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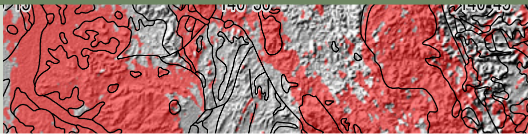
Radiometric Map of Australia provides new insights into uranium prospectivity



New map facilitates rapid assessment

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The new radioelement map of Australia facilitates rapid assessment of uranium prospectivity from national through to local scales. The map shows the distribution of potassium (per cent K), uranium (parts per million (ppm) equivalent U) and thorium (parts per million (ppm) equivalent Th) over 80 per cent of the Australian landmass. It has been calibrated using the recent Australia-Wide Airborne Geophysical Survey (AWAGS) to adjust all the public-domain airborne radiometric surveys in Australia to the International Atomic Energy Agency's (IAEA) Global Radioelement Datum (*AusGeo News 93*).

The new datum provides a baseline for all current and future airborne gamma-ray spectrometric surveys in Australia and, for the first time, enables quantitative assessment of the distribution of potassium, equivalent thorium and equivalent uranium in exposed bedrock and regolith. Uranium concentrations derived from airborne measurements can now be analysed and compared across landscapes with different or similar geological and geomorphological histories. This article briefly describes the concentration of uranium in rocks and regolith, and demonstrates how the new radioelement map of Australia can be enhanced and integrated with other datasets for targeting areas of potential uranium mineralisation.

Uranium at the surface

Airborne gamma-ray spectrometry measures gamma-rays from potassium, thorium and uranium that emanate from the uppermost 30 to 40 centimetres of soil and rock in the crust. Variations in the concentrations of these radioelements largely relate to changes in the mineralogy and geochemistry of rock and regolith materials (for example soils, saprolite, alluvial and colluvial sediments). Potassium abundance is measured directly as gamma-rays emitted when potassium (^{40}K) decays to Argon (^{40}Ar). Uranium and thorium abundances are derived indirectly by measuring gamma-ray emissions associated with the daughter radionuclides bismuth (^{214}Bi) and thallium (^{208}Tl), respectively.

Uranium is the least abundant of the three radioelements in the Earth's continental crust with a concentration estimated to be in the range of 1 to 4 ppm (Rogers and Adams 1978). The abundance of uranium increases during the fractionation of igneous rocks so that acid igneous and volcanic rocks, for example, have higher uranium averages than their mafic and ultramafic equivalents. In Australia, the airborne-measured average concentration of uranium in exposed regolith and bedrock (to a depth of around 30 centimetres) based on the new radioelement data is 1.1 ppm.

Uranium occurs in two main valence states: U^{4+} and U^{6+}. The oxidised form U^{6+} is most common in near-surface conditions and forms complexes with oxygen to create a uranyl ion (UO_2^{2+}). Uranyl ions are mobile and typically form soluble complexes with the anions NO^3, F-, OH-, CO_3^{2}- , SO_4^{2}- and PO^{3-}. The solubility of uranium is favoured by oxidising conditions and acid groundwaters (see *Uranium mineral systems: processes, exploration criteria and a new deposit framework*). Under reducing conditions, the U^{+4} form is contained in insoluble minerals. Weathering and alteration associated with hydrothermal systems can preferentially concentrate uranium compared to thorium. Thorium has a single valence (4^+) in near-surface environments and so its mobility does not alter under changing redox conditions. Importantly, thorium, unlike

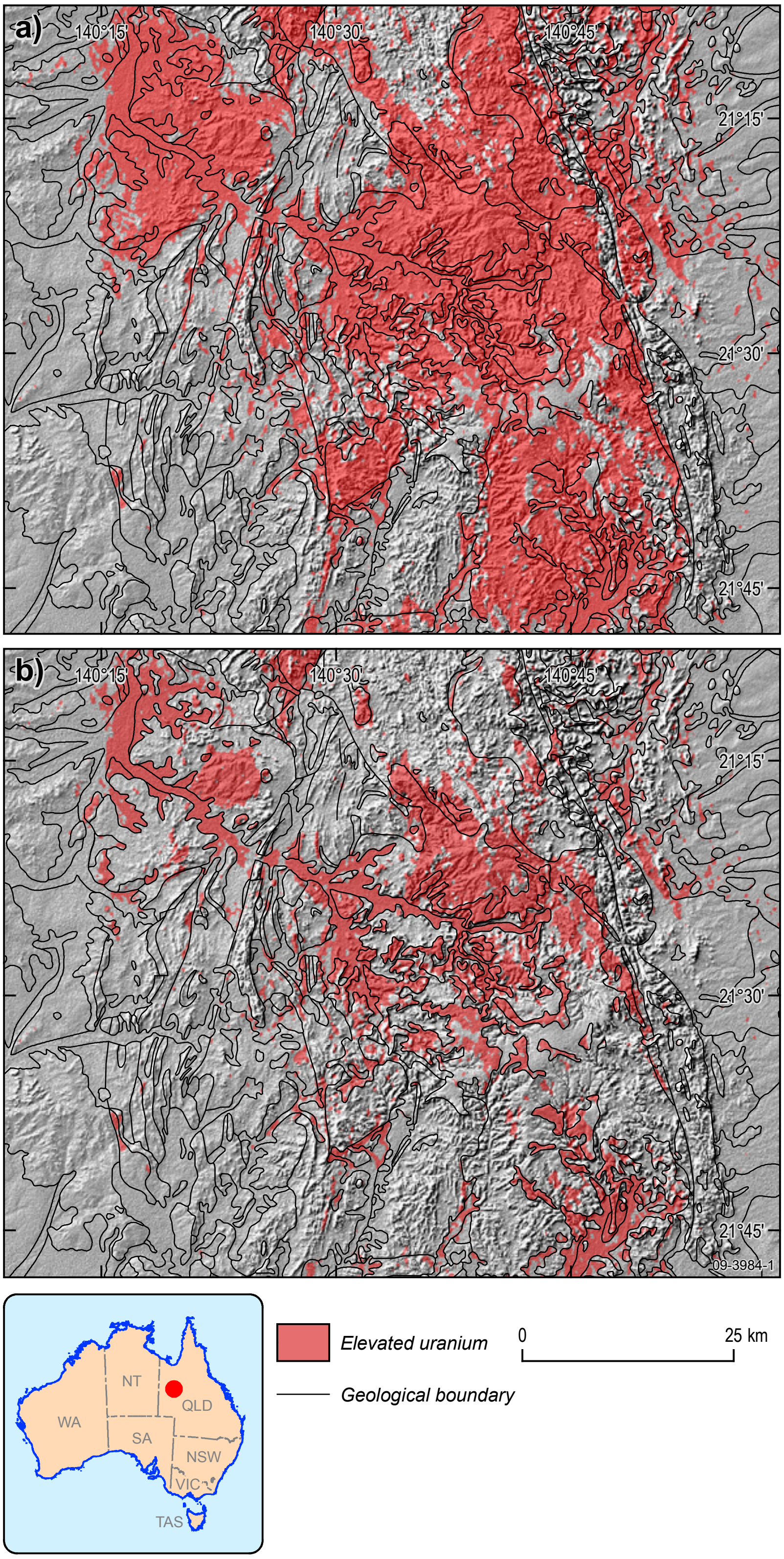

Figure 1. (a) Elevated uranium values relative to background values calculated for crystalline rocks, sedimentary rocks and unconsolidated regolith materials in the southern Mount Isa region. **(b)** Elevated uranium values relative to background values calculated for individual geological units in the southern Mount Isa region.

potassium and uranium, is not usually affected to the same degree by weathering and alteration processes. This enables the use of ratios of K/Th and U/Th ratios as a proxy for detecting areas of mineralisation (Shives et al 1997; Dickson and Scott 1997).

In the regolith, uranium and thorium are associated with more stable weathering products including clay minerals, iron and aluminium oxyhydroxides and resistate minerals (such as monazite and zircon). The presence of organic matter and specific bacteria (for example, sulphate-reducing bacteria) can also influence the distribution of uranium in the regolith. High thorium/uranium ratio values in the weathering profile compared to the underlying bedrock can indicate preferential mobilisation and leaching of uranium, and may indicate nearby sources of secondary uranium mineralisation.

Exploration for secondary uranium deposits

Establishing appropriate uranium background values is a prerequisite to identifying uranium anomalies associated with mineralisation or secondary enrichment processes. Background values of uranium for any given area will change depending on the geology, regolith, geomorphic setting and history, hydrology and climate.

The background uranium values for individual rock or regolith units can be calculated by integrating analysis of uranium data and geological data.

This analysis has been carried out using uranium data from the new *Radiometric Map of Australia* and the new digital *1:1 million Surface Geology Map of Australia* (*AusGeo News 93*). Background uranium averages were calculated for three geological groups; crystalline rocks, sedimentary rocks and unconsolidated regolith materials (such as, alluvial and colluvial sediments). Above-average uranium values for these three groups are shown for an area south of Mt Isa in figure 1(a). Background uranium averages were also determined for individual geological units and elevated uranium values derived from this calculation for the same area are shown in figure 1(b).

Ratios of the radioelements can provide further constraints for identifying potential uranium deposits. Wyborn et al (1994) showed that alteration zones associated with Coronation Hill-style mineralisation have slightly elevated uranium but are strongly depleted in thorium compared to the surrounding rocks which have high levels of both uranium and thorium. A ratio of U^2/Th proved effective in highlighting uranium mineralisation in the area.

The U^2/Th ratio is also effective in separating the primary uranium, associated with uranium-bearing granites, from secondary uranium associated with paleochannel calcrete (such as at Yeelirrie in Western Australia; see figure 2). High U^2/Th ratio values are associated with many uranium deposits in Australia and can be used to highlight new areas of potential mineralisation. These ratio values, and other enhancement techniques using airborne imagery, need to be interpreted in the context of the local geological and regolith setting. For example, some rocks have inherently low thorium compared with uranium and are not associated with mineralisation processes. Nevertheless, normalising techniques using geological units and radioelement ratios provide a rapid approach for locating potential uranium mineralisation which can then be followed up by on-ground validation and assessment.

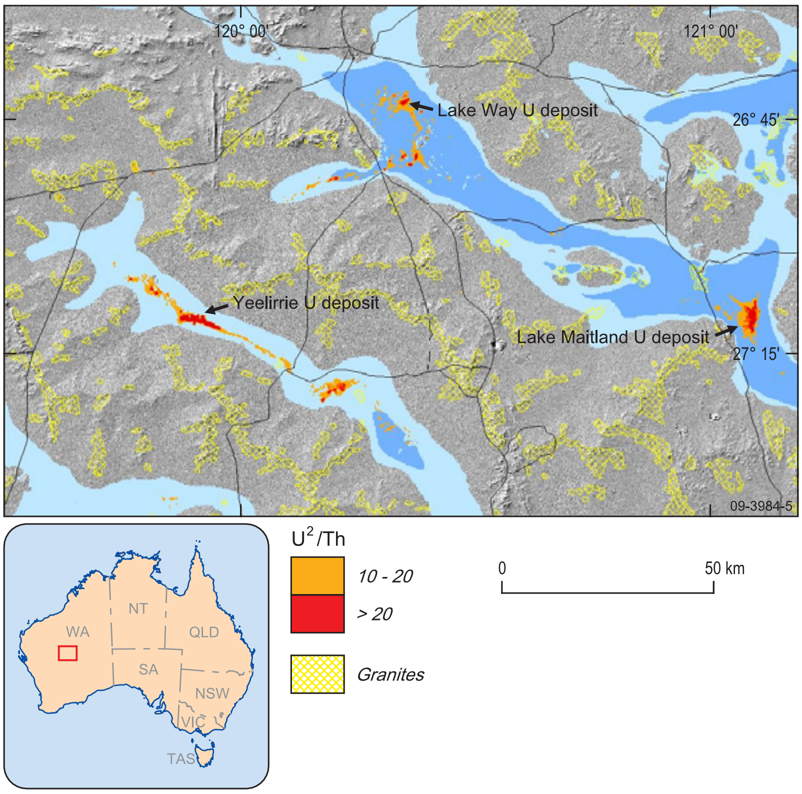

Figure 2. Uranium/thorium ratio (U^2/Th) for the Yeelirrie deposit in Western Australia with paleochannels highlighted in light blue.

Potential limitations and false anomalies

Airborne spectrometry measures surface radioelement concentrations to a depth of approximately 40 centimetres. Uranium mineralisation which is deeper than 40 centimetres will not be detected by airborne spectrometers. Spectrometric mapping of uranium also assumes equilibrium in the ^{238}U decay chain. Disequilibrium can occur where daughter products above the measured Bismuth (^{214}Bi) in the decay chain are either enriched or removed, thereby giving either an over- or under-estimate of uranium. For example, uranium anomalies can be caused by the accumulation of radium (^{226}Ra) in ground waters. Dickson (1995) showed that disequilibrium effects in soils were not large. Soil disequilibrium together with generally low count rates are significant factors that contribute to the noise in uranium channel data.

Uranium concentrations derived from gamma-ray spectrometry are normally expressed in units of 'equivalent' parts per million (ppm eU) as a reminder that these estimates are based on the assumption of equilibrium in their respective decay series. False uranium anomalies can result from disequilibrium processes and it is essential that anomalies identified using airborne data are verified by soil and bedrock geochemistry. Correlation of airborne radioelement values with soil and rock geochemistry (figure 3) is currently being investigated as a means of better understanding issues around disequilibrium, scale and accuracy of the spectrometric method.

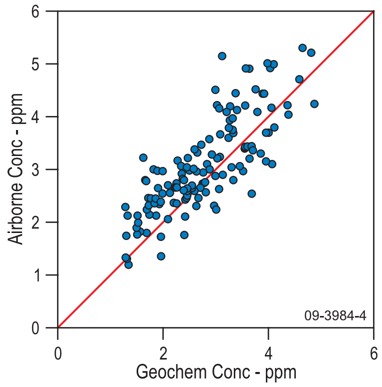

Figure 3. Correlation between soil and airborne measured uranium. The samples analysed were collected as part of the Riverina geochemical survey (de Caritat et al 2007).

Exploring the data

The information above, as well as additional spatial information pertaining to uranium in the Australian environment, will be made available through the 'Uranium Prospector' on the Geoscience Australia website (see link below). Uranium Prospector is a virtual globe using the NASA World Wind application which allows the user to display, visualise and interpret a suite of information related to uranium. Some of the themes include; location of known uranium deposits, uranium occurrences, normalised uranium and ratio distributions using lithological units, uranium channel data, airborne first vertical derivatives magnetics, and the U^2/Th ratio image.

For more information

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Related websites/articles

AusGeo News 92: New Radiometric Map of Australia

www.ga.gov.au/ausgeonews/ausgeonews200812/radiometrics.jsp

AusGeo News 93: New digital geological map of Australia

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Radiometric Map of Australia datasets

www.ga.gov.au/minerals/research/national/radiometric/index.jsp

Uranium mineral systems: processes, exploration criteria, and a new deposit framework (Geoscience Australia Record 2009/20)

www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69124