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Abstract

High resolution airborne gamma and MASTER imagery were collected over the upper South Alligator River valley, Kakadu National Park, in order to assess the state of abandoned uranium mine and mill sites and to detail the wider landscape of the valley. The area is a complex landscape in terms of differences in physiography: elevation; outcropping lithology; structure; water bodies and vegetation type. The investigation utilised high resolution 50m line spaced airborne gamma survey (AGS) data and VIS-SWIR-TIR regions of 10m MASTER coverage. The eU, eTh, and K airborne gamma channels were described as single bands and ratios, and enhanced by a high resolution DEM captured during the survey. MASTER data was calibrated to apparent reflectance, and endmembers selected from field spectra, image data and through spectral and spatial compressing using the Minimum Noise Fraction, Pixel Purity Index and n-Dimensional Visualiser in ENVI® software. DEM integration was used to enhance the MASTER information. Data fusion of the AGS data with MASTER imagery increased the usefulness of the AGS data, which highlighted the abandoned mine sites and, combined with ground-based spectrometry, was used to define the areas of potential radiological risk within the valley. Collection and analysis of tight line spaced AGS data is recommended for identifying radiologically contaminated areas on and near abandoned mine sites, and for targeting ground-based investigations. Integrating a higher spatial and spectral dataset such as MASTER enhances the usefulness of the AGS for mine site assessment. In the present case the derived images, combined with available geological data and ground truthing, detailed the wider landform features and provided a cost-effective method for assessing the state of abandoned mine sites.

Mapping the upper South Alligator River Valley using integrated datasets

Kirrilly Pfitzner and Paul Martin[1]

1 Introduction

The project discussed in this paper was designed to provide an overall indication of radiological issues within the upper South Alligator River valley, as well as to detail the wider landscape of the valley. It was considered cost and time effective to test the suitability of the use of remotely sensed data and image processing techniques to assess the state of the abandoned mine sites and surrounding areas.

The upper South Alligator River valley area is approximately 200km south east of Darwin and approximately 90km south west of Jabiru in the Northern Territory of Australia, now within the boundaries of Kakadu National Park (see figure 1). The upper reaches of the South Alligator River valley were explored for uranium during the 1950s and 1960s, with more than fifty radiological anomalies being identified. The zones of uranium mineralisation were found in deposits of carbonaceous shale or ferruginous silty-shale of the early Proterozoic Koolpin Formation (Stuart-Smith *et al* 1988). The deposits were characterised by a high uranium content with some deposits having concentrations up to 2.5% U_3O_8. Thirteen of these anomalies were mined between 1952 and 1964, producing approximately 1000 tonnes of U_3O_8.

The mines were small, with mining methods including open cuts, adits, shafts and open stoping. Development also included a battery and ore treatment site, and a small mill using a solvent extraction technology. Mining ceased in a period before the introduction of contemporary environmental legislation, and the sites were abandoned with no attempt at rehabilitation for minimisation of environmental impacts. Examples of mines in the area include Coronation Hill, El Sherana, Scinto V, and Rockhole Mine. The South Alligator Mill tailings area near Rockhole Mine Creek is an area of known tailings deposition with very little containment occurring during mining operations. Pacific Gold mines NL removed most of the tailings and contaminated soil between 1985-86 and subsequently shaped the area to approximate natural contours, and then ripped and seeded the site (Tims *et al* 2000).

The valley was incorporated into Stage 3 of Kakadu National Park in 1987, and is managed by Parks Australia North. The valley area is a popular destination for tourists, and is of cultural significance to the indigenous Jawoyn people. A hazard reduction works program, aimed at reducing both radiological and physical hazards, was completed in 1992. The main elements were to fill in shafts and close off adits and to bury any significant quantities of radioactive waste or contaminated materials. Regular monitoring for erosion, radiation and revegetation has since been implemented with background gamma radiation in the valley measured at 0.15 μGh^{-1} (Waggitt 1998).

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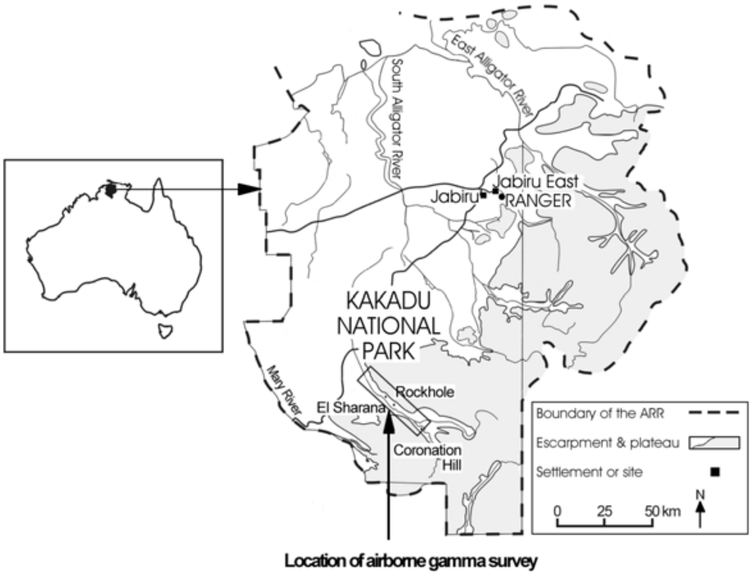


Figure 1 Map of the Alligator Rivers Region encompassing Kakadu National Park and the location of the survey study area

As many of these sites are small and may only be visibly characterised on the surface by an adit or shaft, the remotely sensed options for direct mine site assessment were limited. Because these mines are uranium mineralised, and therefore expected to contain elevated radium-226, an airborne gamma-ray survey was considered an appropriate dataset for this analysis. However, due to the small size of the mine sites it was not known prior to the survey whether or not a detectable and useful gamma signal would be obtained.

Gamma rays are emitted during the decay of some naturally occurring elements. For the NaI(Tl) detection systems normally used in airborne survey work, the most useful gamma rays correspond to potassium-40 (1.46 MeV), bismuth-214 (1.76 MeV) from the uranium-238 decay series, and thallium-208 (2.62 MeV) from the thorium-232 decay series (Horsfall 1997). The total count window covers the complete spectrum. Airborne gamma survey (AGS) interpretations have been used extensively for mineral exploration and geological mapping (Galbraith and Saunders 1983, Smith 1985, Zhang *et al* 1998), and to a lesser extent for geomorphology and soil interpretations (Cook *et al* 1996, Denham 1997, Dickson and Scott 1997, Wilford *et al* 1997), with few cases relating to environmental contamination and nuclear accidents (Rybach *et al* 2001, Winkelmann *et al* 2001). By comparison, there have been few examples of AGS for assessing the environmental state or radiological risk of existing or rehabilitated uranium mine sites. This is surprising given that the equivalent uranium (eU) channel of AGS data represents a measure of radium-226 in surface soils, which is expected to be elevated in uranium mine and mill material such as waste rock and tailings. Based on promising results of AGS data as a tool in radiological impact assessment at the rehabilitated Nabarlek uranium mine (Martin 2000), this study acquired very high spatial resolution AGS data with 50m line spacing in order to test the capability of AGS to provide information on the state of radiological risk of physically very small historical mining areas. To assist, MASTER imagery was acquired, and 1:100 000 topographic and geological data, allowing the wider landscape to be detailed.

The major objectives of the overall project were to: determine whether remotely sensed data can provide useful information to assess the state of small abandoned uranium mines; determine the suitability of an airborne gamma survey to assess any radiological impact in the valley; provide a detailed radiological description of the sites in order to judge radiological risk; provide spatially accurate and detailed locations of mine sites; and, detail the wider landscape of the upper South Alligator River valley.

2 Methods

2.1 Data acquisition and processing

Remotely sensed datasets, including airborne gamma survey data and MASTER data, and published data in the form of 1:100 000 topographical data and geological map sheets were acquired for this project. The datasets were all sub-sampled to cover the same geographic region and projected to the Geodetic Datum of Australia, 1994, Zone 53. All processing was performed in ENVI® 3.5. Each of these datasets is briefly described below.

Map Sheets: Published 1:100 000 map sheets were acquired to aid in the remotely sensed data assessment. Four map sheets cover the study area, including El Sherana, Mundogie, Jim Jim and Ranford Hill, sourced from GeoScience Australia. The topographical map sheets were scanned, rectified, mosaiced and subset to cover the region. Geological unit grouping was based on the most recently revised Stow map area. Although a more detailed (1:75 000) geological interpretation has been performed (Needham 1998), the extent does not fully cover the area of interest and therefore the 1:100 000 geological data was used.

Gamma data: The primary remotely sensed dataset was a high resolution airborne gamma survey (AGS), flown in October 2000, acquiring radiometric data (eU, eTh, K, and total count rates), magnetic intensity and digital elevation data. The AGS data was captured by UTS Geophysics and flown in a northwest–southeast direction, surveying 3,403 line km. The AGS channel data was collected with a 50 litre Exploranium GR820 spectrometer with the survey heights above the ground measured with a radar altimeter. Nominal line spacing and tie line spacing were 50m and 500 m, respectively. Nominal ground speed was 50 m s^{-1}; the count period for collection of radiometric spectra was 1 s. Accurate survey heights above the terrain were measured using a King radar altimeter installed in the aircraft, with a reported accuracy of 0.3 m and a resolution of 0.1 m, with a typical differentially corrected accuracy of 2–3 metres (horizontal). A requirement was placed on UTS Geophysics that data only be collected after 9 a.m. on any day, in order to avoid striping in the eU channel images due to early morning peaks in concentration of Rn-222 in the air column.

Processing and gridding of the radiometric data was performed by UTS Geophysics (for further information see Pfitzner and Martin 2000). Interpolation resulted in 12m pixels. Statistics for the eU, eTh, K and total count (TC) channels were calculated. The higher counts of the eU channel were delineated by iteratively using the eU channel threshold at 150 count intervals to highlight the elevated radiological areas (Pfitzner *et al* 2001a,b) which were integrated with the MASTER data. Individual channels were described as colour enhanced single channels, and integrated with the elevation data. The AGS data was also analysed as ternary KThU (RGB), and band ratios. MASTER data was merged with the AGS data to increase the spatial discrimination of features.

MASTER data: Multispectral 50-band MASTER data, spectrally covering the VNIR-TIR was acquired during September 2000, at 10 m spatial resolution. MASTER data were spectrally subsetted to exclude noisy bands, resulting in a 42-band dataset, and converted from radiance to at-sensor reflectance using the attributes provided. Data were converted to apparent reflectance by applying the "Flat Field" method and validated by comparing field spectra and spectral signatures of known targets. The reflectance data was georectified to the digital topographical data. The MASTER data covered a larger area than the AGS and was therefore subset to encompass the AGS data. The MASTER data was described as colour composites from the varying spectral regions. MNF transformations were applied to the full 42-band dataset, as well as separately to the VIS-NIR, SWIR, and TIR regions. For each of these regions, PPI was calculated and the higher pixels thresheld into the n-Dimensional Visualiser. Endmembers were also selected from field spectrometer data and image pixels. Mapping was performed using Matched Filtering. The resulting maps were interpreted three-dimensionally, with the aid of the AGS DEM.

2.2 Ground-based work

Fieldwork in the form of ground radiation surveys was performed with the aim of ground truthing the airborne gamma results and, in particular, investigating areas of elevated eU signal. Measurements were made with a portable NaI(Tl) γ spectrometer positioned 1 m above the ground. A number of transects were made with location measured by hand-held Garmen GPS. Due to field access difficulties, field studies at Coronation Hill and Saddle Ridge were not performed. In order to describe dose rates measured over the sampling sites, the ground-based measurements (Bq/kg) were used to estimate the adsorbed dose rate ($\mu Gy.h^{-1}$) due to terrestrial-origin gamma rays.

3 Results

3.1 Map Sheets

Merged topographical data provided an overall outline of the region and was used to correlate the known historical mining areas with their geographical location. Uranium anomalies, identified by the Northern Territory Geological Survey (1999) were overlain on the topographic data (figure 2). Examples of uranium anomalies that were mined during the 1950-1960s including the tailings deposition area are also referenced and highlighted in figure 2.

The geological units of the area, sourced from the 1:100 000 map sheets are highlighted in figure 3 and a brief description of the stratigraphy is provided in Table 1. The Namoona Group includes the Masson Formation (Pnm) and Stag Creek Volcanics (Pns), where Stag Creek Volcanics overlie and intertongue with the Masson Formation. Unconformably overlying the Namoona Group is the Mundogie Sandstone (Ppm) of the Mount Partridge Group, which is unconformably overlain by the South Alligator Group, characterised by outcrops of Koolpin Formation (Psk), Shovel Billabong Andesite (Psb), Gerowie Tuff (Psg) and Kapalga Formation (Psp). The South Alligator Group, characterised by iron-rich carbonaceous and dolomitic sediments, and volcanics, rests unconformably on older rocks and is conformably overlain by the Finniss River Group, of which, the Burrell Creek Formation (Pfb) is the only member. The Zamu Dolerite (Pdz) is pre-orogenic and intrudes the Burrell Creek Formation and Shovel Billabong Andesite and is unconformably overlain by the El Sherana Group (and younger units). The El Sherana Group is divided into the Scinto Breccia (Pbs), Coronation Sandstone (Pbc) and Pul Pul Rhyolite (Pbp). The Edith River Group overlies the earlier units, with marked angular unconformity, and is faulted against them in places. The group includes the basal Kurrundie Sandstone (Pek) and the Plum Tree Volcanics (Pep). The Edith River Group is unconformably overlain by the Middle Proterozoic Katherine River Group (Kombolgie Formation Phk), and flat lying Cretaceous sediments.

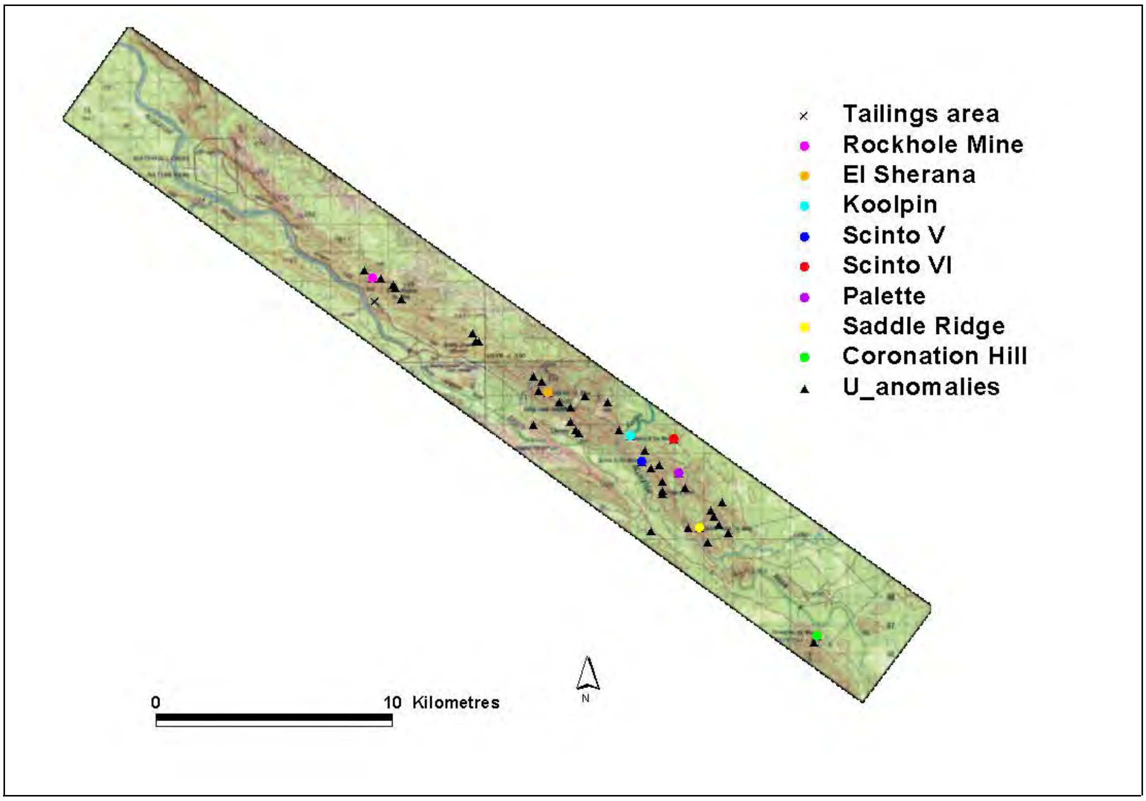


Figure 2 Merged 1:100 000 topographical data of the region highlighting the known historical uranium mining locations

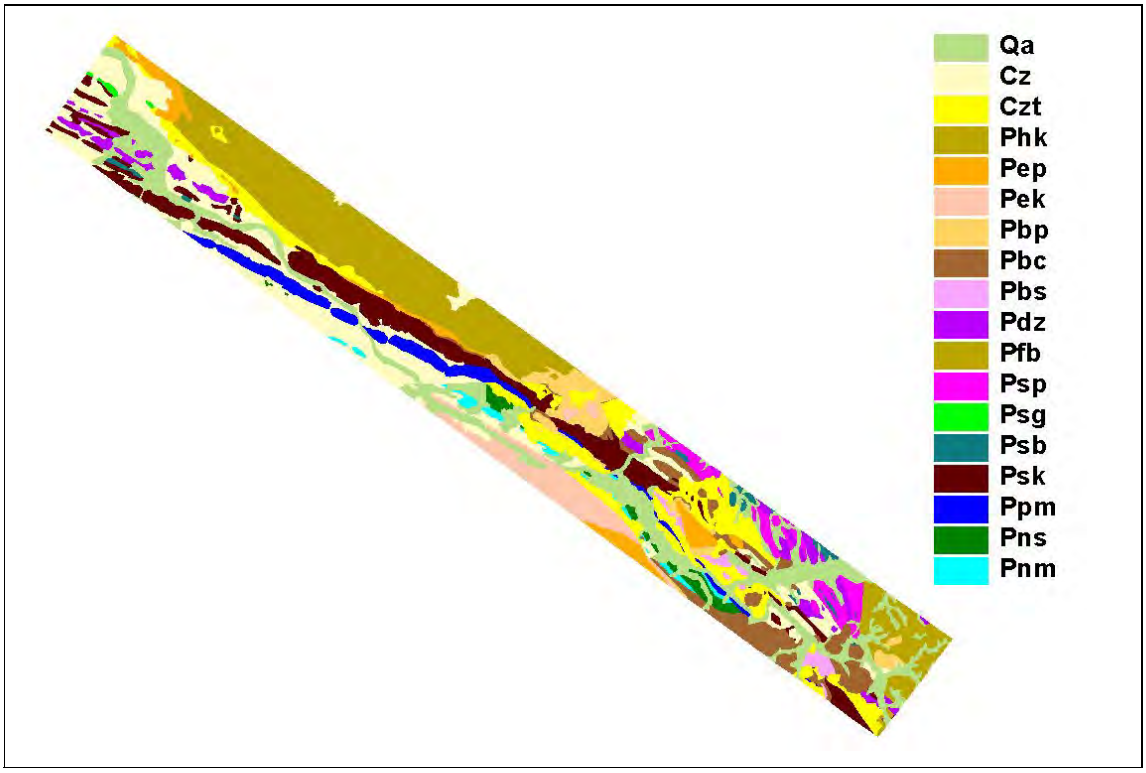


Figure 3 Merged 1:100 000 Geological data highlighting stratigraphic differences

Table 1 Overview of geological units in the region (Adapted from Stuart-Smith *et al* (1988)

				Rock Type	Physiography
CAINOZOIC		Quaternary sediments	Qa	Silt, sand, clay, locally consolidated grey sandy siltstone among some drainage courses, creek and river alluvium.	Occupies the courses and floodplains of the South Alligator River System, within channels of the major creeks and in drained depressions.
		Tertiary to Quaternary sediments	Cz Czt	Skeletal soils gradational red - yellow earth soils. Sandstone, quartzite & schist rubble, sand, talus scree	Talus slopes & sandy to gravelly skeletal soils, mostly developed in situ, widespread.
PROTEROZOIC	Katherine River Group	Kombolgie Formation	Phk/ Phe	Medium to coarse well-sorted buff clayey quartz sandstone	Deeply dissected Arnhem Land Plateau bordered by escarpments up to 200m high.
	UNCONFORMITY				
	Edith River Group	Plum Tree Volcanics	Pep	Massive pink to purple rhyodacitic ignimbrite, minor rhyolitic and tuff	Crops out beneath the Kombolgie Formation escarpment
		Kurrundie Sandstone	Pek	Massive purple clayey medium to coarse lithic quartz sandstone, pebble and cobble conglomerate, fine to coarse quartz sandstone, minor brown micaceous sandy siltstone	Crops out as a prominent strike ridge
	UNCONFORMITY				
	El Sherana Group	Pul Pul Rhyolite	Pbp	Altered purple to pink rhyolitic ignimbrite, minor agglomerate and glassy black rhyolite, rare siltstone and shale welded tuff, minor andesite	Exposed as rocky ridges
		Coronation Sandstone	Pbc	Clayey purple very coarse pebbly quartz sandstone, cobble conglomerate at base, interbedded shale, siltstone, greywacke, minor felsic and mafic volcanics	Mostly confined to the valley of the South Alligator River
		Scinto Breccia	Pbs	Pink siliceous phosphatic hematite sandy chert breccia	Irregularly distributed, commonly resting upon silicifed dolomite of the Koolpin Formation or other older carbonate rocks.
	UNCONFORMITY				
	Pre-Orogenic Intrusions	Zamu Dolerite	Pdz	Massive medium to coarse grey quartz dolerite and foliated amphibolite	Well exposed sills as low rubble-strewn ridges or prominent bouldery hills up to 160 m high, the presence of dolerite at shallow depth indicated by deep reddish brown soil and scattered rubble.
	Finniss River Group	Burrell Creek Formation	Pfb	Foliated fine to coarse metafeldspathic greywacke, chlorite-muscovite-quartz schist, phyllite and phylliticsiltone	Exposed on low rubbly rises and in creek beds, mostly covered by thin skeletal soils, Cainozoic sand and laterite or Quaternary alluvium
	South Alligator Group	Kapalga Formation	Psp	Ferruginous siltstone with chert bands; phyllite and carbonaceous shale; interbedded siltstone, greywacke, slate , arkose, sandstone	Poorly exposed as low strike ridges, or within erosion gullies, and is mostly covered by thin skeletal soils and rubbly soils
		Gerowie Tuff	Psg	Tuff, tuffaceous sediments, argillite, minor ferruginous siltstone	Crops out as low rubble-strewn rises
		Shovel Billabong Andesite	Psb	Massive greenish-grey altered pitchstone, variolotic andesite and minor microdiorite	Extensively jointed and fractured pavements, low sandy rises with scattered rubble and thick reddish brown soil.
		Koolpin Formation	Psk	Hematitic metasiltstone and phyllite. Dark grey graphitic phyllite, phyllitic siltstone, silicified dolomite. Lenses of stromatolitic dolomite, rare medium quartz greywacke.	Physically, the Koolpin Formation forms a line of rugged hills flanking the South Alligator River in a 1 km wide northwest-trending belt.
	UNCONFORMITY				
	Mount Partridge Group	Mundogie Sandstone	Ppm	Very coarse sericitic foliated quartzite and minor pebble conglomerate. Minor carbonaceous silty phyllite.	Characterised as a strike ridge up to 500m high with steep dips (commonly >70%), strongly faulted.
	UNCONFORMITY				
	Namoona Group	Stag Creek Volcanics	Pns	Massive pale-green altered intermediate-mafic flows & breccia. Minor green fine-coarse altered vitric tuff at base.	Poorly exposed, deeply weathered and mostly covered by thick skeletal soils and other Cainozoic deposits.
		Masson Formation	Pnm	Coarse dolarenite, pyritic quartzite, brown silty phyllite	Top 400 m outcrops forming beds up to 1 m thick and exposed as low strike ridges.

3.2 Airborne Gamma Survey (AGS) data

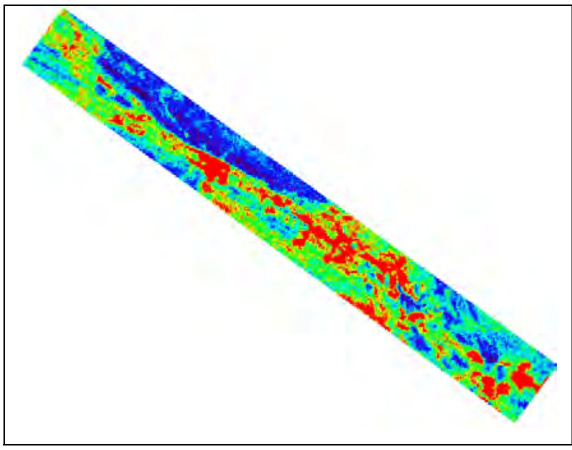
Previous analyses showed that the areas of highest eU signal correspond to known mine site locations (Pfitzner *et al* 2001a, Pfitzner *et al* 2001b). The strongest eU signal from the AGS were received at the South Alligator Mill Tailings area (1681 counts/s), El Sherana (1516 counts/s), Rockhole adit (1463 counts/s), and Palette (1461 counts/s). Of the remaining sites, in decreasing order of counts/s, maximum count rates received were Coronation Hill (1215), Scinto VI (1076), Saddle Ridge (952), Weighbridge (750), Battery Burial site (655), followed by Koolpin mine (540). The AGS was found to be particularly useful for highlighting these regions of greater count rates for determining ground-based field studies.

Figure 4 highlights the K, eTh, eU, and Total Count (TC) channels as colour enhanced images, ternary K, eTh, eU (RGB), and elevational data. Not surprisingly, the highest counts of the eU channel (figure 4a) correspond to the uranium mineralised Koolpin Formation, where associated with the historical mines. Moderate values also corresponding to the abandoned mine areas in the Scinto Breccia. Where the Coronation Sandstone unit cuts across the mines, the eU is high, although low elsewhere in the area. Moderate eU values are found in the Pul Pul Rhyolite. The Plum Tree Volcanics are characterised by low counts, apart from the mining areas. Quaternary alluvium is of low-moderate counts throughout the area in the eU channel, although high counts are seen in the southeast, not associated with known mining activities.

The eTh (figure 4b) channel showed elevated counts where the mines are located in the Koolpin Formation (low elsewhere in this unit), very high counts throughout the Pul Pul Rhyolite, and moderate-high values in the Scinto Breccia and Coronation Sandstone (very variable). Moderate-low values were found in the Stag Creek Volcanics, and Mundogie Sandstone. eTh values were found to be variable within the Kurrundie Sandstone (high readings in some areas of the unit and low elsewhere). Like the eU channel, the Plum Tree Volcanics are characterised by low counts, apart from the mining areas. The unconsolidated Tertiary to Quaternary sediments were found to be generally moderate in the eTh channel throughout the area, and the Quaternary alluvium moderate throughout the area, with high values in the south-east, as was found in the eU channel.

Unlike the eU and eTh channels, the K channel (figure 4c) showed high values in the Masson Formation, Mundogie Sandstone, Gerowie Tuff, Burrell Creek Formation, Shovel Billabong Andesite, and Coronation Sandstone. The Gerowie Tuff characteristically has two to three times higher radioactivity (potassium and thorium) than background for the region (Stuart-Smith *et al*, 1984). High values were found in the Koolpin Formation, as with the other channels. Moderate values in the K channel were associated with Stag Creek Volcanics, Zamu Dolerite and Scinto Breccia. Like the eU and eTh channels, the Plum Tree Volcanics are high at the mines, and otherwise low in this unit. The Tertiary to Quaternary unconsolidated sediments showed moderately high values in the K channel. The Quaternary alluvium showed moderate K values in the area, with high values in an area to the southeast.

The ternary image (figure 4d) highlights the course of the South Alligator River due to low count rate in all three channels, and the white bright area to the southeast of the area (not associated with mining activities) suggests high activity in all three channels. The uranium mineralised Koolpin Formation is represented as bright blue, and greenish-blue regions highlight areas of both high uranium and thorium.



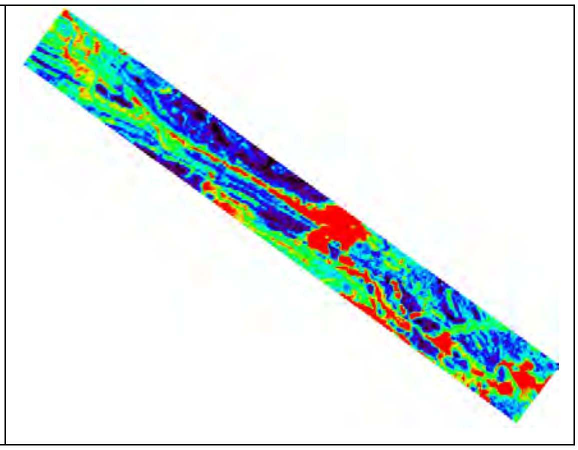


Figure 4a. eU (colour enhanced)

Figure 4b. eTh (colour enhanced)

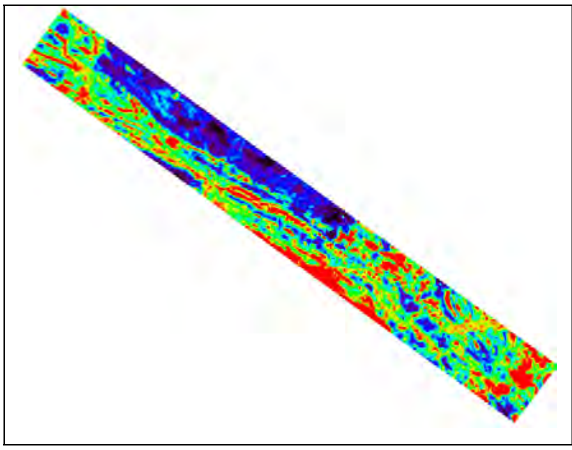
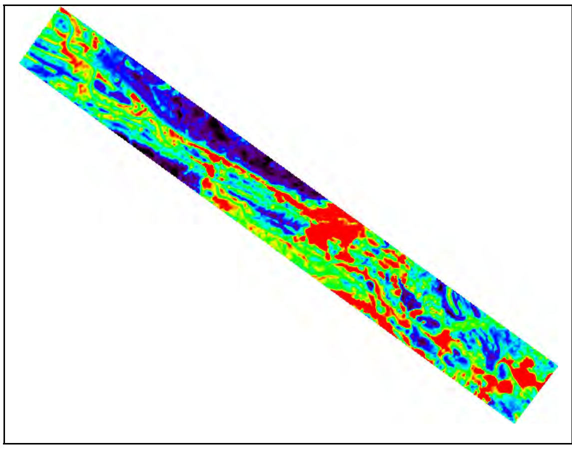


Figure 4c. K (colour enhanced)

Figure 4d. K, eTh, eU (RGB)



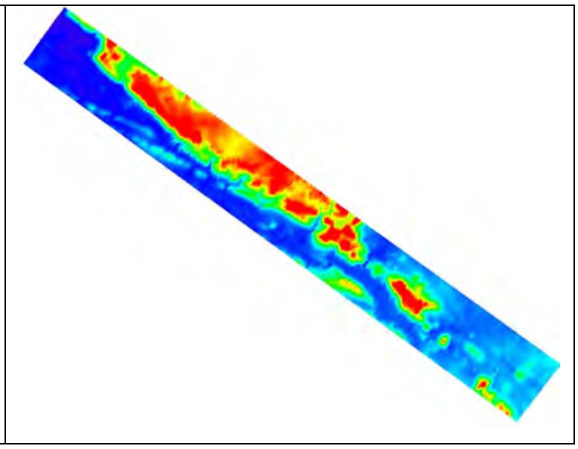


Figure 4e. TC (colour enhanced)

Figure 4f. DEM (colour enhanced and stretched)

Figure 4 The AGS data

The TC is an integrated measure across the spectrum. Since the number of counts recorded will be substantially greater than that in any of the individual bands, the counting statistical fluctuations will be much lower for the TC. As a consequence, in some cases, the spatial resolution for the TC band may be better than that for the individual bands, particularly for those areas of lower counts. Consequently for most areas, the TC image (figure 4e) provides better delineation of lithological and waterbody boundaries.

The Kombolgie Formation dominates the highest elevation areas in the DEM (figure 4f) to the northeast of the study area. Other prominent high elevation peaks in the area include Pul Pul Hill (middle of the southern half of the scene) and Coronation Hill (to the south west edge of the area). The subtle change in the DEM also highlights the direction of river flow being from southeast to northwest, as the overall elevation within the River valley decreases towards the northwest.

The airborne gamma data highlighted that there is an area to the southeast that is high in K, eTh, eU and TC, and can be clearly seen as a white bright area on the ternary image (figure 4). This area is not associated with mining activities.

3.3 Modis ASTER simulator (MASTER) data

Figure 5 provides RGB colour composites of the VNIR and SWIR regions of the MASTER data. The false colour composite of the VNIR highlights vegetation in red and iron-rich lithologies in green. The spatial resolution of the MASTER data was found to be too coarse to detail the historical mine sites, but proved useful in highlighting the surrounding landscape. The South Alligator River could clearly be identified dissecting the region and was separable from the light bright blue water of Gunlom Falls, deep-water billabongs, tributaries and dams. The red soil dirt track and other iron-rich features were mapped from the VNIR region. Riparian vegetation of differing greenness, woodland vegetation and grasslands were also clearly distinguishable in the VNIR. Variability in the unconsolidated sediments attributed to differing soil types (from river sand, granite derived river sand, and clays) were separated. The orange colours in the north west of the SWIR scene highlight the Koolpin Formation with the contact of the Gerowie Tuff (lighter yellow). All spectral regions of the MASTER data highlighted the Kurrundie Sandstone (Pek) as a distinct unit and that the Arnhem Land Plateau (Phk) and Zamu Dolerite (Pdz) are greatly variable in spectral reflectance. The TIR region highlighted quartz rich areas, the bleached sandstone, and silicifed units.

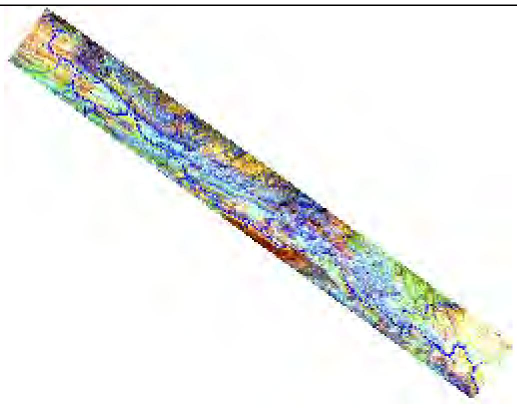
	
MASTER VNIR bands 7, 5, 3 (RGB)	MASTER SWIR bands 25, 12, 9 (RGB)

Figure 5 Selected displays of MASTER data

3.4 Integrated datasets

The MASTER data was merged with the AGS (as illustrated in figure 6) and the AGS DEM viewed three dimensionally with the VIS-TIR MASTER data, providing greater detail of the wider landscape and enhancing interpretations of the topography and erosion susceptibility of the mining areas. The most striking topographic differences included the Mundogie and

Kurrundie Sandstones, northwest trending hills of the Koolpin Formation, Pul Pul Rhyolite as rocky ridges, and the distinctive Arnhem Land Plateau. The high count (in all AGS channels) non-mining area to the southeast of the region corresponded to the Burrell Creek Formation and alluvium. Inspection of the MASTER data further to the southeast (not included in the overlapping AGS region) revealed a prominent 10 km^2 granite outcrop, which is reportedly radiologically high (P Ferenczi, NT Department of Business, Industry & Resource Development, 2002, pers comm).

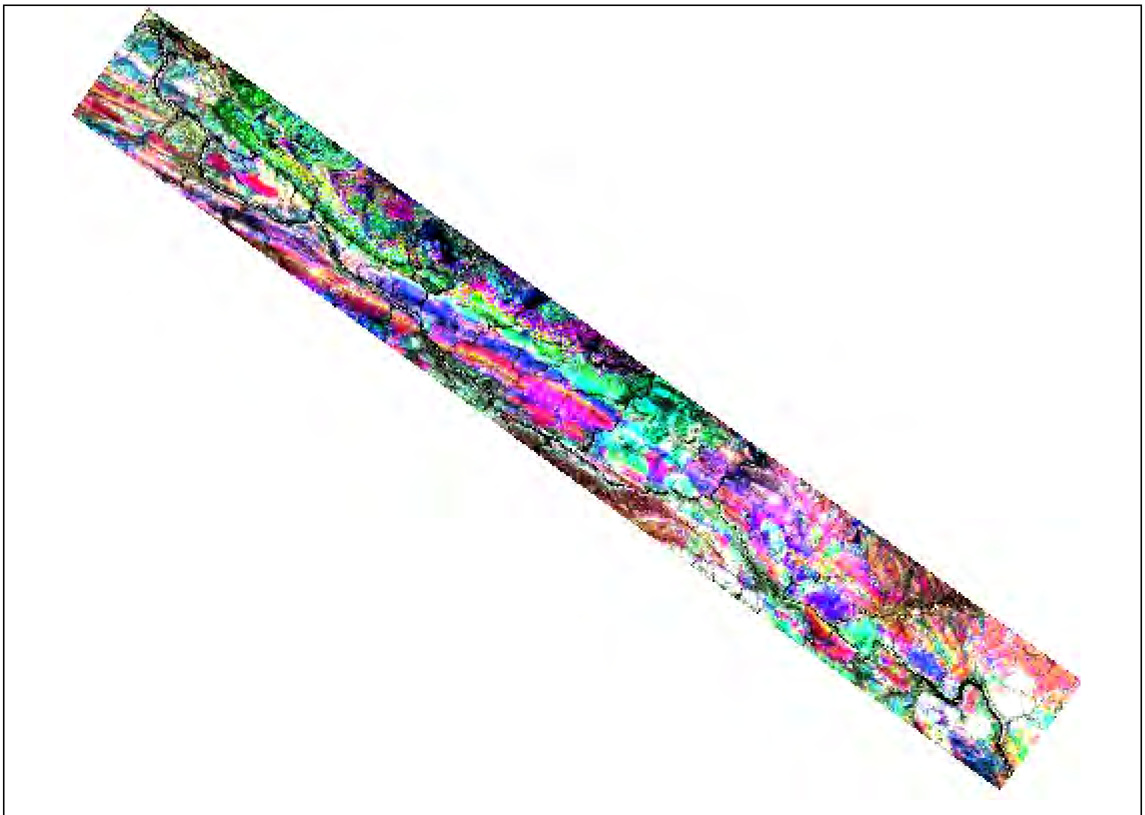


Figure 6 K, eTh, eU (RGB) merged with band 5 of MASTER data

3.5 Ground-based studies

A range of airborne gamma values covered the transects and associated sampling sites. Ground-based validation showed that the highest count rates were received at the South Alligator Mill tailings area, with highest readings being characterised by small-localised patches of elevated eU, often associated with clayey material. Of the other sites measured, ground-based validation showed that the highest rates were received at Palette over two very small patches of crushed rock that appeared to be associated with more recent drilling, rather than historical mining activities. Of the remaining sites, in decreasing order of ground-based spectrometer readings, maximum count rates were recorded at El Sherana, Scinto V, Weighbridge, Koolpin, and Scinto VI.

4 Discussion

The outcome of the AGS showed that it is particularly useful for highlighting regions of eU anomalies for subsequent ground truthing. Comparison of the overall results of the AGS with the results from ground-truthing exercises showed that the ground-based measurements follow the general trend of the AGS (i.e. areas of highest count rates generally exhibited the highest activities during the ground-truthing). It proved very useful in highlighting areas of comparatively high radiation levels that were later identified during ground-based measurements.

Direct comparison of the ground data with individual image pixels of the AGS proved unsuccessful (Pfitzner *et al* 2001a, 2001b). The reason for this is that areas of higher activities appear in small pockets at most of the sites, whereas the true resolution of the image will be at best 50 m x 50 m, since the nominal line spacing was 50 m, with individual readings integrated over an average distance of 50 m along each line. In situations such as this where there are small, well-defined areas with relatively high gamma radiation fields (i.e. more than an order of magnitude greater than "background") surrounded by areas of relatively low gamma radiation fields, then the maximum airborne signal received will be largely influenced by, and often dominated by, the radioactivity in the ground in the small, high activity areas. Using the airborne signal to estimate actual soil concentrations or dose rates would result in a significant underestimate for the high regions. For the method applied to calculate a gamma dose rate for the present AGS dataset, see Bollhöfer *et al* (2002).

Nevertheless, the AGS data was found to be cost and time effective for targeting ground-based studies. The AGS data correlated well with published geology and highlighted variations within geological units. The spatial resolution of the MASTER data was not great enough to detail the small mining areas, but highlighted the physiography of the region. Combined with the AGS DEM, the landforms of the area are predominantly elevated, with hills and ridges, lesser areas of gentle slopes and narrow floodplains. Associated with areas of high elevation are shallow stony soils, small areas of sandy lowland soils and alluvial soils. Vegetation is dominated by riparian open forest, woodland (*Eucalyptus*) and grassland.

It should be emphasised that the effective dose rates (received via pathways of digestion, inhalation, and external exposure) have been estimated at a maximum of 0.3 mSv above background in a year (for local Aboriginal people) ranging to 0.001 mSv above background in a year (for park visitors). These are very small doses above the natural background and are certainly not high enough to cause concern. Further information on the calculation of these dose rates is given in Bollhöfer *et al* (2002).

5 Conclusions

Despite the small physical size of the abandoned uranium mine sites in the upper South Alligator River valley, the high resolution AGS was found to indeed detect gamma signals from these localised regions and provided an overall indication of the locations of elevated gamma signals. The eU channel results highlighted that elevated gamma signals emanated from previously known mining locations, the majority of which having mechanisms such as warning signs and fencing already in place to minimise risk. The AGS survey was found particularly cost and time effective in determining and prioritising the location for detailed ground-based studies. As a result of large localised variations of gamma radiation on the ground, it was found that ground-based gamma studies were required to detail the source and exact location of gamma radiation indicated by a particular ground resolution element of the AGS data. The MASTER data provided landscape detail aiding interpretation.

The use of high resolution AGS data, combined with high spectral and spatial resolution imagery such as MASTER imagery, provided a cost and time effective method for assessing the state and radiological nature of small abandoned uranium mines and detailed the wider landscape of the upper South Alligator River valley.

Acknowledgment

The acquisition of the airborne gamma survey was jointly funded by Parks Australia North and the Environmental Research Institute of the Supervising Scientist (***eriss***).

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Powerpoint slides

Mapping the upper South Alligator River valley using integrated datasets

Kirrilly Pfitzner & Paul Martin

Objective

To provide

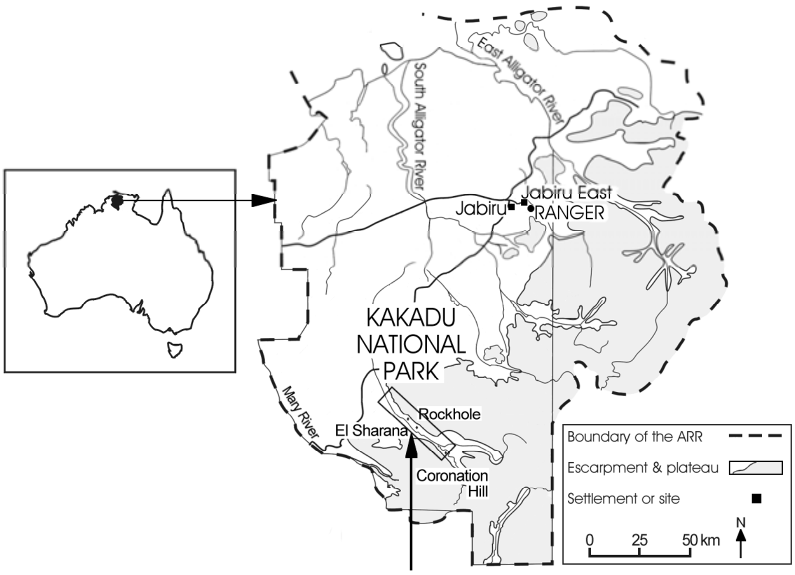
an overall indication of radiological issues

within the upper South Alligator River valley

and to detail the wider landscape.

Study area:

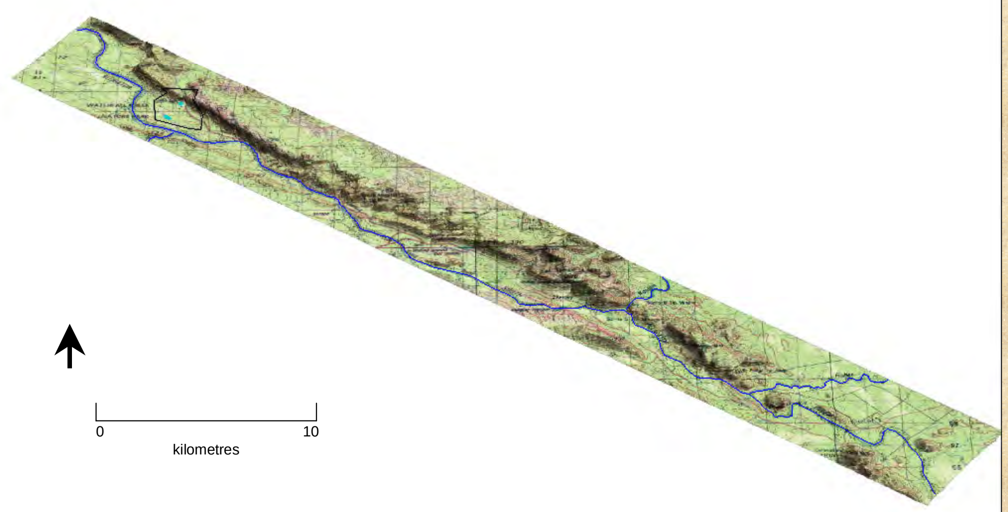
The location of the upper South Alligator River valley

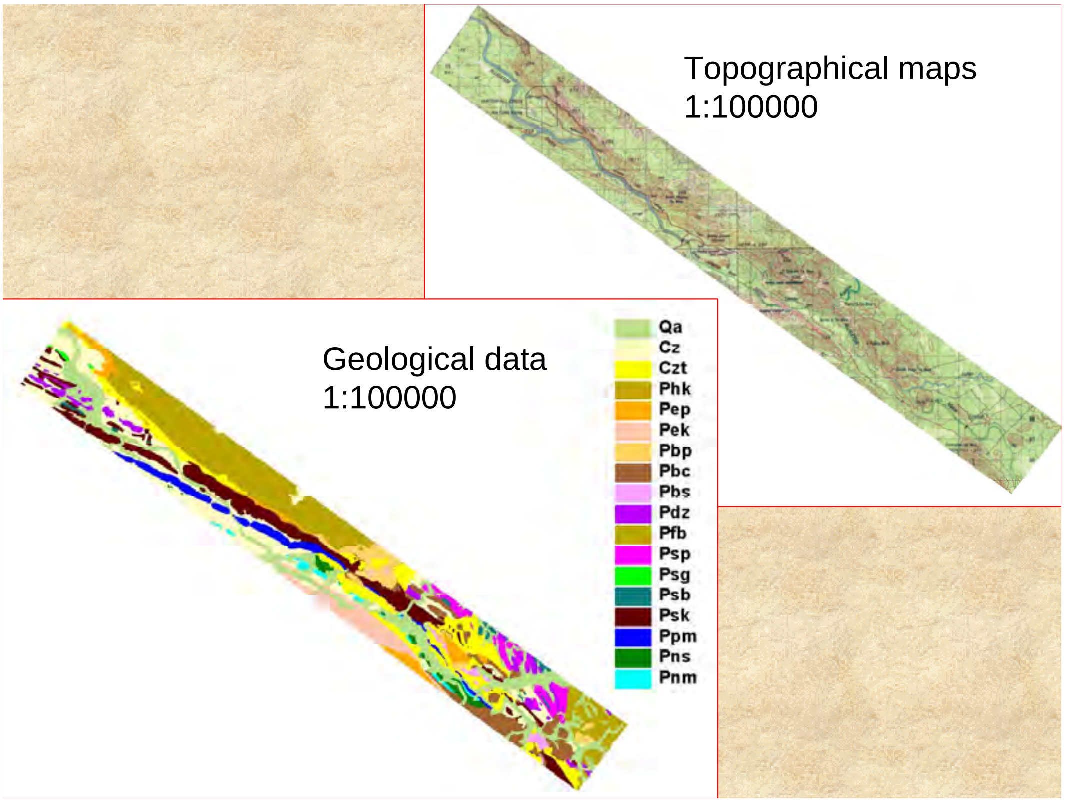


Upper South Alligator River area

Study area:

The upper South Alligator River valley area





Mining history of the area

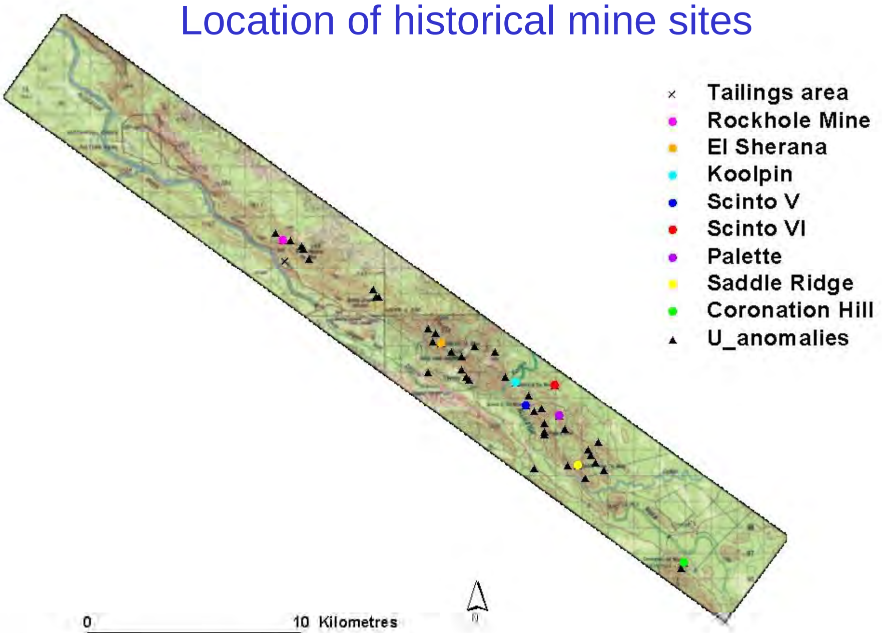

El Sherana West open cut

- 13 small U mines, prospects & a small mill operated in the 1950s-60s
- deposits characterised by high U content, up to 2.5% U_3O_8, producing ~ 1000 tonnes of U_3O_8.
- small open cuts and adits
- prior to contemporary environmental legislation
- sites abandoned in 1964 without rehabilitation for minimisation of environmental impacts


Saddle Ridge open cut

Abandoned mine sites

Location of historical mine sites



To provide an overall indication of radiological issues within the upper South Alligator River valley and to detail the wider landscape

Project objectives:

- To determine whether remotely sensed data can provide useful information to assess the state of small abandoned uranium mines
- Determine the suitability of an airborne gamma survey to assess any radiological impact in the valley
- Provide spatially accurate and detailed locations of mine sites
- Detail the wider landscape of the valley

Remotely sensed data

1. airborne gamma data
2. airborne MASTER data
3. IKONOS imagery

- topographical and geological data

1. High resolution airborne gamma data

- data collected = K, eTh, eU, TC, magnetics & elevation data
- 50 L NaI(Tl) Spectrometer
- 50 m spatial resolution

2. MASTER imagery

- 50 bands covering the VNIR,SWIR, MIR and TIR
- 10 m spatial resolution

3. IKONOS imagery

- 4 band VNIR at 4 m resolution and 1 band pan at 1 m spatial resolution

- 1: 100 000 digital geology and topographical data

Image Processing of AGS:

- To highlight radiological anomalies:

↓

eU channel

↓

statistics

↓

colour enhanced and contrast stretched

↓

threshold at 150 counts/sec intervals at counts greater than 350 counts/s

↓

eU classes

- To detail the wider landscape:

↓

All channels colour enhanced and viewed with high resolution DEM

↓

Band ratios

Image Processing of MASTER:

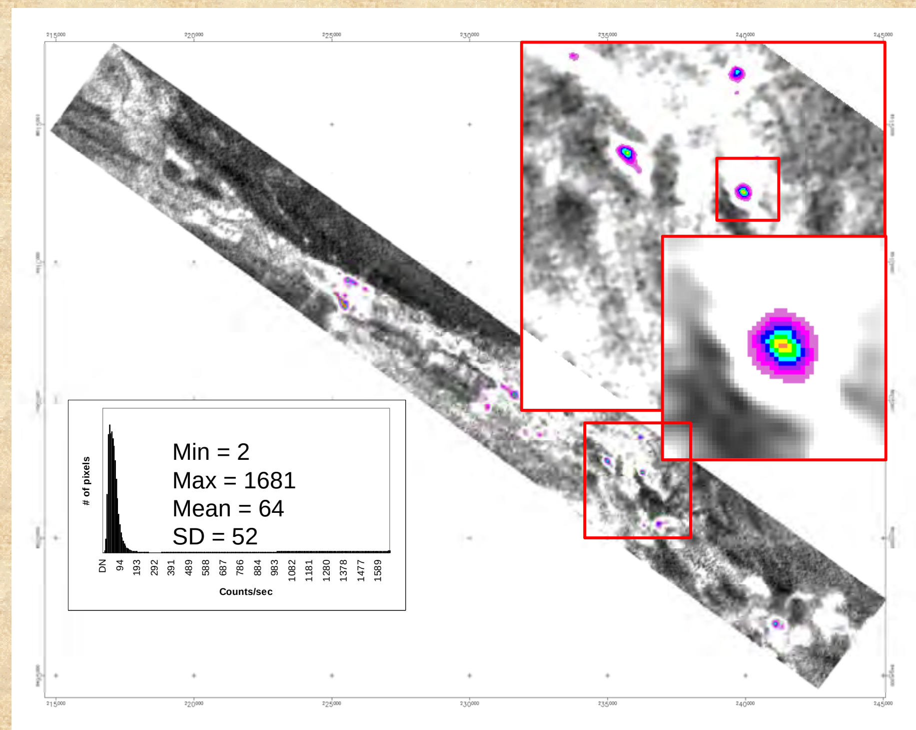
Spectral subset
↓
Converted to at-sensor reflectance
↓
Converted to apparent reflectance using Flat Field method
↓
Reflectance data georectified
↓
Spatial subset
↓
MNF transformations of full 42-band dataset, and separately to the VNIR, SWIR and TIR regions
↓
Endmember collection
↓
Matched Filtering

IKONOS: 4 scenes geocorrected, colour balanced, and subset

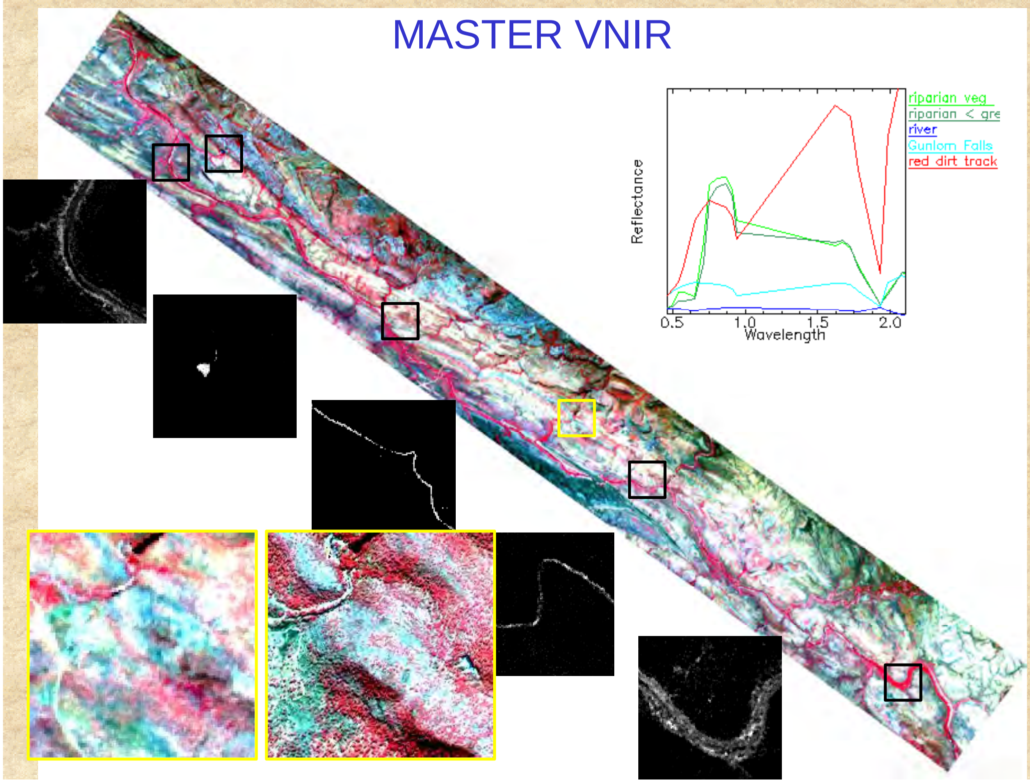
Data integration

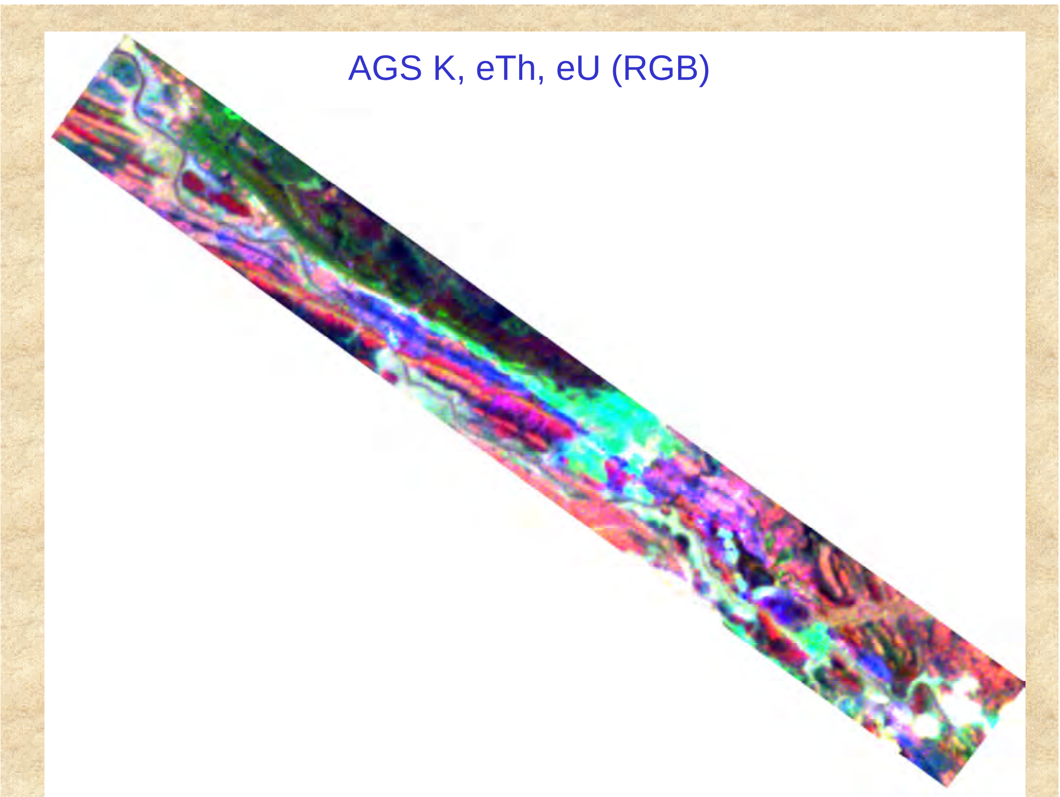
- eU count classes integrated with topographical data, MASTER and IKONOS imagery
- MASTER data merged with AGS
- Geological boundaries used with KThU
- MASTER and IKONOS 3D visualisation with AGS DEM

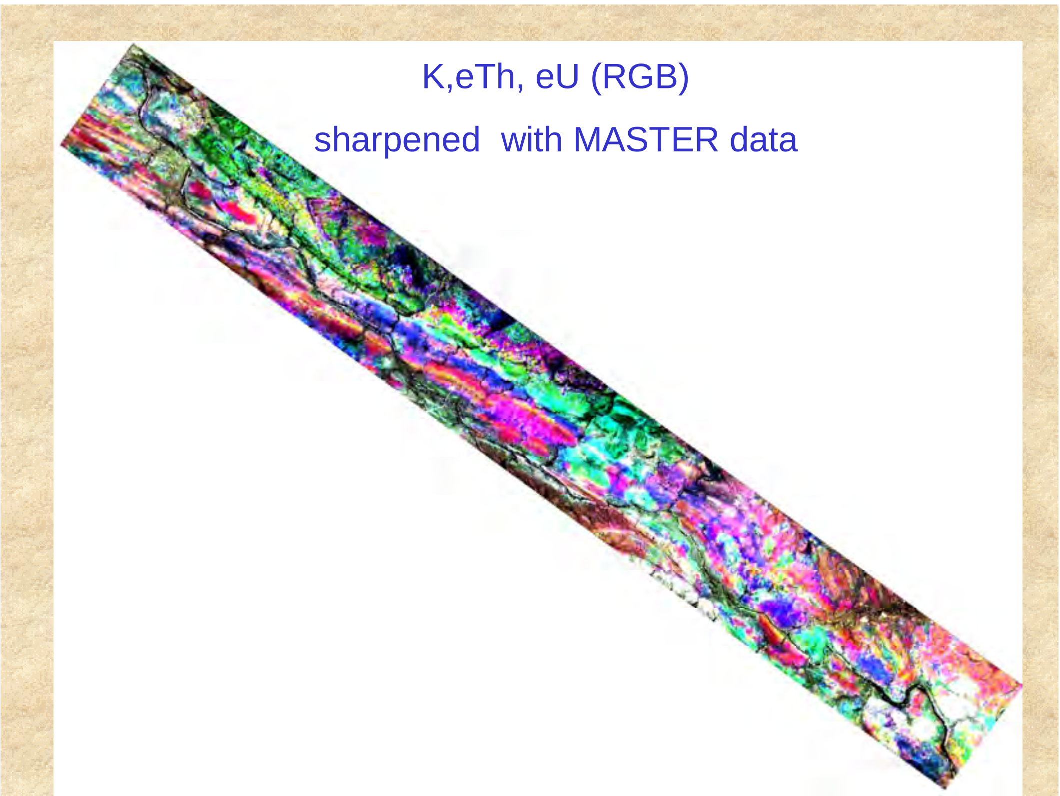
eU AGS results for radiological assessment



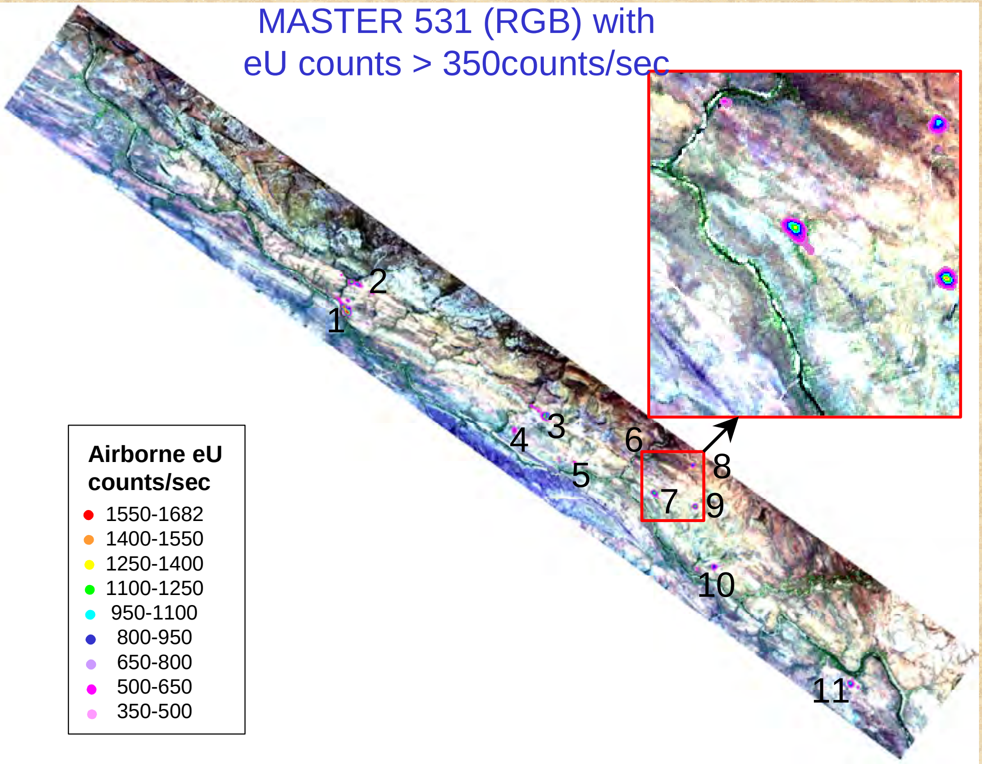
MASTER VNIR




AGS K, eTh, eU (RGB)


K,eTh, eU (RGB)
sharpened with MASTER data

MASTER 531 (RGB) with eU counts > 350counts/sec



Fieldwork

• Ground radiation surveys with portable NaI(Tl) γ spectrometer

Discussion

• AGS with tight line spacing was effective in locating small areas of elevated gamma signals such as abandoned mine sites

• AGS found to be cost and time effective for targeting ground-based studies

• MASTER data provided landscape detail aiding in interpretation

• Combining the high resolution DEM with MASTER imagery increased the usefulness of the MASTER for landscape detail

• Combining the increased spatial resolution of the MASTER data with the AGS sharpened the AGS data for landscape detail

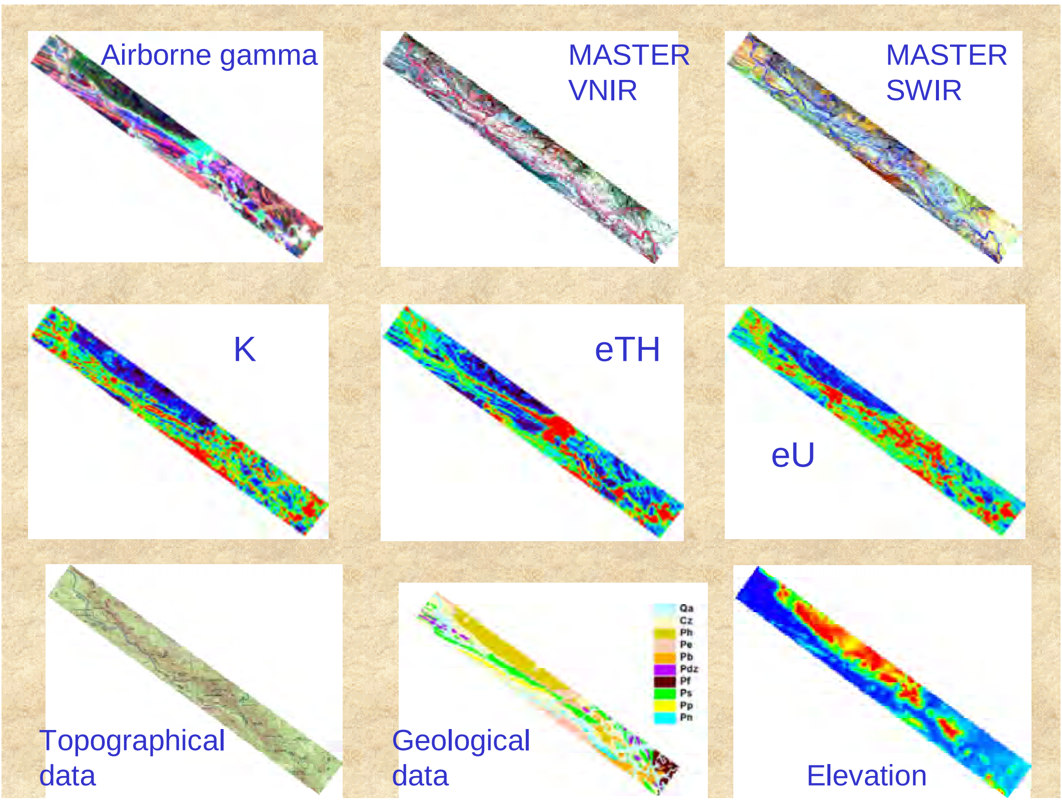
Conclusion

The use of high resolution AGS data combined with high spatial and spectral MASTER imagery, provided a cost and time effective method for assessing the radiological nature of small abandoned uranium mines and to detail the wider landscape of the upper South Alligator River valley.

Further work

➢ Poster presentation to land managers and owners
➢ 25m line spaced AGS at the abandoned Sleisbeck U mine

Acknowledgement: The acquisition of the airborne gamma survey was jointly funded by Parks Australia North and ***eriss***



NOTE: Effective dose (received via pathways of ingestion, inhalation, and external exposure) have been estimated at a maximum of 0.3 mSv above background in a year (for local Aboriginal people) ranging to 0.001 mSv above background in a year (for Park visitors).
These are very small doses above natural background and are certainly not high enough to cause concern.