid shows better continuity of anomalies and interpolation between flight lines. The positions of the flight lines are evident in the minimum curvature grid as E-W lines of high-frequency speckle corresponding to the original observation points.

Assisting Exploration for Strategic Minerals

To bring the use of this technology into focus, we have chosen to examine some carbonatite-hosted deposits, as these have been regarded as somewhat exotic, and there is little in the geophysics literature concerning their expression. Three examples are examined. Each has a strong airborne magnetic expression, which creates the initial focus. Often a distinctive "swirl" character is present. They are also often associated with a topographic high, and the gamma-ray signal, if adequately enhanced

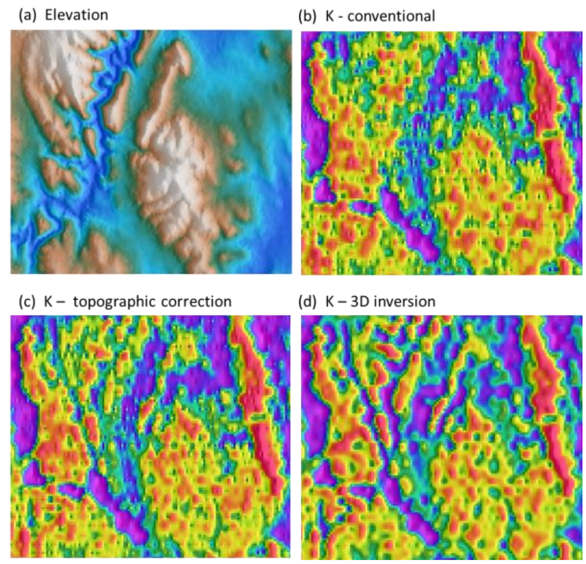


Figure 5: Pseudo-colour images from the SE Lachlan survey area: (a) digital elevation model, (b) K concentration (%) gridded using minimum curvature (c) K concentration (%) after topgraphic correction - gridded using minimum curvature, and (d) K concentration gridded using 3D inversion. The images are centred on (149:04:39.99 E, 35:40:25.74 S) and are about 15 km wide. Data courtesy of the Geological Survey of NSW.

using the innovations described earlier in this paper, can assist in clarifying the nature of the carbonatite and its internal zoning.

Two examples from Australia are Nolan's bore in the Northern Territory, and Mt Weld near Laverton in Western Australia. Nolans Bore (Figure 6) is one of the world's largest and most intensively explored rare earth deposits. The most abundant rare earth-bearing minerals in this deposit are fluorapatite, allanite and monazite. It was found using airborne gamma-ray spectrometric data.

Mt Weld is a carbonatite-hosted deposit with significant reserves (Figure 7). The magnetics show a prominent signature, but the almost complete leaching of near-surface fission elements results in a very subdued gamma-ray spectrometric response.

Figure 8 shows an early stage exploration target in Namibia that is suspected to be a carbonatite. The magnetics show a stark example of multiple deep intrusives. The gamma-ray spectrometric data (lower) show surface drainage features. Further work on extracting more information from the gamma-ray spectrometric data is warranted. It is believed that just one drill hole has been placed into this area to date.

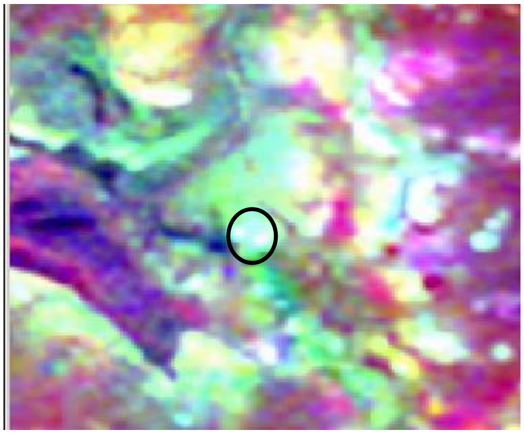
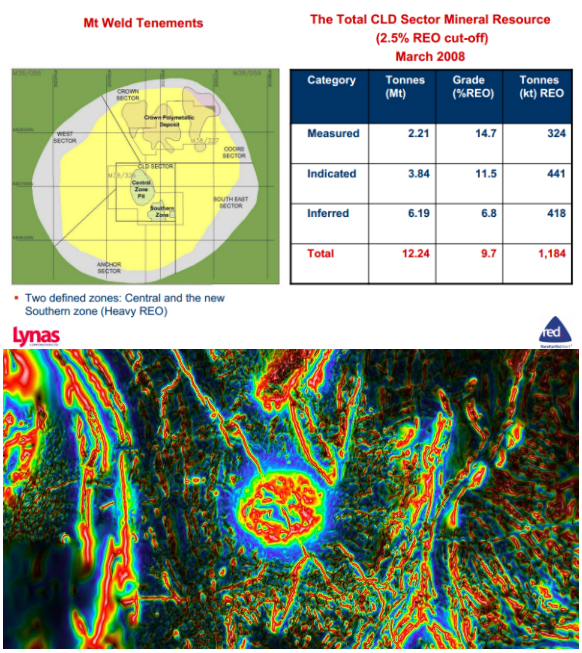


Figure 6: Nolans Bore WA, found initially using the radiometrics data. Spectral anomaly with an RGB of K/Th/U showing the deposit as a Th/U high.



Category	Tonnes (Mt)	Grade (%REO)	Tonnes (kt) REO
Measured	2.21	14.7	324
Indicated	3.84	11.5	441
Inferred	6.19	6.8	418
Total	12.24	9.7	1,184

Figure 7: Mt Weld rare earth oxide deposit. (a) schematic plan, (b) mineral resources, (c) magnetic response, with rtp, drape tilt angle. Data courtesy of the Geological Survey of WA.

Conclusions

The quest for more efficient and advanced exploration technology for finding subtle strategic mineral deposits continues. Gamma-ray spectrometry has an important role to play in this quest. Recent developments in the processing of airborne gamma-ray spectrometric data have improved the method's utility for the detection of subtle radioelement anomalies. The three case histories demonstrate the range of states to be encountered, from complete definition to almost entirely missing. In the latter case, nearby drainage patterns can still assist the interpretation.

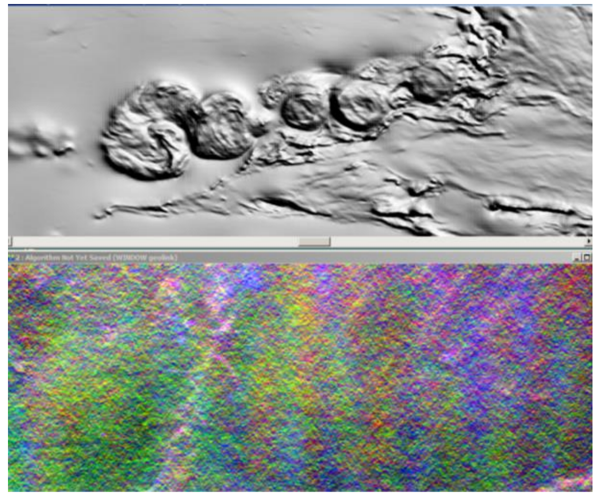


Figure 8: Early stage Namibian carbonitite identification: (a) Grey-scale magnetic survey area, with charcteristic swirl (b) Spectral image RGB of K/Th/U without the new terrain correction, showing mostly local drainage patterns. Data courtesy of the Geological Survey of Namibia.

Systematic application on a regional or country-wide basis for a relatively small cost is now feasible for countries such as Australia, Namibia, Finland and Nigeria, as these countries have now established a comprehensive survey database that is consistent. A big-data approach, using the ideas in this paper, can aid exploration undercover, compared to some of the "non-physics" methods that are currently in vogue.

References

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