# THE RADIOMETRIC MAP OF AUSTRALIA

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## INTRODUCTION

Geoscience Australia and State and Territory Geological Surveys have systematically surveyed most of the Australian continent over the past 40 years using airborne gamma-ray spectrometry to map potassium, uranium and thorium elemental concentrations at the Earth's surface. The quality of the radiometric data acquired over this period varies markedly. Early surveys (prior to about 1990) were flown with a line spacing of about 1500 m and a 16 litre detector at a flying height of 150 m agl. Later surveys have been flown with a detector volume of 32 litres and a line spacing of 500 m, or closer, and flying heights of 100 m, or better. The use of high-performance survey aircraft have now enabled flying heights to be lowered to heights of 60-80m for regional surveys and even lower for detailed surveys.

The extent of the digital airborne gamma-ray spectrometric coverage of Australia is shown in Figure 1. For early surveys (shown in blue in Figure 1), the results were usually reported in units of counts per second. Thus the magnitudes of these data values depend on both the instrumentation used in the survey (such as crystal volume) and the survey parameters (such as nominal flying height). This means that the results from early surveys that used different instrumentation and survey parameters are not directly comparable. Also, even where survey acquisition systems were calibrated to report results as equivalent concentrations of the radioelements, limitations in the calibration of these instruments and temporal variations in radiation output from the earth often result in mis-matches between surveys along their common boundaries.

These problems limit the usefulness of the gamma-ray spectrometric data, as surveys are not easily combined into regional compilations, and quantitative comparisons between radiometric signatures from different surveys are difficult. The solution is to adjust all of Australia's public-domain gamma-ray spectrometric data to a common datum. This will enable surveys to be easily merged into larger regional compilations, and thus facilitate the recognition and interpretation of broad-scale regional features in the data.

This paper describes the adjustment of Australia's National Radioelement Database to a common datum. We have used an Australia-wide Airborne Geophysical Survey (AWAGS) to adjust all the public-domain radiometric surveys in Australia to the International Atomic Energy Agency's (IAEA) Global Radioelement Datum. The levelled database has been used to produce the first "Radiometric Map of Australia" – levelled and merged composite potassium (% K), uranium (ppm eU) and thorium (ppm eTh) grids over Australia at 100 m resolution. Interpreters can use these grids to reliably compare the radiometric signatures observed over different parts of Australia. This enables the assessment of key mineralogical and geochemical properties of bedrock and regolith materials from different geological provinces and regions across the continent.

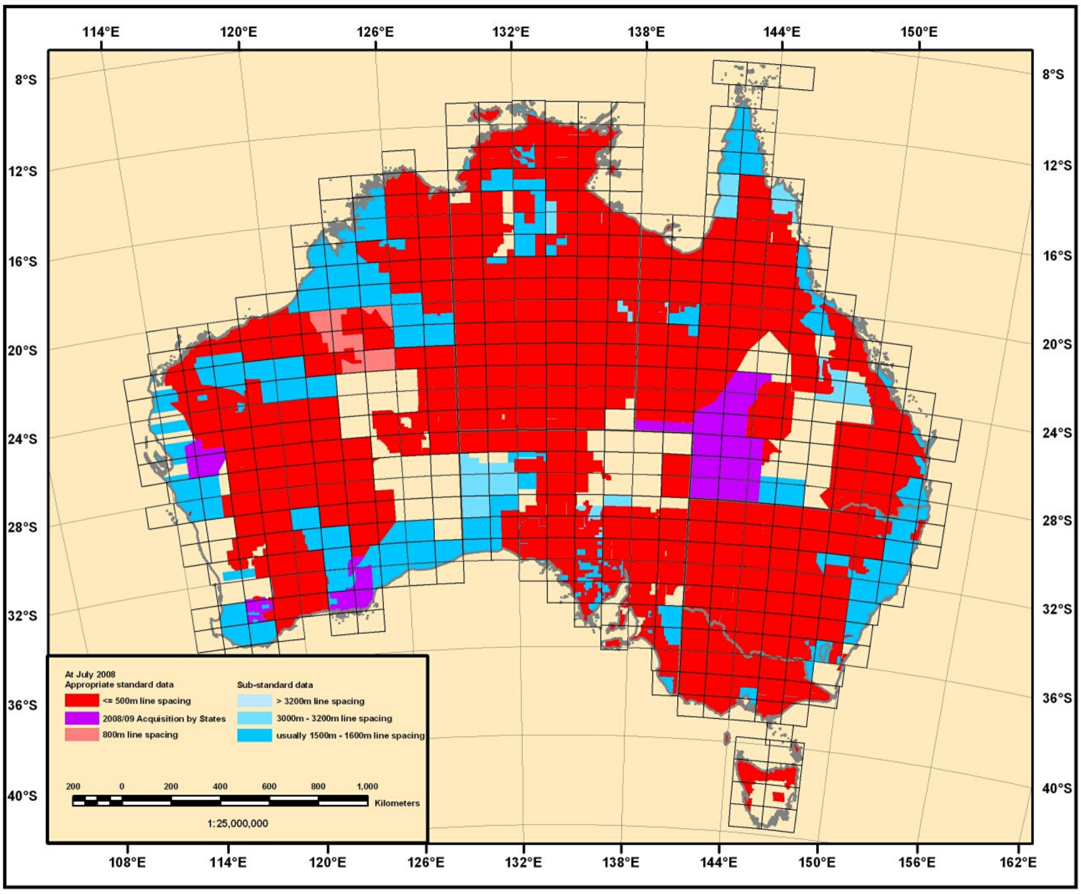


*Figure 1: Digital airborne gamma-ray spectrometric survey coverage of Australia (1970-2008).*

## THE AWAGS SURVEY

Geoscience Australia has undertaken an Australia-wide Airborne Geophysical Survey, funded under the Australian Government's Onshore Energy Security Program, to serve as a radioelement baseline for all current and future airborne gamma-ray spectrometric surveys in Australia. The survey was flown in 2007 by UTS Geophysics Pty Ltd using a Cresco aircraft (Figure 2) at a nominal terrain clearance of 80 m above ground level along north-south flight lines spaced 75 km apart and east-west tie lines spaced 400 km apart (Figure 3). A 33 litre NaI(Tl) detector was used in the survey.

The IAEA (IAEA, 2009) recommended that all gamma-ray spectrometric surveys be referenced to a global radioelement datum based on reference standards issued by the IAEA's Seibersdorf Laboratory (IAEA, 1987). The reference standards and the procedures to be followed in ensuring surveys are referenced to this datum have been described by Matolin et al. (2005) and Minty (2006).

Every effort was made to ensure that the gamma-ray acquisition system used on the AWAGS survey was correctly calibrated, and the data processed to international standards (IAEA, 2003). However, bearing in mind that most surveys show some inconsistencies due to limitations in calibration and data processing, Geoscience Australia has back-calibrated the AWAGS survey to ensure that the final data represent the best possible radioelement datum for Australia.

*Figure 2: The Cresco survey aircraft used by UTS Geophysics to fly the AWAGS survey, undergoing spectrometer calibrations at Canberra airport.*

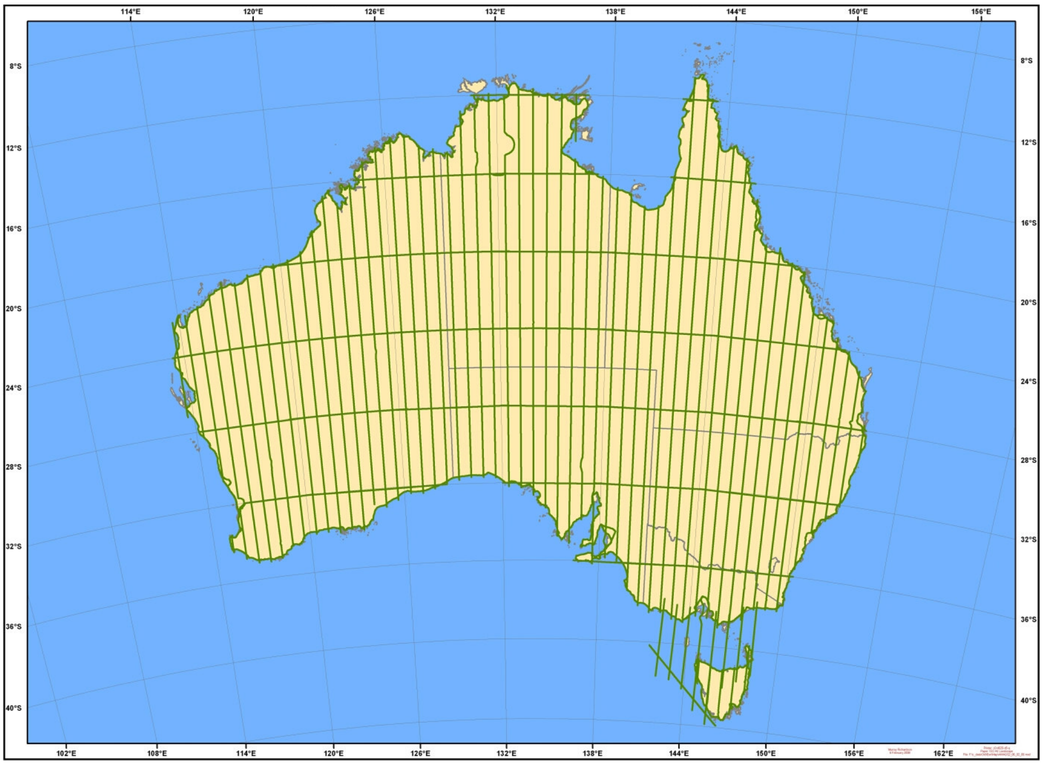


*Figure 3: Locations of the AWAGS survey flight lines flown in 2007.*

## BACK-CALIBRATING TO THE IAEA DATUM

Grasty et al (1992) described a procedure for the back-calibration of older airborne gamma-ray surveys using a portable gamma-ray spectrometer. The portable spectrometer is used to estimate the concentrations of the radio-elements beneath carefully selected portions of some of the airborne survey flight lines. If the source-detector geometry is appropriate (a flat earth approximating a $2\pi$ geometry), then portable spectrometers can be used to acquire radioelement concentration estimates that are far more accurate than those from an airborne system. This is mainly because the background component of radiation for portable spectrometers on the ground is far lower, relative to the signal, than for airborne systems, and counting times can also be increased to obtain precise estimates of the radioelements. For ease of access, ground measurements are typically taken where the flight lines are intersected by a road. For each of K, U and Th, the ratios of the average airborne radioelement concentration estimates (in the vicinity of the ground readings) and the average ground concentrations are used to estimate the required correction factors.

We have back-calibrated the AWAGS survey using 47 field sites located beneath a selection of AWAGS flight lines (Figure 4). We chose the Riverina area of south-central New South Wales for the back-calibration because of the subdued topography and ease of access along the ubiquitous road network. At each back-calibration site, four 300 s measurements were taken using an Exploranium GR320 portable spectrometer. Two measurements were taken on each side of the road with measurements spaced about 20 m apart. We then computed the ground concentration estimates (and associated standard errors) at each back-calibration site and compared these with the mean concentration estimates (and associated standard errors) from the airborne data within a radius of about 800 m of the calibration site. The ratios of the mean ground and airborne concentration estimates are the back-calibration correction factors (scaling factors) for each site.

The computed errors in the correction factors estimated for each site thus incorporate both counting errors and the geological variability at the site and within the field of view of the airborne spectrometer. This is important, as the final AWAGS correction factors for each of K, U and Th were calculated as the weighted average of all the site correction factors, with each site weighted inversely by their error variances.

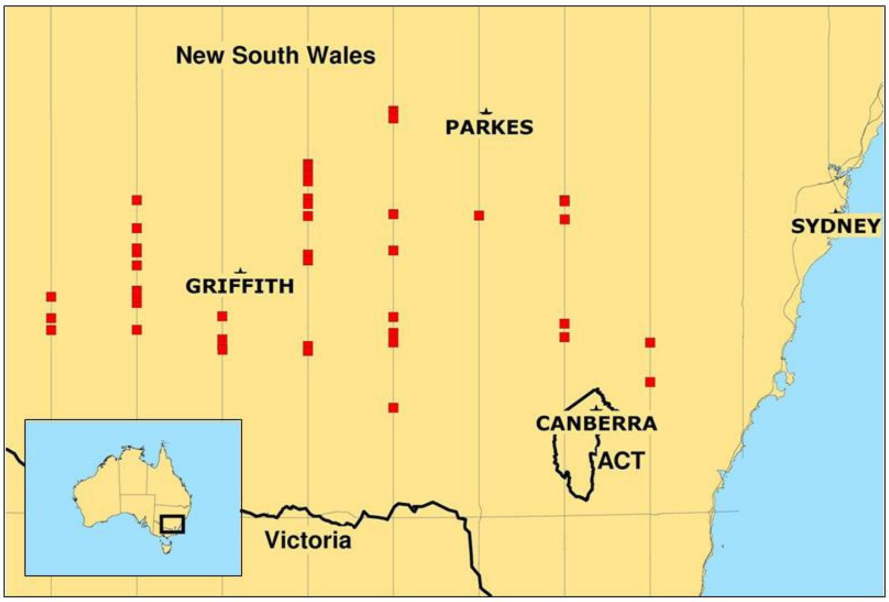


*Figure 4: Locations of AWAGS back-calibration field sites.*

The field of view at airborne survey heights is several hundreds of metres in diameter and, ideally, a single airborne measurement should be compared with many ground measurements spread within the field of view of the spectrometer. However, this is impractical as many airborne samples are required to obtain sufficient precision at each back-calibration site and ground measurements are time-consuming and costly. So, to mitigate the possibility that the ground and airborne measurements are not representative of the same source, we carefully selected calibration sites for their uniformity of radioactivity, and weighted each site according to the estimated variance of its correction factors as described above. Back-calibration sites where either the airborne or ground data show high variability thus receive a low weighting in the final averaging to obtain the mean correction factors for the AWAGS survey.

We also computed a DC adjustment to the AWAGS K, eU and eTh estimates by performing a preliminary merge of the radiometric database (as described in the following section) and then computing over-water means from several surveys spread around the Australian coastline. The correlation between the ground and airborne measurements prior to back-calibration are shown in Figure 5. A far better correlation between ground and airborne measurements is obtained after back-calibrating the AWAGS survey data (Figure 6).

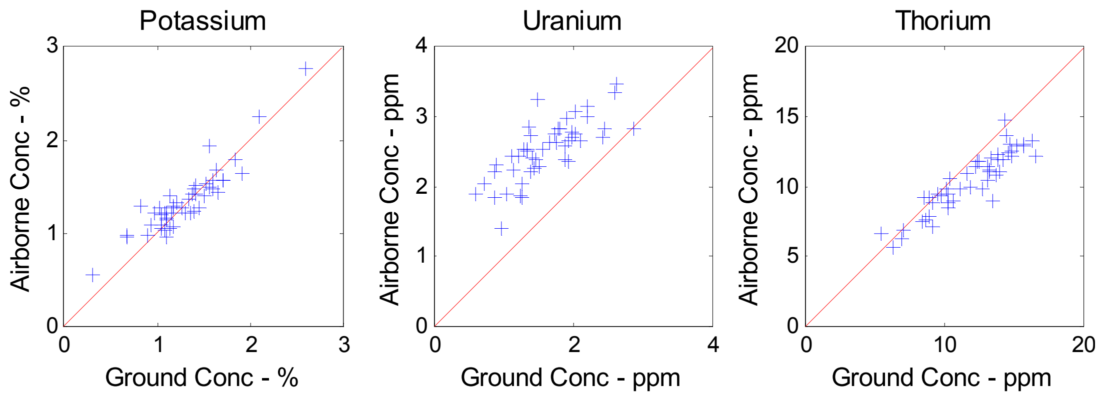


*Figure 5: Correlation between airborne and ground radioelement estimates for each of K, eU and eTh prior to back-calibration of the AWAGS data.*

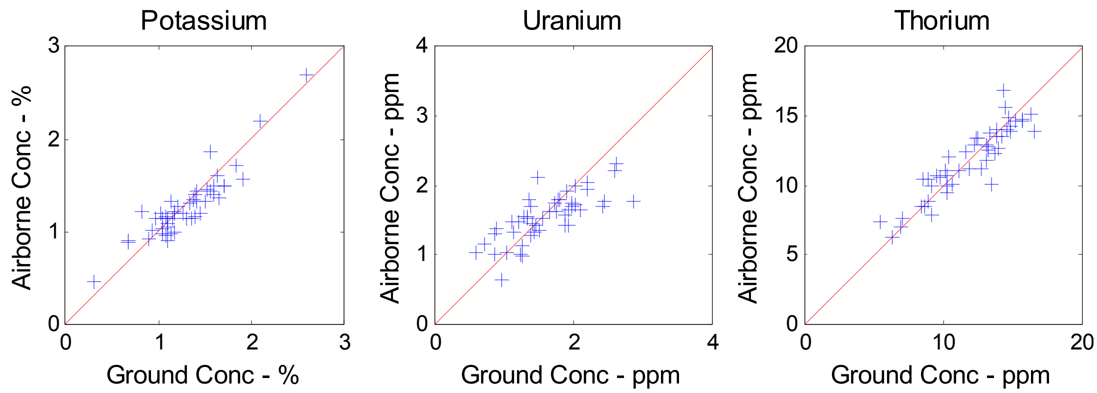


*Figure 6: Correlation between airborne and ground radioelement estimates for each of K, eU and eTh after back-calibration of the AWAGS data.*

## LEVELLING THE NATIONAL RADIOMETRIC DATABASE

We have used an enhancement of the method described by Minty (2000) to adjust the surveys that comprise the national radioelement database to a common datum. We estimate for each survey in the national database correction factors that, once applied, minimize both the differences in radioelement estimates between surveys (where these surveys overlap) and the differences between the surveys and the AWAGS traverses (where these overlap). This effectively levels the surveys to the IAEA datum to produce a consistent and coherent national gamma-ray spectrometric coverage of the continent.

The correction factors comprise both a level shift and a scaling of the gridded survey data. We calculate a relative shift and scale for each overlapping grid pair and for each grid that overlaps the AWAGS traverses. We then use these relative shifts and scales to calculate absolute correction factors that bring the grids to the same level as the AWAGS traverses while still honouring the relative shift and scale parameters for overlapping grid pairs in a least-squares sense (Figure 7).

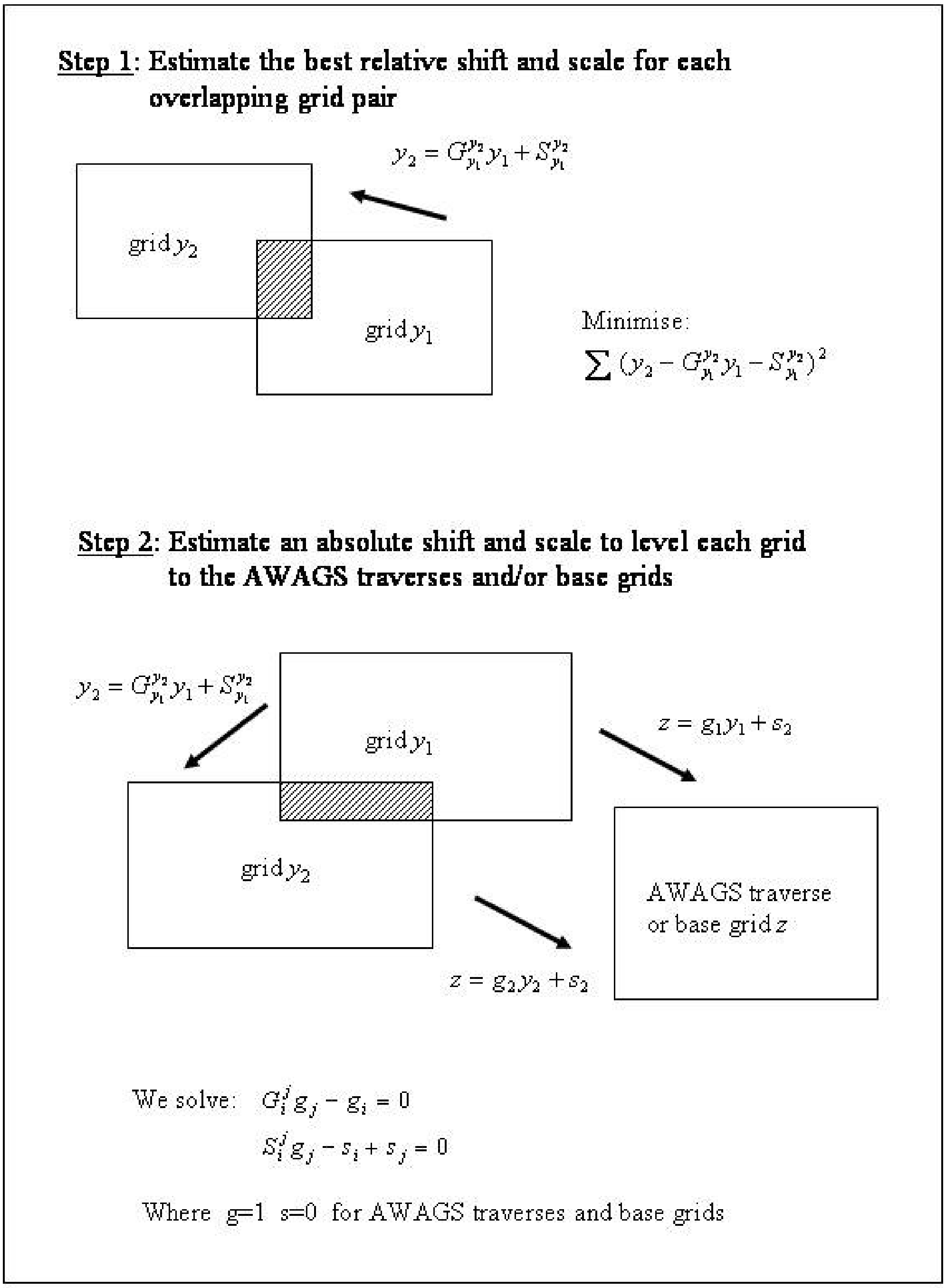


*Figure 7: Grid levelling methodology (after Minty 2000). See Minty (2000) for explanation of the symbols.*

Figures 8 and 9 show an example of the successful application of the method to the Pilbara region of Western Australia.  Using both the overlap between survey grids and the intersection between the AWAGS traverses and the survey grids we have been able to successfully level the thorium grids to the AWAGS thorium datum.

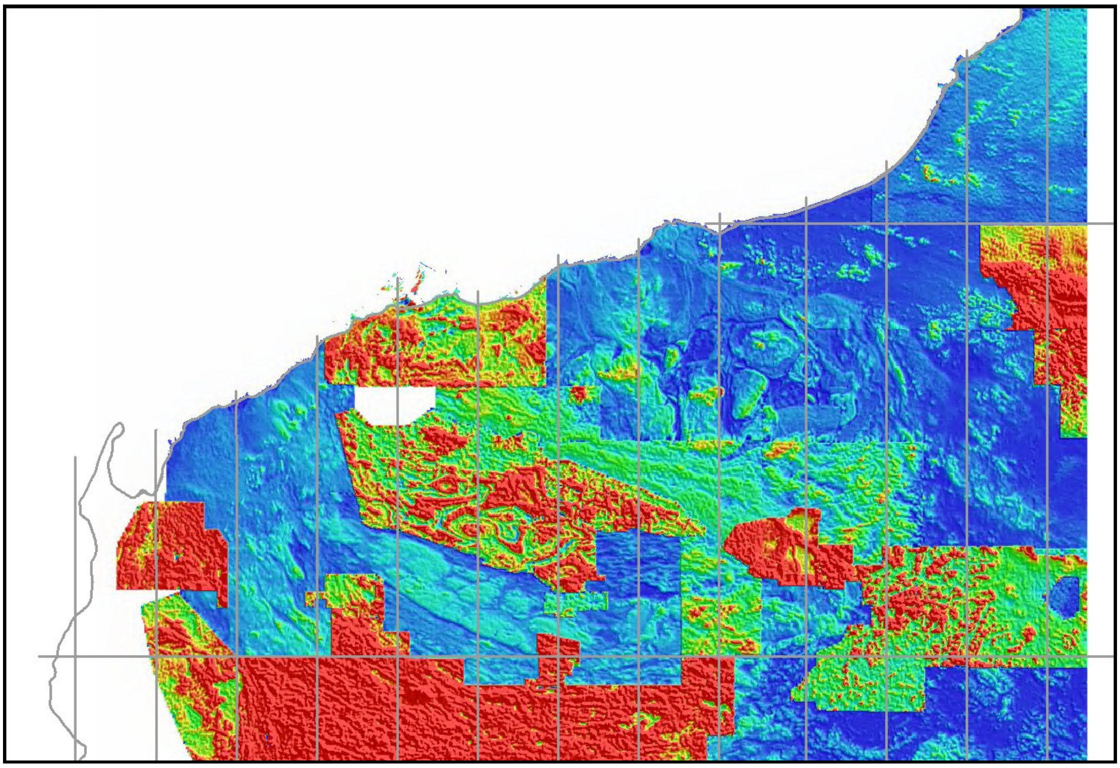

*Figure 8: eTh data for the Pilbara region, Western Australia, prior to grid levelling.*

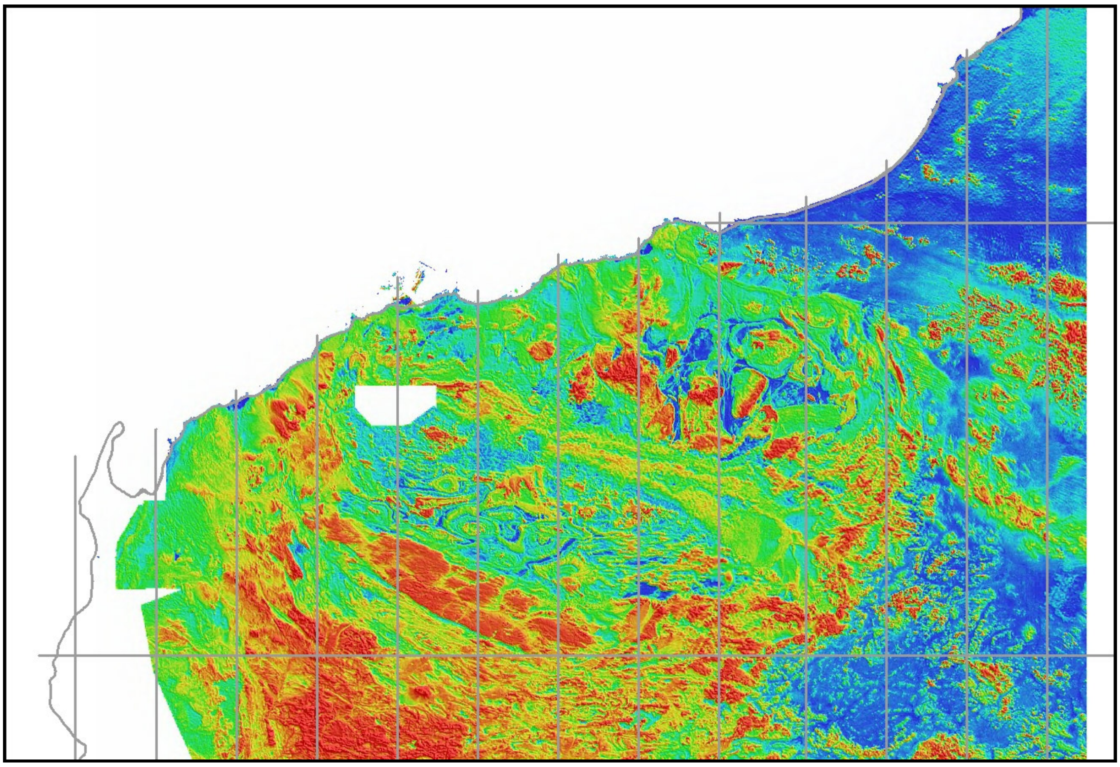

*Figure 9: eTh data for the Pilbara region, Western Australia, after grid levelling.*

## THE RADIOMETRIC MAP OF AUSTRALIA

The levelled database, comprising over 540 surveys, has been used to produce the first "Radiometric Map of Australia" – composite levelled, merged and feathered grids of Australia for each of K, eU and eTh at 100 m resolution. The composite K, eU and eTh grids have been used to produce a range of derivative grids as follows:

a) dose rate (computed as 13.078*K(%) + 5.675*eU(ppm) + 2.494*eTh(ppm) – after IAEA, 2003);
b) thorium/potassium ratio;
c) uranium/potassium ratio;
d) uranium/thorium ratio; and
e) total dose due to natural sources of radiation (computed by adding estimates of cosmic dose at ground level to the terrestrial dose calculated in (a) above).

A pseudocolor image of the dose rate is shown in Figure 10, and a ternary image of the 3 radioelements (K-red, eU-blue, eTh-green) derived from the levelled database is shown in Figure 11. The radiometric responses and patterns shown in Figure 11 largely reflect the surface geochemistry and mineralogy of bedrock and regolith materials. In general, actively eroding felsic volcanic and igneous rocks are delineated by high concentrations of the radioelements and appear in white to reddish hues. Low radioelement concentrations (black hues) correspond to ultramafic rocks and quartz rich sandy materials (e.g. quatzites, sandstones and unconsolidated sands). Water bodies appear black in the ternary image.

Most of the gamma-ray responses relate to the distribution of regolith materials (e.g. weathered bedrock, alluvium and colluvium) that reflect the overall antiquity and geomorphic stability of the Australian continent. Many of the relatively high eTh and low K responses (green – green/blue hues) relate to ferruginous lags and weathered surfaces.

## CONCLUSIONS

The airborne gamma-ray spectrometric method provides estimates of the concentrations of the radioelements on the ground that can be used for a range of different applications including geological mapping, mineral and petroleum exploration, geomorphological studies and environmental mapping. The AWAGS survey has enabled a consistent and coherent national gamma-ray spectrometric radioelement database to be developed which will benefit all these applications. The new levelled database has been used to generate, for the first time, a "Radiometric map of Australia" which provides a seamless coverage of gridded radioelement estimates over most of the continent.

Because the data have been levelled to a consistent radioelement datum, researchers can now reliably relate geochemical patterns observed in one area to similar patterns observed elsewhere, and to better appreciate the significance of broad-scale variations in radioelement concentrations. For example, Palaeozoic granites in eastern Australia can now be quantitatively compared and assessed for areas of potential mineralisation and geothermal prospectively. A consistent radioelement datum also enables the use of quantitative modelling and processing techniques that enhance or integrate the radiometric imagery with other datasets (e.g. magnetics, Landsat TM and gravity) to be applied over much larger areas.

There are thus many applications that will be able to take advantage of the new updated database. These include:

- uranium and thorium exploration through the ability to make quantitative comparisons between radiometric signatures in different survey areas;
- heat flow studies and assessment of geothermal energy resources;
- the derivation of a radiation risk map of Australia for natural sources of radiation;

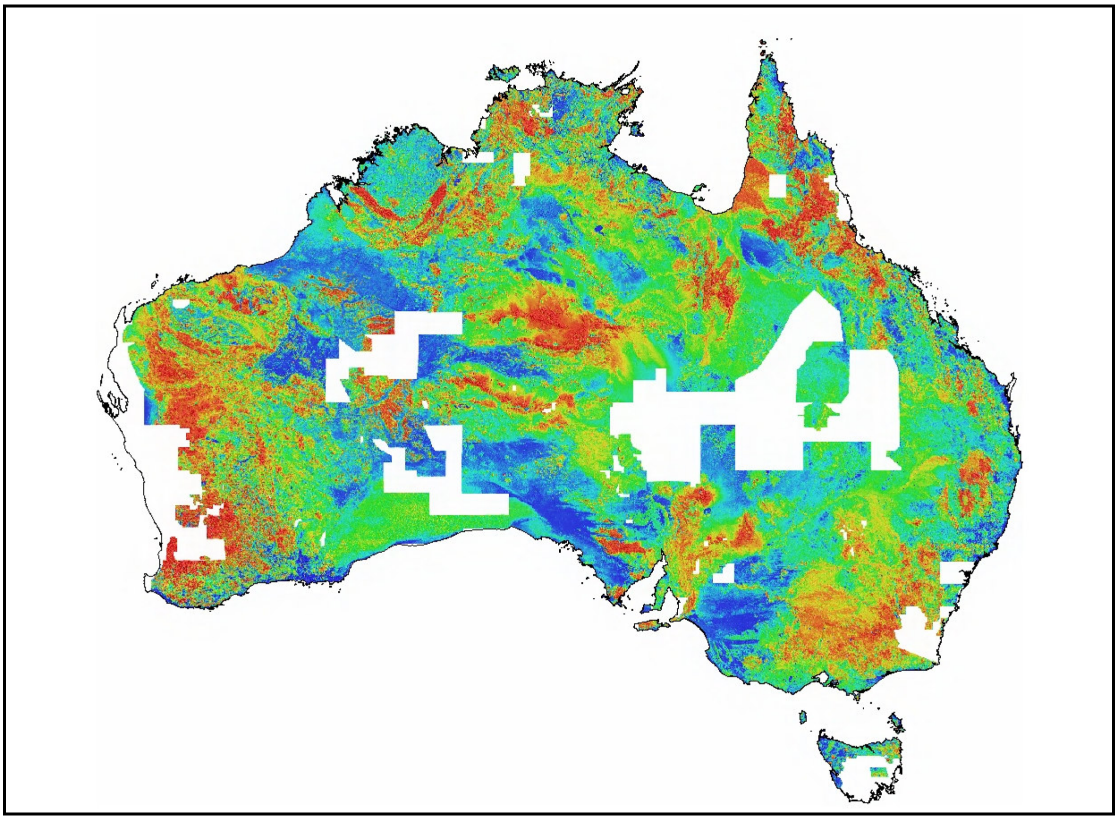

*Figure 10: Psudocolour image of air-absorbed dose rate (nG/h) over the Australian continent.*

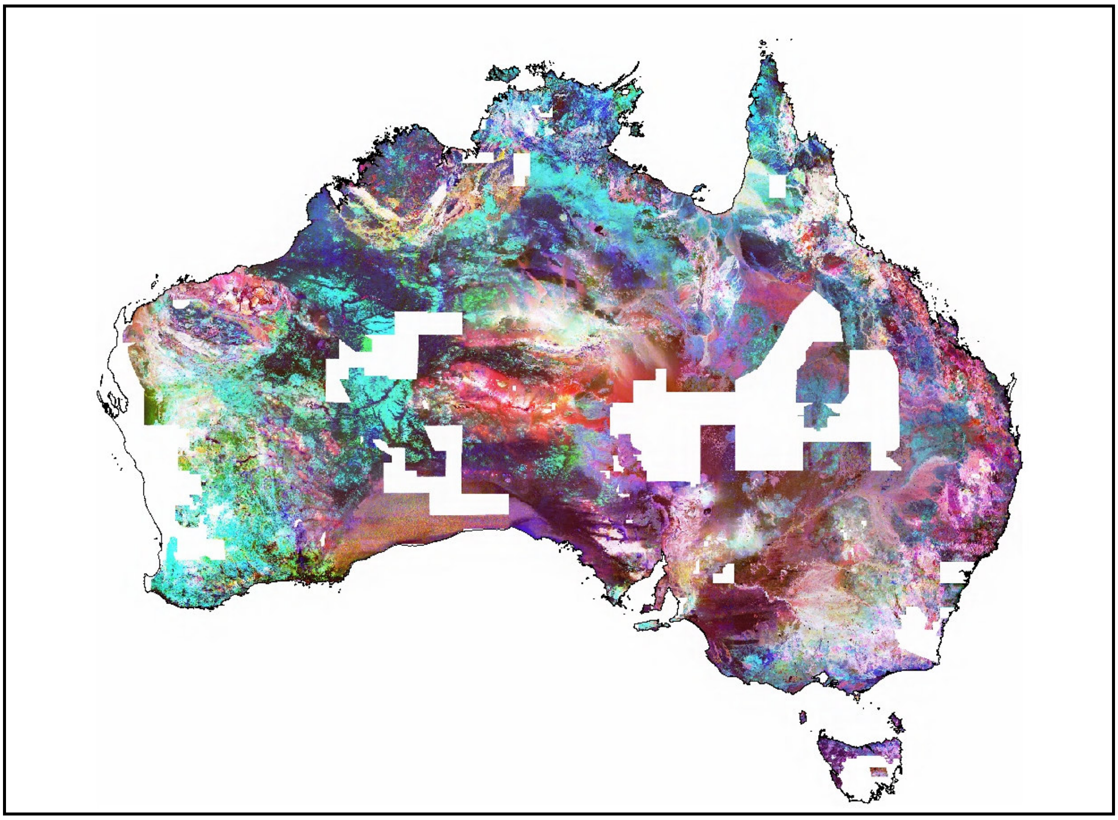

*Figure 11: Ternary image (K-red, eU-blue, eTh-green) of Australia derived from the new levelled National Radioelement Database.*

- research in land-use modelling, sustainability, agricultural and forest productivity, radiation risk, mineral exploration, regional geology, regolith and soils; and
- direct comparisons with geochemical data.

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