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Airborne gamma survey of the upper South Alligator River valley: Third Report

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supervising scientist

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Environmental Research Institute of the Supervising Scientist **(*eriss*)**

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Summary

A number of small uranium mining and milling operations took place in the 1950s and 1960s in the upper South Alligator Valley. The sites were abandoned in 1964, with no effort to rehabilitate any effects that mining and milling may have resulted in. A hazard reduction program has since been undertaken. Staff from OSS regularly monitor the abandoned mine sites for erosion and revegetation, which is supplemented with periodic radiological inspections. In October 2000, an airborne gamma survey was flown over the upper South Alligator River area[1] in order to gain an overview of the location of any radiological issues within the area. This type of survey is done from an aeroplane with an instrument onboard called a "gamma ray spectrometer". The particular gamma ray spectrometer used measures the emissions from the decay of three radioactive elements in surface material like soils and rocks. The signals originate from the decays of potassium (K), thorium (Th), and uranium (U)[2]. These signals give measures of the abundance of the elements in the ground over which the aeroplane flies. From this survey, ***eriss*** is preparing images of the radioactivity levels around the valley area. ***eriss*** have also carried out other field-based measurements in the area. This is being done to help Parks Australia North (PAN) prepare a management plan for old uranium mine and mill sites in the area.

In a previous report, the results from the U emissions of the airborne gamma survey around the Gunlom Uranium Mill and the Rockhole Mine Creek area were discussed. This report discusses the results we have found for the other mine sites covered in the airborne survey. Figure 1 (on the next page) shows part of a topographical map covering the study area described in this report, illustrating the location of features such as the South Alligator River, Koolpin Creek, and Fisher Creek.

[1] This gamma survey was funded equally by ***eriss*** and Parks Australia North

[2] Technically, the U and Th signals do not represent uranium and thorium, respectively. The so-called "U signal" is a result of the decay of Bi-214 (a daughter of uranium) whereas the “Th signal” is a result of the decay of Tl-208 (a daughter of thorium).

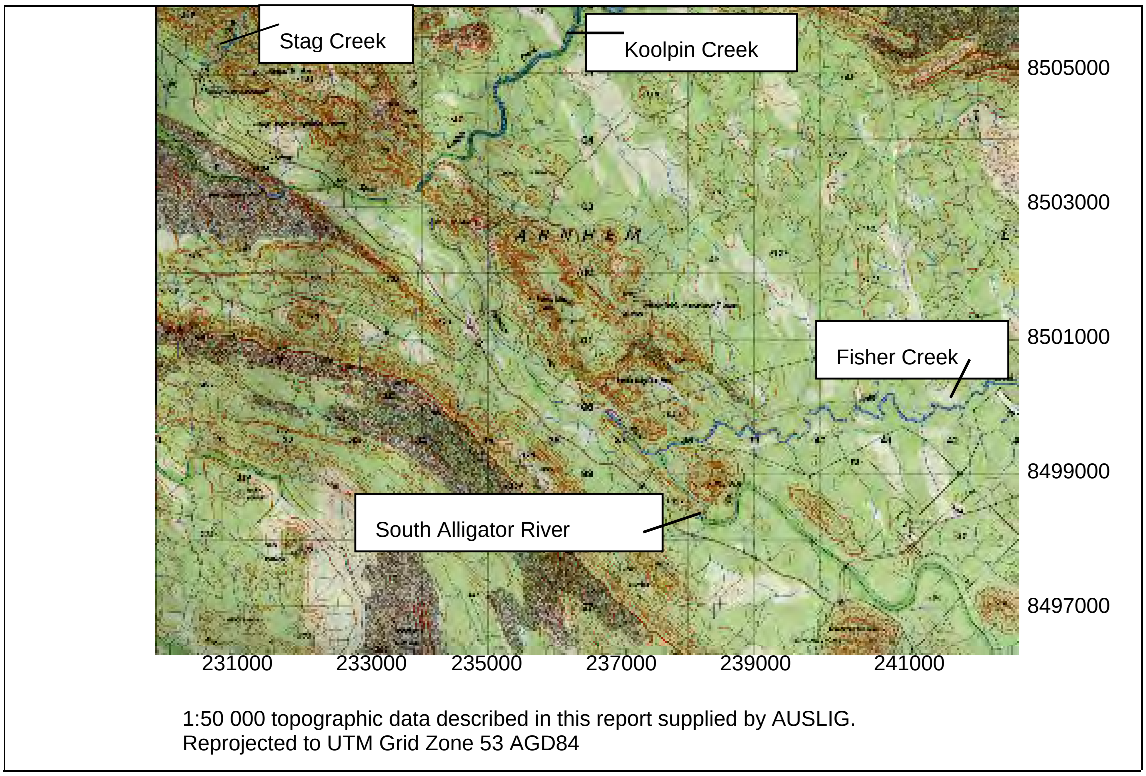


Figure 1. Subset of topographic map covering some of the old mine sites, highlighting the South Alligator River, Koolpin Creek, Fisher Creek, and Stag Creek.

Figure 2 (on the next page) shows results from the U signal of the airborne gamma survey in various colours overlain on the greyscale topographical map. Orange shows the area with highest uranium signal, yellow next highest, green next, and so on. Figure 3 displays these old mine locations.

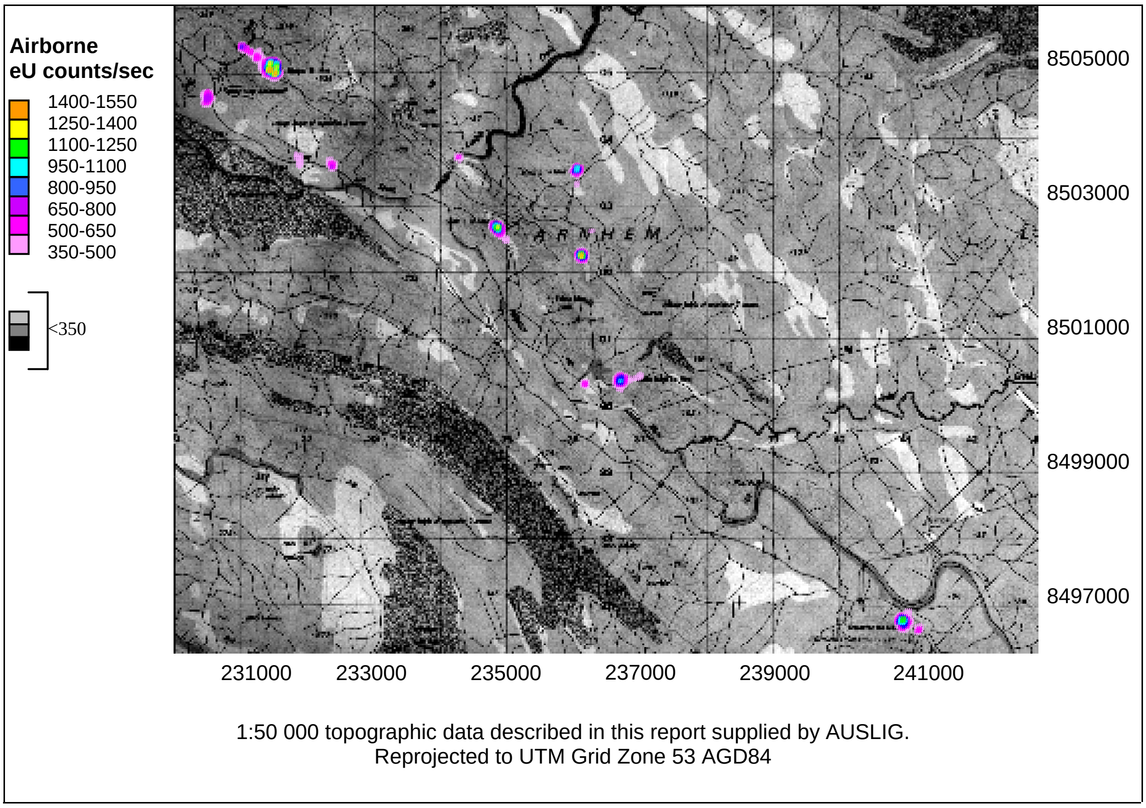
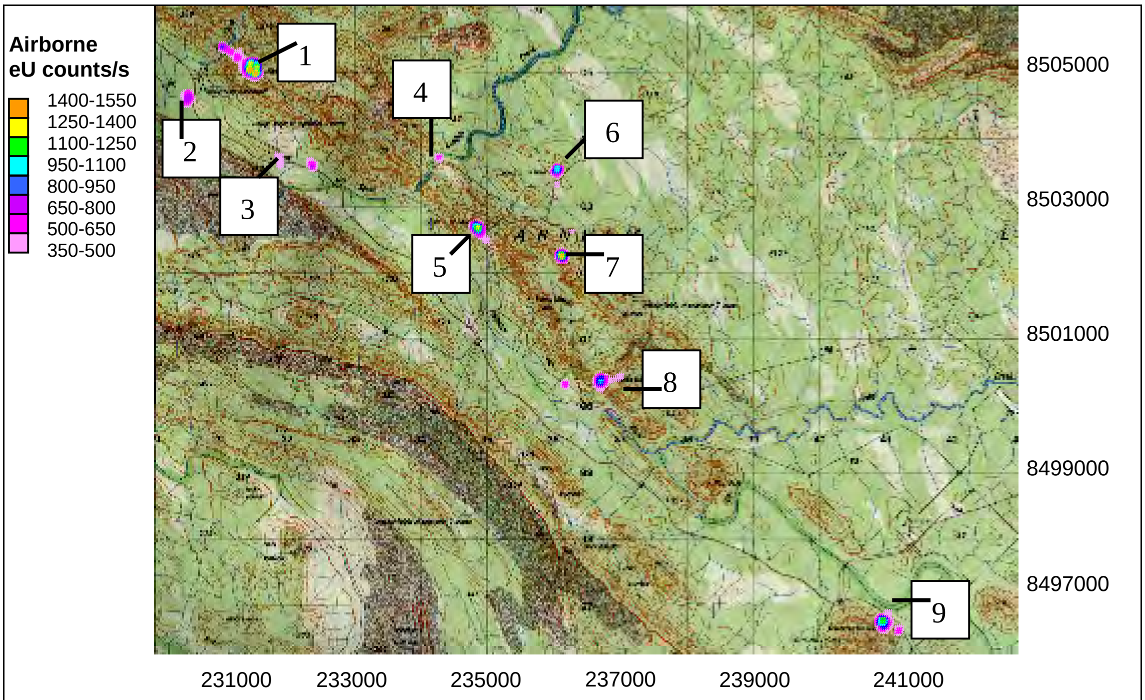


Figure 2. "Uranium Signal" counts overlain on the topographical map.



1:50 000 topographic data described in this report supplied by AUSLIG.
Reprojected to UTM Grid Zone 53 AGD84

1 = El Sherana Mining area
2 = Weighbridge Burial site area
3 = Battery Burial site area
4 = Koolpin Mine
5 = Scinto V Mining area
6 = Scinto VI Mining area
7 = Pallete Mining area
8 = Saddle Ridge Mining area
9 = Coronation Hill Mining area

Figure 3. "Uranium Signal" counts overlain on the topographical map, with known mine site locations.

Figure 2 shows that there are a number of areas of higher uranium signals. A good thing is that all of the higher readings correspond to known abandoned mine sites. In other words, there were no areas detected of higher levels that were previously unknown. Except for the Weighbridge burial site, these old mine sites have radiation warning signs clearly displayed. According to the airborne survey count rates displayed in figure 2, the areas with the highest counts correspond to El Sherana and Pallete mines. Scinto V recorded the next highest count readings. Of the remaining sites, in decreasing count rates, were Coronation Hill, Scinto VI, Saddle Ridge, Weighbridge, Koolpin mine, followed by the Battery burial site. There are a few areas of lower counts, including an area near the old battery site, and an area on the Koolpin track NNE of Pallete. The airborne gamma survey was found to be particularly useful in highlighting these regions of greater counts for determining ground-based field studies.

eriss has examined many of the abandoned mine sites in the dry season of 2001 during a field study to determine the exact location and extent of radioactivity. The mine sites examined included Scinto V, Koolpin, Pallete, El Sherana, Weighbridge burial site, Battery burial site and Scinto VI. Due to access difficulties, both physical and cultural, we have not performed field studies at Coronation Hill or Saddle Ridge. The field survey showed that the highest signals are coming from two very small patches near the Pallete mining area, with the highest reading at a site that appeared to be associated with recent drilling. This site is difficult to access. Readings taken at locations in and around the El Sherana pit provided the next highest readings. The El Sherana pit area is also quite difficult to access. One field site reading at Scinto V, downslope of the mine pit area, recorded the next highest reading we measured. Although there is general agreement between the airborne and field results, the airborne survey does not always show smaller areas that contain higher U patches, but provides a guide for field-based studies.

The airborne gamma survey and fieldwork suggest there is erosion of material from the mine pits to downslope areas at Scinto V and El Sherana. Scinto VI, Koolpin mine and the Weighbridge burial site appear radiologically contained. Water was evident in the pit during the field visit to Scinto V. Field observations suggest that during the wet season, the pit water breaches over the pit wall and flows downslope through an erosion gully towards a creek, with finer higher activity material deposited in the low-lying area southeast of the pit. At El Sherana, the overall appearance of the airborne image, with higher counts received around the mine pit area, and ceasing downslope at the Stag Creek Dam site, also suggest erosion processes of material outside the mine pit site into Stag Creek. The airborne survey results suggest that Scinto VI is radiologically contained. Koolpin mine appears radiologically contained. Pallete mine also appears relatively contained, with the highest radiological readings emanating from the remains of recent drilling. Weighbridge burial site appears radiologically contained. Referring to the airborne gamma image, it appears that there is a plume of material emanating from Saddle Ridge towards the east, although this has not been field verified. Coronation Hill was also not field verified, but appears contained according to the airborne gamma image.

The fourth report (Bollhöfer *et al*, 2001) in the Airborne Gamma Survey of the South Alligator River will contain information about how much radiation people receive in this area. This report will include radiation dose information that concern local Aboriginal people, Parks Australia North workers and the general public.

Technical Summary

This report is the third in a series concerning the project "Airborne gamma survey of the upper South Alligator River Valley". A previous report (Pfitzner *et al* 2001) focused on a subset of the airborne gamma survey covering the Gunlom Uranium Mill residue (tailings area) and Rockhole Mine Creek area. This report describes the results obtained for the remaining mine sites, which include Scinto V, Scinto VI, Pallete, El Sherana and Koolpin. The primary remotely sensed data set described in this report is the eU channel of a 50m line spaced airborne gamma survey. A topographical map was also used to provide a geographic relationship with the airborne gamma data.

According to the airborne gamma results, eU count rates over the study area ranged from 4 counts/second up to 1516 counts/second. Count rates greater than 350 counts/s, divided into intervals of 150 counts/s, were used to highlight the higher count areas. The results showed that all higher eU signals in the study area corresponded to known mine site locations. The strongest eU signals from the airborne gamma survey were received at El Sherana (1516 counts/s) and Pallete (1461 counts/s). Significant count rates were also recorded around Scinto V (1280 counts/s). Of the remaining sites, in decreasing order maximum count rates received were Coronation Hill (1215 counts/s), Scinto VI (1076), Saddle Ridge (952), Weighbridge (750), Battery burial site (655), followed by Koolpin mine (540 counts/s). A few areas of lower counts (between 400 and 700 counts/s) were also indicated from the airborne data. These sites are an area near the old Battery site (655 counts/s), an area on the Koolpin Track (409 counts/s) NNE of Pallete, and an area W of Saddle Ridge (567 counts/s). The airborne gamma survey was found to be particularly useful in highlighting these regions of greater count rates for determining ground-based field studies.

In July 2001 ***eriss*** staff performed a radiation ground survey of Scinto V, Scinto VI, Pallete, El Sherana, Koolpin, the Weighbridge burial site and the Battery burial site. In October 2001 ***eriss*** staff performed a second radiation ground survey of the El Sherana pit area. Due to access difficulties, both physical and cultural, field studies at Coronation Hill and Saddle Ridge were not performed. Field-based NaI gamma spectrometer readings at one site at Pallete, the El Sherana pit area and another site within the pit at Scinto VI were not possible due to very high counts received which resulted in an inability of the spectrometer software to stabilise the spectrum. Of the sites which were measured, field validation showed that the highest rates were received at Pallete, with the highest reading (obtainable) corresponding to 5246 Bq/kg over two very small patches of crushed rock downslope from the Pallete open cut mining area, which appeared to be associated with recent drilling. Readings taken at locations in and around the El Sherana pit recorded up to 4927 Bq/kg. One field site reading at Scinto V recorded the next highest reading (3220 Bq/kg) which was measured downslope of the mine pit in a lowland area. The airborne gamma survey and fieldwork suggest there is erosion of material from the mine pits to downslope areas at Scinto V and El Sherana.

Based on the field-based NaI spectrometer readings only, dose rates for the measured sites were generally less than 1μG/hr, however, field-based results recorded up to 2.6μG/hr (excluding the higher areas where spectrometer readings were not possible). Refer to Bollhöfer *et al* (2001) for further information on dose levels.

The airborne survey results were invaluable in determining field-based studies. It was found that field-based measurements can vary dramatically over small distances. The 50m spatial resolution of the airborne survey was too great to detail the small areal patches of high eU signals. Airborne gamma survey results can be used as a guide for determining the location of field-based studies. However, it is difficult to determine direct correlations with actual soil concentrations or gamma dose rates at specific locations (see Bollhöfer *et al*, 2001).

Introduction

This is the third in a series of reports concerning the project "Airborne gamma survey of the upper South Alligator River valley". The first report in this series was published as ***eriss*** Internal Report (IR) number 353 (Pfitzner and Martin, 2000) and the second as IR 377 (Pfitzner *et al* 2001). The second report focused on a subset of the airborne gamma survey covering the Gunlom Uranium Mill residue and Rockhole Mine Creek study area. This report covers a number of other mine sites including Scinto V, Scinto VI, Pallete, El Sherana, and Koolpin. In particular, it is the purpose of this report to discuss the variation in eU signal around these sites obtained by the airborne survey, and to relate the signals to geographic locations. Field-based gamma spectrometry results over the area will also be discussed and correlated to the airborne signals. Refer to Bollhoefer *et al* (2001) for information on dose levels.

Future reports will further detail the radiometric, magnetic, elevation data, and other remotely sensed data sets captured over the area.

Airborne gamma survey

The remotely sensed data set described in this report is a 50m line spaced airborne gamma survey, flown in October 2000. Parks Australia North and ***eriss*** jointly funded the acquisition of the airborne gamma data set.

In October 2000, UTS Geophysics conducted a low-level airborne geophysical survey. Refer to Pfitzner and Martin (2000) for details concerning image acquisition, survey parameters, data processing performed by UTS Geophysics, and the initial remotely sensed data results. Image data received was projected in the AGD84 coordinate system, Universal Transverse Mercator projection, derived from the Australian Geodetic datum. The raw counts have been interpolated, and in this case, the smallest element size is 12 m on the airborne imagery. The airborne gamma survey extent is illustrated in Figure 4, with the red box highlighting the subset area described in the remainder of this report.

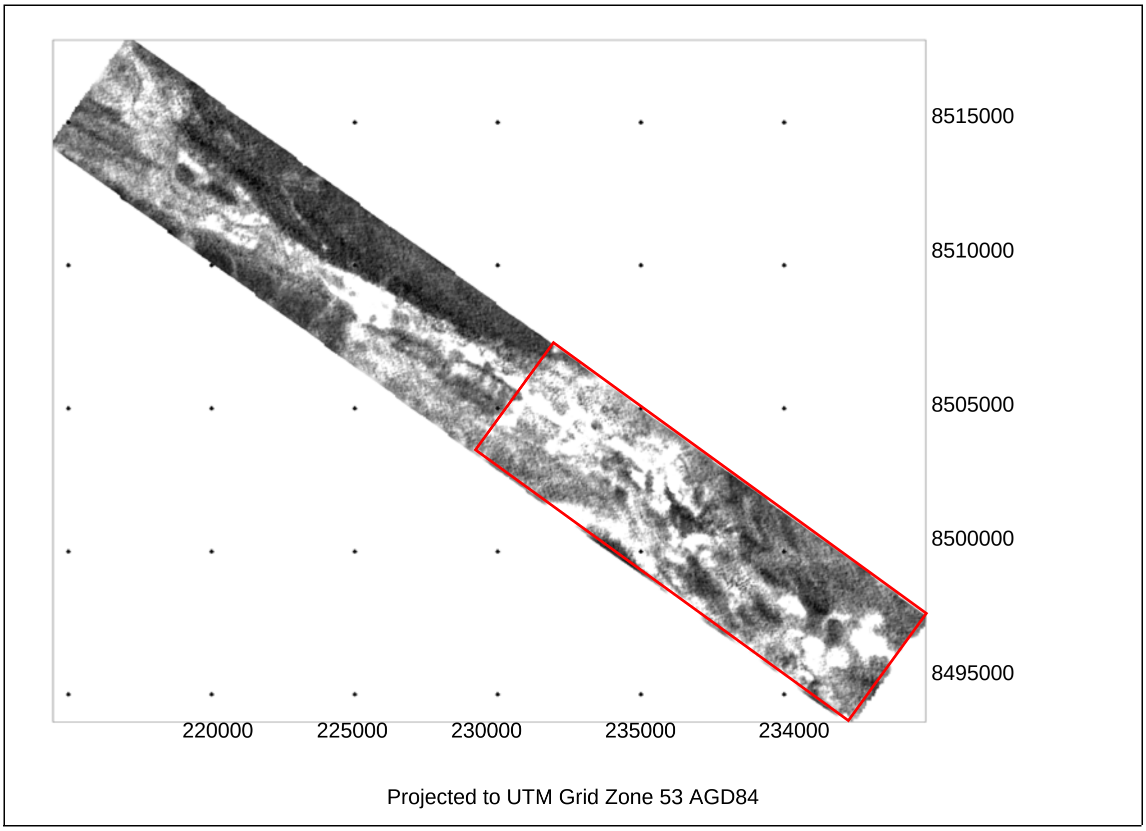


Figure 4. Airborne gamma survey extent (eU channel displayed).

The red box highlights the subset area described in the remainder of this report.

Topographical Map

A topographical map of the area was used to provide a geographical relationship with the airborne data, particularly the abandoned mine sites, South Alligator River, Fisher Creek, Koolpin Creek and Stag Creek locations. Part of the El Sherana 1:50 000 topographical map (Series R722, Sheet 5470-4, Edition 1-AAS) covering the area was digitally scanned. The map, which is produced by AUSLIG in the Australian Geodetic Datum 1966, was digitally registered to the easting and northing grid lines on the map, and then reprojected to the Australian Geodetic Datum 1984 to provide the same projection as the airborne gamma data. Figure 5 illustrates the rectified subset of the topographical map covering the study area, and highlights the major river and creeks in the area.

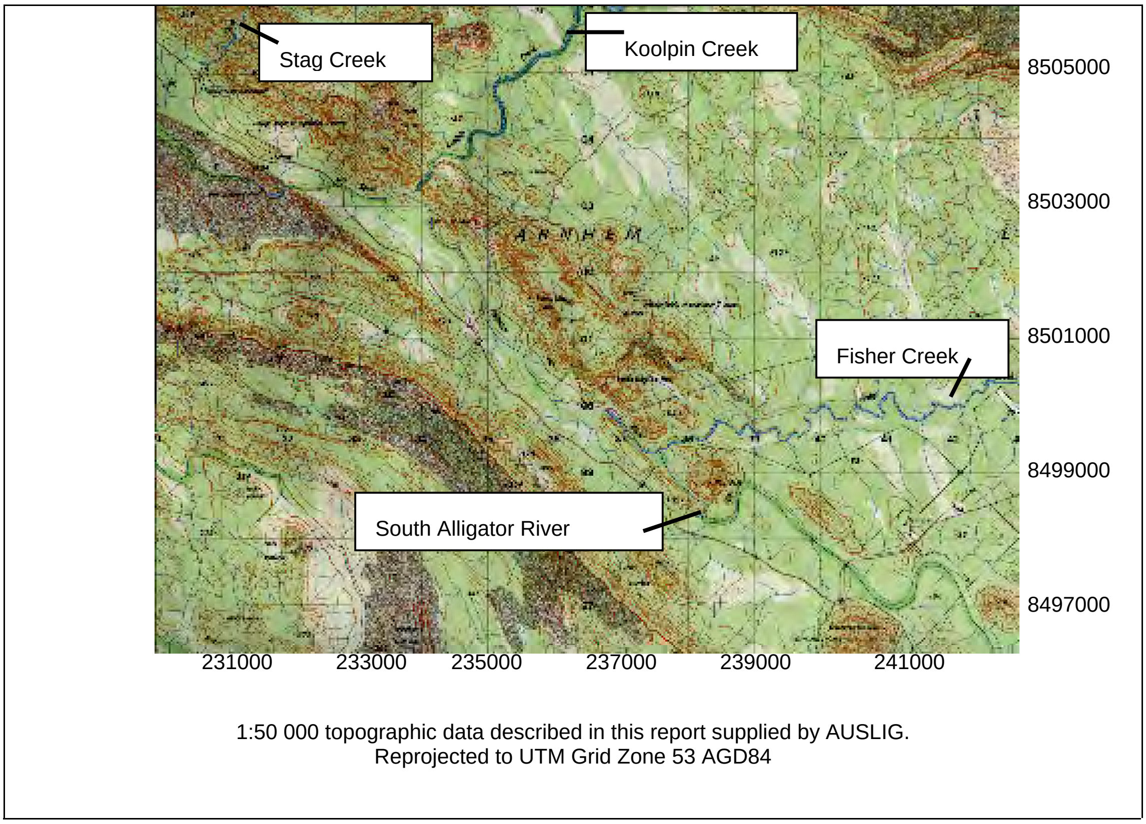
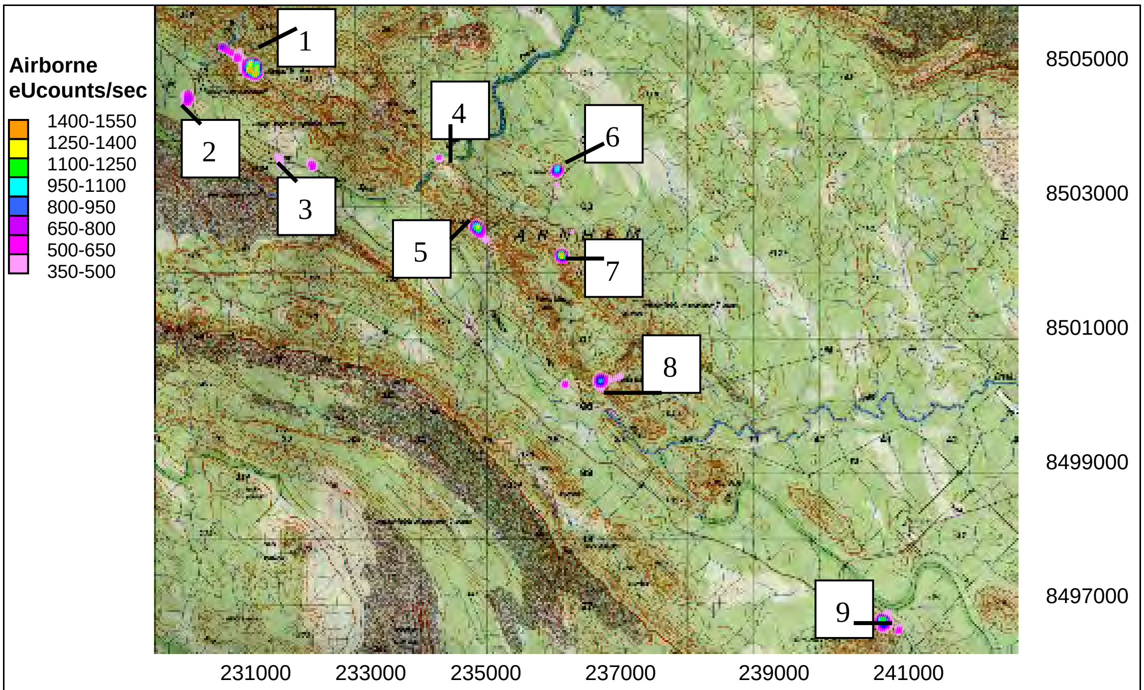


Figure 5. Subset of topographic map covering some of the old mine sites, highlighting the South Alligator River, Koolpin Creek, Fisher Creek, and Stag Creek.

Image Interpretation

According to the airborne gamma results, eU count rates over the study area ranged from 4 counts/second up to 1516 counts/second. To highlight the higher counts/second received from the airborne gamma survey, the range of digital numbers in the eU channel greater than 350 counts/s were thresheld into ranges of 150 digital numbers. Eight classes resulted, and a colour was assigned to highlight the sources of varying levels of higher count rates. The digital numbers in counts/second (and associated colours) resulting was: 1400-1550 (orange), 1250-1400 (yellow), 1100-1250 (green), 950-1100 (cyan), 800-950 (blue), 650-800 (purple), 500-650 (magenta), and 350-500 (mauve). The lowest counts, less than 350 counts/s are not discussed in this report. Figure 6 illustrates these ranges, with count rates less than 350 being displayed as the true-colour topographical map.



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3 = Battery Burial site area
4 = Koolpin

5 = Scinto V Mining area
6 = Scinto VI Mining area
7 = Pallete Mining area
8 = Saddle Ridge Mining area
9 = Coronation Hill Mining area

Figure 6. "Uranium Signal" image in the area overlain on the topographical map, with known mine sites highlighted.

Referring to the counts received from the airborne gamma survey highlighted in figure 6, the regions over the study area with higher count rates (>800 counts/s) showed that all higher eU signals in the study area corresponded to known mine site locations. The strongest eU signals from the airborne gamma survey were received at El Sherana (1516 counts/s) and Pallete (1461 counts/s). Significant count rates were also recorded around Scinto V (1280 counts/s). Of the remaining sites, in decreasing maximum count rates received, were Coronation Hill (1215 counts/s), Scinto VI (1076), Saddle Ridge (952), Weighbridge (750), Battery burial site (655), followed by Koolpin mine (540 counts/s). A few areas of lower counts (over 400 counts/s) which were also indicated from the airborne data. These sites are an area near the old Battery site to the NE of the Battery site on the main track to Gimbat (655 counts/s), an area on the Koolpin Track (409 counts/s) NNE of Pallete, and an area W of Saddle Ridge (567 counts/s). The airborne gamma survey was found to be particularly useful in highlighting these regions of greater count rates for determining ground-based field studies. Each of these mine sites is discussed in more detail in the next section.

Fieldwork Site Discussions

Fieldwork at Scinto V, Scinto VI, Pallete, El Sherana, Koolpin, Weighbridge, the Burial site and a non-abandoned mining location (near the Battery), were performed between July-October 2001 with the aim of correlating the airborne gamma results with ground-based gamma spectrometer results. Field-based measurements were made with a portable NaI (Tl) γ spectrometer positioned 1 m above the ground. A number of measurements were made, mostly with readings taken at 20 m intervals along transects.

A range of airborne gamma values cover the transects and associated sampling sites. The location of sampling sites were made in the field using a hand-held Garmen GPS, recorded in AGD84. The sampling sites in the following figures (also displayed in AGD84) may not appear exactly 20m apart on the transect line which may be a function of the pixel resolution of the image (where the position of the plotted transect is limited to the nearest pixel) and possibly a result of the slight inaccuracy of the hand-held GPS. The sites are discussed in order of field visit, Scinto V, Koolpin, Weighbridge, Pallete, El Sherana, and Scinto VI. Lastly, the field results from other non-abandoned mine locations including the area near Battery area are provided.

i. Scinto V

Figure 7 shows one of the transects (Line 0) made at Scinto V, the sampling points (to the nearest pixel) and count rates greater than 350 counts/s of the airborne image overlain on a subset of the topographic map. Figures 8a and 8b (derived from a colour-infrared digital scene), have been included to provide greater spatial detail around the Scinto V site. Table 1 gives the GPS coordinates and corresponding closest image coordinates as well as the airborne gamma image value of the eU channel (counts/s) and the ground-based spectrometer reading in Bq/kg.

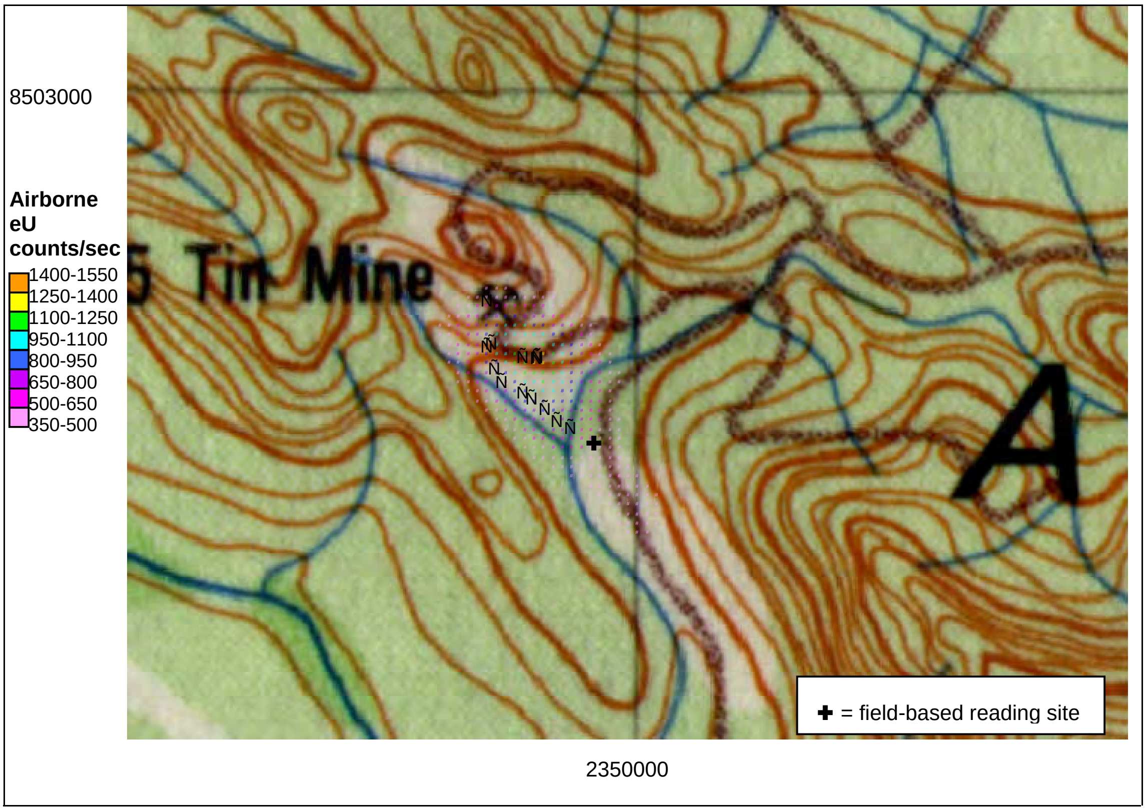


Figure 7. “Uranium Signal” counts at Scinto V overlain on the topographical map (AGD84).

Referring to figure 8, transect L0 (sampled in July 2001), at Scinto V began to the NW on top of the mine pit on the first bank at position 0 (P0). The next position, P1 was recorded next to the mine pit on the west side (although the GPS coordinate does not correlate well with this in Figure 8). P2 was recorded on the old mine access track and, P3 in an erosion gully that appeared to start at the pit, cross the road and drain in a SE direction towards the creek. The transect readings P4 and P5 were made on the slope of the erosion gully, P6 and P7 in a lower area downslope and P8 over what appeared to be the lowest area of the transect, not far from the creek. P9 was made close to the creek edge in quite waterlogged soil. P10 was recorded across the Creek, next to the main track approximately 10m from the 2nd gate to Koolpin Gorge (the coordinate associated with P10 in figures 7 and 8 and Table 1 is an estimate). The position of the transect was chosen based on evidence of erosion from the pit downslope. The transect therefore followed what appeared to be a drainage line for overflow water from the pit towards the creek. Three ground-based readings (L6P0-P2), correlating to the area of highest signals emanating from the airborne survey over Scinto V were sampled in October 2001. Referring to figure 8, it can be seen these three readings were taken on the track towards the mine pit.

According to table 1, L0P8, in the low-lying area has the highest reading observed along the transect at 3220 Bq/kg. Although the readings were spatially variable, overall, there is suggestion of erosion of material from within and outside the mine pit, with the finer higher activity material deposited in the low-lying area (transect L0). The fieldwork also confirmed high readings along the track (L6), with measurements ranging between 1124-1199 Bq/kg. Scinto V is located close to the track to Koolpin Gorge, with the immediate pit area being fenced and signed. To the north of P10 there is a permanent water spring, which is a significant Aboriginal Sacred Site.

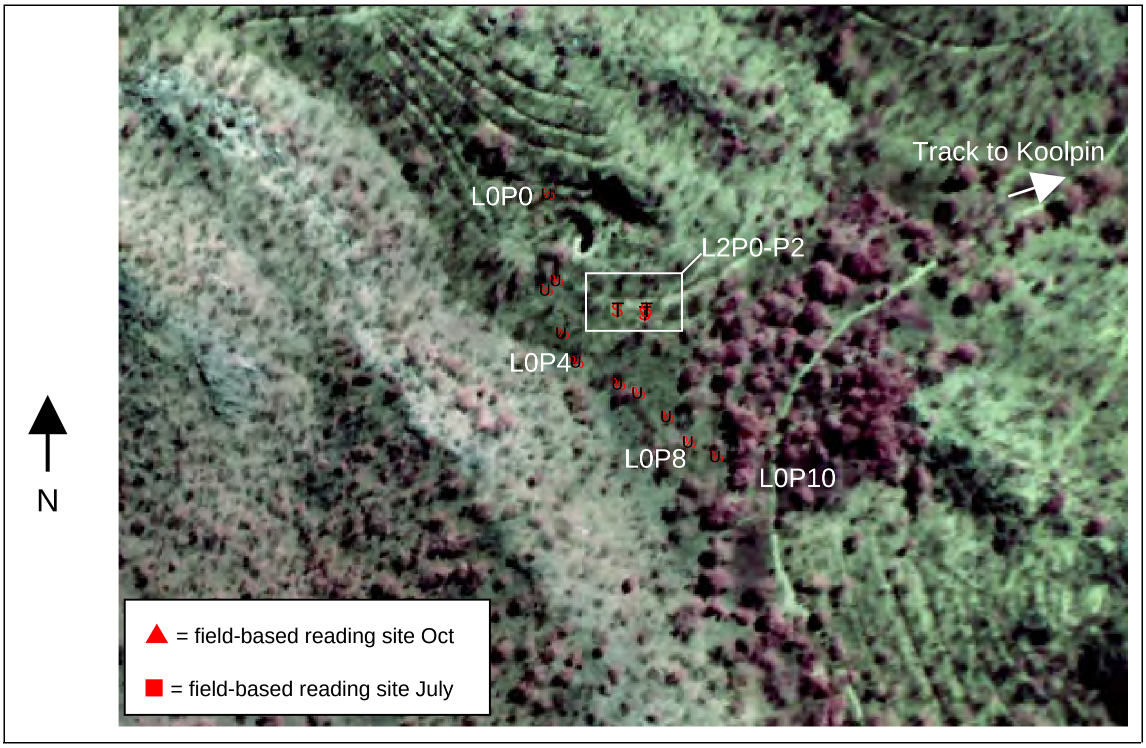


Figure 8a. Colour-infrared (IR, R, G) digital scene providing greater spatial detail around the Scinto V site, illustrating the location of the sampling positions.

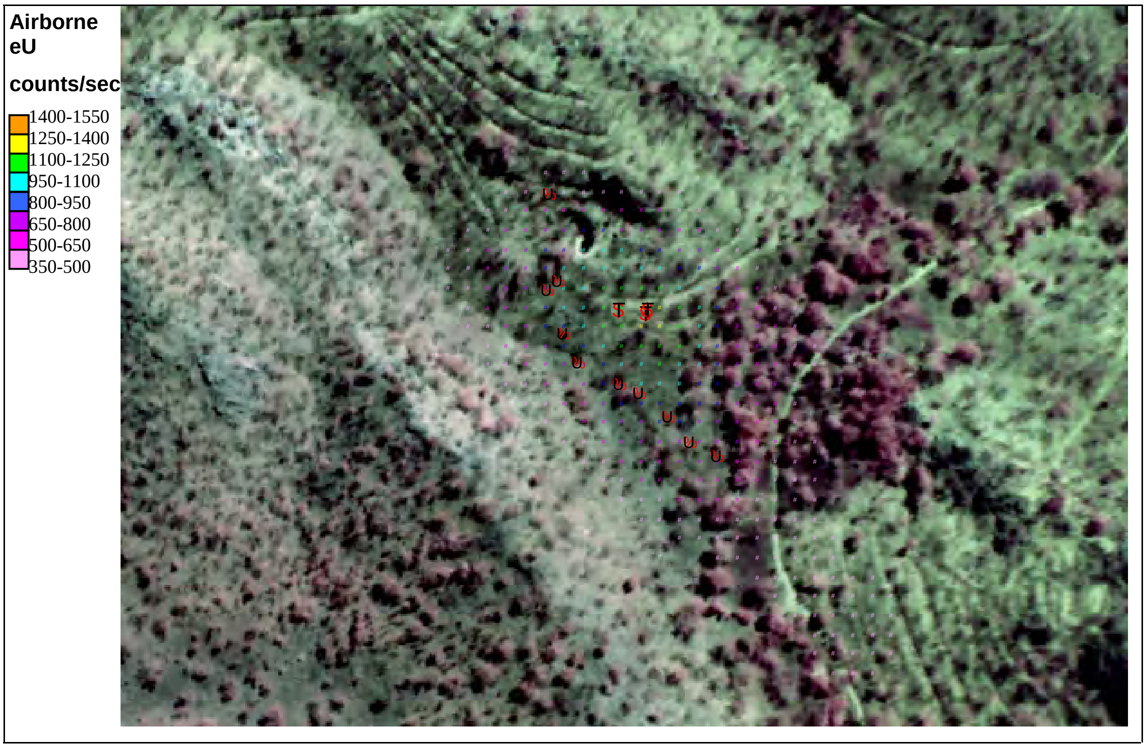


Figure 8b. Colour-infrared (IR, R, G) digital scene providing greater spatial detail around the Scinto V site, with the airborne counts overlaid.

Table 1.

SCINTO V

Line and Position	GPS easting	GPS northing	Image easting	Image northing	Image value (counts s-1)	Spectrometer value eU (Bq/kg)
	Coordinates in AGD84 Due to 12m image pixels, the image coordinates will differ slightly to the field GPS coordinates					
L0P0	234810	8502731	234808	8502732	463	552
L0P1	234815	8502676	234820	8502672	976	1132
L0P2	234809	8502671	234808	8502672	870	1347
L0P3	234819	8502644	234820	8502648	936	1162
L0P4	234828	8502626	234828	8502624	799	943
L0P5	234854	8502612	234856	8502612	920	697
L0P6	234866	8502606	234868	8502600	883	1760
L0P7	234884	8502592	234880	8502588	808	1473
L0P8	234898	8502576	234904	8502576	732	3220
L0P9	234915	8502567	234916	8502564	662	180
L0P10*	Across the creek, by the track				~433	355
L6P0	234872	8502656	234868	8502660	1280	1199
L6P1	234873	8502658	234856	8502660	1222	1153
L6P2	234855	8502658	234880	8502660	1271	1124

* L0P10 on figures 7 and 8 are estimated

ii. Koolpin

Figure 9 shows the transect (Line 1) made at Koolpin, the sampling positions (to the nearest pixel) and count rates greater than 350 counts/s of the airborne image overlain on a subset of the topographic map. Table 2 gives the GPS coordinates and corresponding closest image coordinates as well as the airborne gamma image value of the eU channel (counts/s) and the ground-based spectrometer reading in Bq/kg.

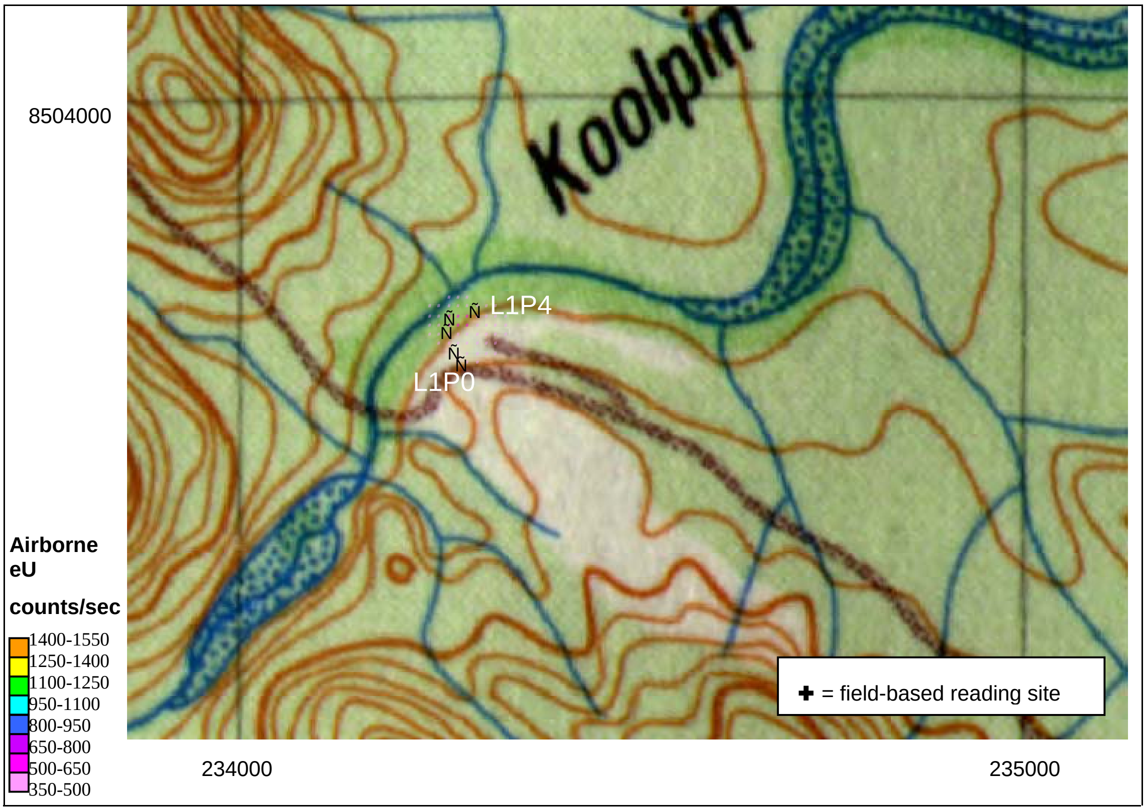


Figure 9. "Uranium Signal" counts at Koolpin overlain on the topographical map (AGD84).

Referring to figure 9, line 1 at Koolpin began next to the pit on the east site (L1P0), with P1 and P2 positioned at 20m intervals along the fence line (in a northerly direction). P3 was recorded in a dry creek bed that appeared to be an extension of the pit in the wet season. Poor satellite coverage and uncertain GPS positioning occurred at position 3 due to tree cover. P4 was recorded over an arbitrary low point.

Position 1 (P1) in table 2 shows a field-based result of 2142 Bq/kg, recorded near slatey rocks.

Table 2.

Transect L1 at KOOLPIN

Line and Position	GPS easting	GPS northing	Image easting	Image northing	Image value (counts s-1)	Spectrometer value eU (Bq/kg)
	Coordinates in AGD84 Due to 12m image pixels, the image coordinates will differ slightly to the field GPS coordinates					
L1P00	234283	8503655	234280	8503656	340	224
L1P01	234276	8503670	234280	8503668	370	2142
L1P02	234266	8503697	234268	8503692	454	816
L1P03	234271	8503713	234268	8503716	535	1077
L1P04	234303	8503722	234304	8503716	475	1416

iii. Pallete

Figure 10 shows the transect (Line 2) made at Pallete, the sampling positions (to the nearest pixel) and count rates greater than 350 counts/s of the airborne image overlain on a subset of the topographic map. Table 3 gives the GPS coordinates and corresponding closest image coordinates as well as the airborne gamma image value of the eU channel (counts/s) and the ground-based spectrometer reading in Bq/kg.

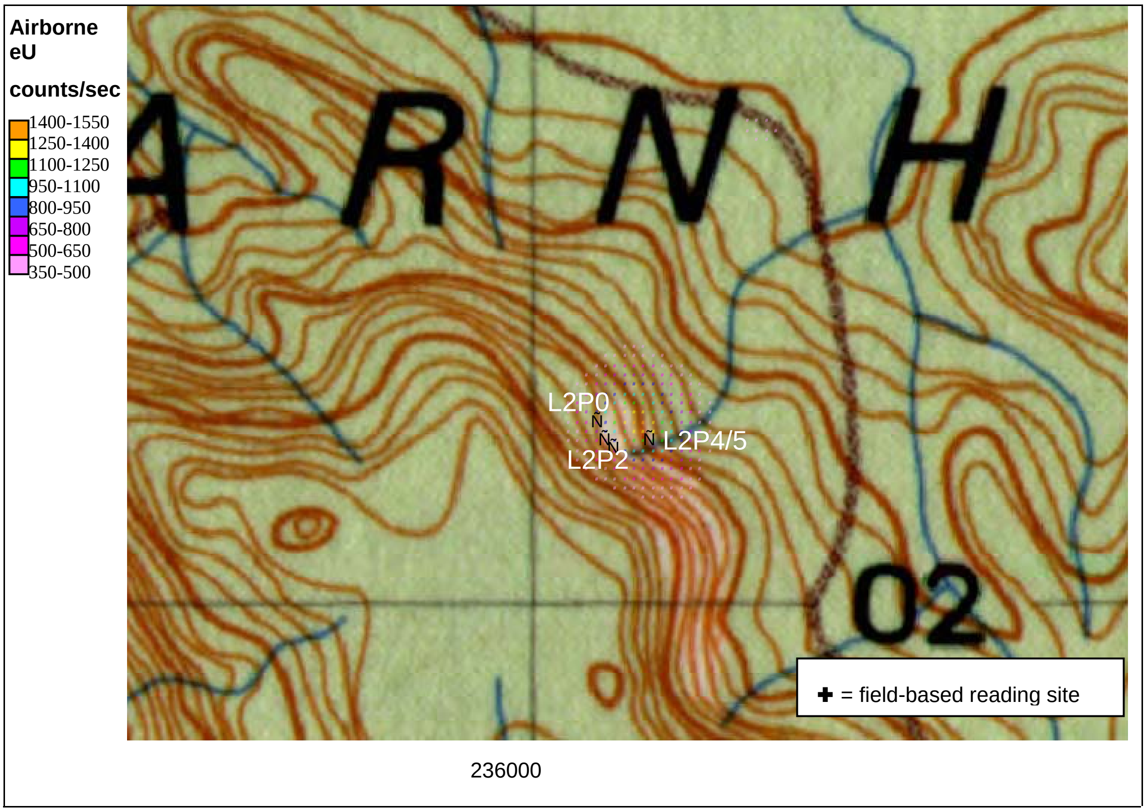


Figure 10. "Uranium Signal" counts at Pallete overlain on the topographical map (AGD84).

The coordinates recorded at Pallete are uncertain due to poor satellite coverage (as a result of close proximity to the escarpment). Line 2 at Pallete began near the pit close to a drill hole, where the counts were too high to record a reading. P1 was taken right next to the pit 20m away from P0, and P2 and P3, 20 m further along. Although the readings along P1-P3 were high, the airborne survey suggested that the highest counts were further east. P4 and P5 were taken down the lower embankment in an E direction from the previous positions. The area was generally disturbed. Positions 4 and 5 (located less than five metres apart) were recorded over patches of crushed rock, as figure 11 illustrates. The area appeared to be associated with recent drilling, as two 150 mm PVC seating collars were present and patches of crushed rock appeared to be the remains of drilling (see figure 11). P5 recorded 5246 (Bq/kg). The mining area around Pallete is quite difficult to access.

Table 3.

Transect L2 at PALLETE

Line and Position	GPS easting	GPS northing	Image easting	Image northing	Image value (counts s-1)	Spectrometer value eU (Bq/kg)
	Coordinates in AGD84 Due to 12m image pixels, the image coordinates will differ slightly to the field GPS coordinates					
L2P00	236083	8502231	236080	8502228	773	Too high*
L2P01	236091	8502209	236092	8502204	756	2860
L2P02	236103	8502198	236104	8502192	758	1749
L2P03	No Satellite detection					164
L2P04	236148	8502209	236152	8502204	1190	2732**
L2P05	Positioned less than 5 m away from position 4		236152	8502216	1290	5246

Satellite detection poor at all sites

*Ground-based reading too high for spectrometer reading

**Reading taken sideward from area, as too high for spectrometer reading. Spectrometer value (Bq/kg) at L2P04 is therefore an underestimate.

Figure 11. The small piles of crushed drill rock near Pallete can be seen.

iv. El Sherana

Figure 12 shows the count rates greater than 350 counts/s of the airborne image near the El Sherana mine overlain on a subset of the topographic map. Positions of two sampling points (L3P0 and P1), made in July, N of Stag Creek Dam on the slope SE of the El Sherana mine are shown. A subset of the El Sherana pit area shows another 12 sampling sites, taken in October at El Sherana West. Figure 13 (a subset of a colour aerial photograph), has been included to provide greater spatial detail. Table 4 gives the GPS coordinates and corresponding closest image coordinates as well as the airborne gamma image value of the eU channel (counts/s) and the ground-based spectrometer reading in Bq/kg for these positions.

L3P0 and P1 were recorded near Stag Creek, at the base of the incline towards the El Sherana mining area (figure 12). Although these field-based readings increased upslope, further readings were not made due to access difficulties. Line 7 (L7) was recorded in October 2001 when a helicopter was made available for access to the mine pit area (***eriss*** and PAN jointly funded the helicopter flight). L7P0 was originally set up 1m to the S (of the position illustrated in figure 12) over clay type sediment, although the ground-based reading was too high for a spectrometer measurement. The spectrometer was then moved 1m to the N over greater amounts of leaf matter. L7P1 and P2 were recorded in a transect line WNW of L7P0, with an average reading of 3342 Bq/kg. These readings were taken in general hilly areas, of material probably sourced from the pit, generally appearing ore bearing. Transect L7P3-L7P6 began near the edge of the pit in a transect SW to an erosion gully (P6) heading away from the pit. P7 was recorded on top of a hilly area over rocks appearing to be ore bearing. P8 was recorded to the NNW of the pit, 1m east from a covered (grate) shaft. P9 – P11 were taken in the pit bed, beginning in the SE of the pit heading NW. The overall appearance of the airborne image, with higher counts received around the mine pit area, and ceasing downslope at the Stag Creek Dam site suggest erosion processes of material outside the mine pit site into Stag Creek.

It should be noted that airborne counts between 350-500 were recorded over the El Sherana Camp area. However, this area was not field assessed as Tims and Ryan (1998) previously surveyed the Camp area, and recorded, on average 0.1μGy.h-1 for a number of abandoned buildings.

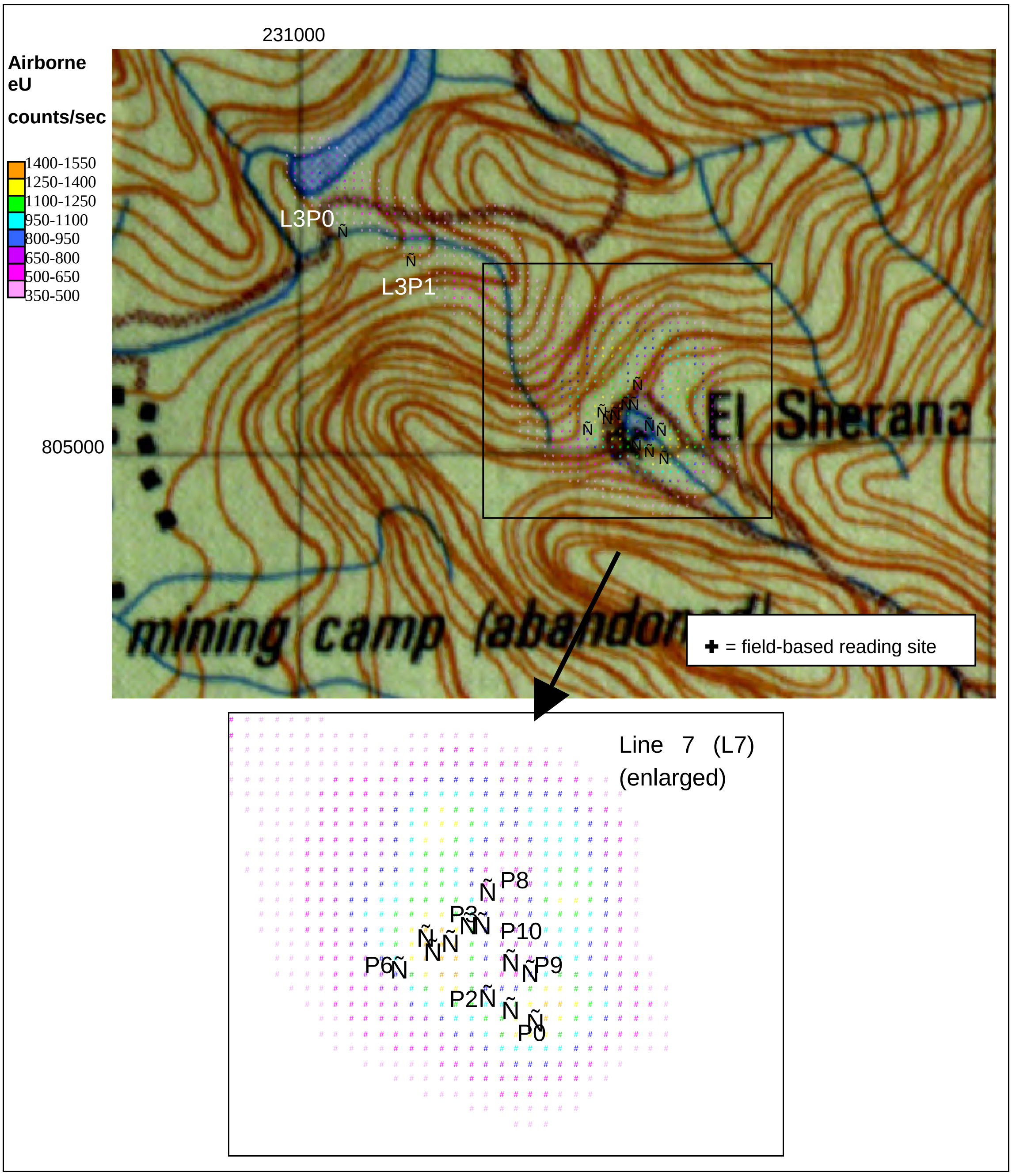
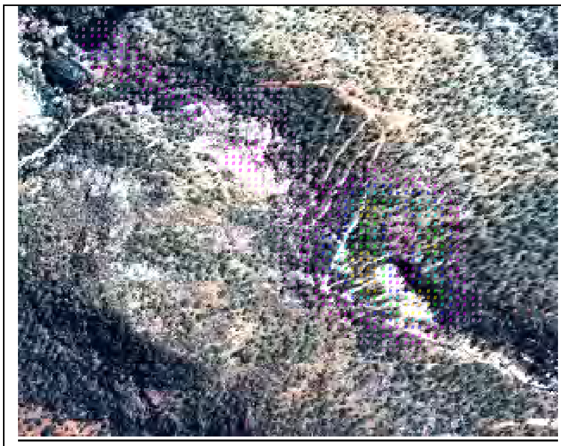


Figure 12. "Uranium Signal" counts at El Sherana overlain on the topographical map (AGD84) showing an enlarged subset of Line 7 (L7).



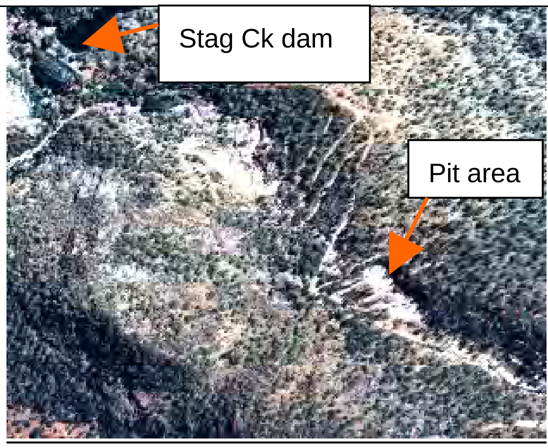


Figure 13. Portion of a colour aerial photograph for greater spatial detail.
Scene on left has counts overlain, used for comparison with scene on right.

Table 4.

Transect L3 and L7 at El Sherana.

Line and Position	GPS easting	GPS northing	Image easting	Image northing	Image value (counts s-1)	Spectrometer value eU (Bq/kg)
	Coordinates in AGD84 Due to 12m image pixels, the image coordinates will differ slightly to the field GPS coordinates					
L3P00	231074	8505288	231076	8505288	332	373
L3P01	231172	8505247	231172	8505252	434	681
L7P0	231536	8504962	231532	8504964	1459	3204
L7P1	231516	8504971	231520	8504976	1216	3109
L7P2	231497	8504981	231496	8504976	1062	4714
L7P3	231482	8505039	231484	8505036	1170	2650
L7P4	231467	8505025	231472	8505024	1427	1395
L7P5	231454	8505018	231460	8505012	1543	2768
L7P6	231427	8505004	231424	8505000	940	1152
L7P7	231448	8505029	231448	8505024	1484	2065
L7P8	231498	8505067	231496	8505072	647	1619
L7P9	231532	8505001	231532	8505000	865	4927
L7P10	231516	8505010	231520	8505012	593	3968
L7P11	231493	8505039	231496	8505036	942	2623

v. Weighbridge

Figure 14 shows the transect (Line 4) made at Weighbridge, the sampling points (to the nearest pixel) and count rates greater than 350 counts/s of the airborne image overlain on a subset of the topographic map. Table 5 gives the GPS coordinates and corresponding closest image coordinates as well as the airborne gamma image value of the eU channel (counts/s) and the ground-based spectrometer reading in Bq/kg.

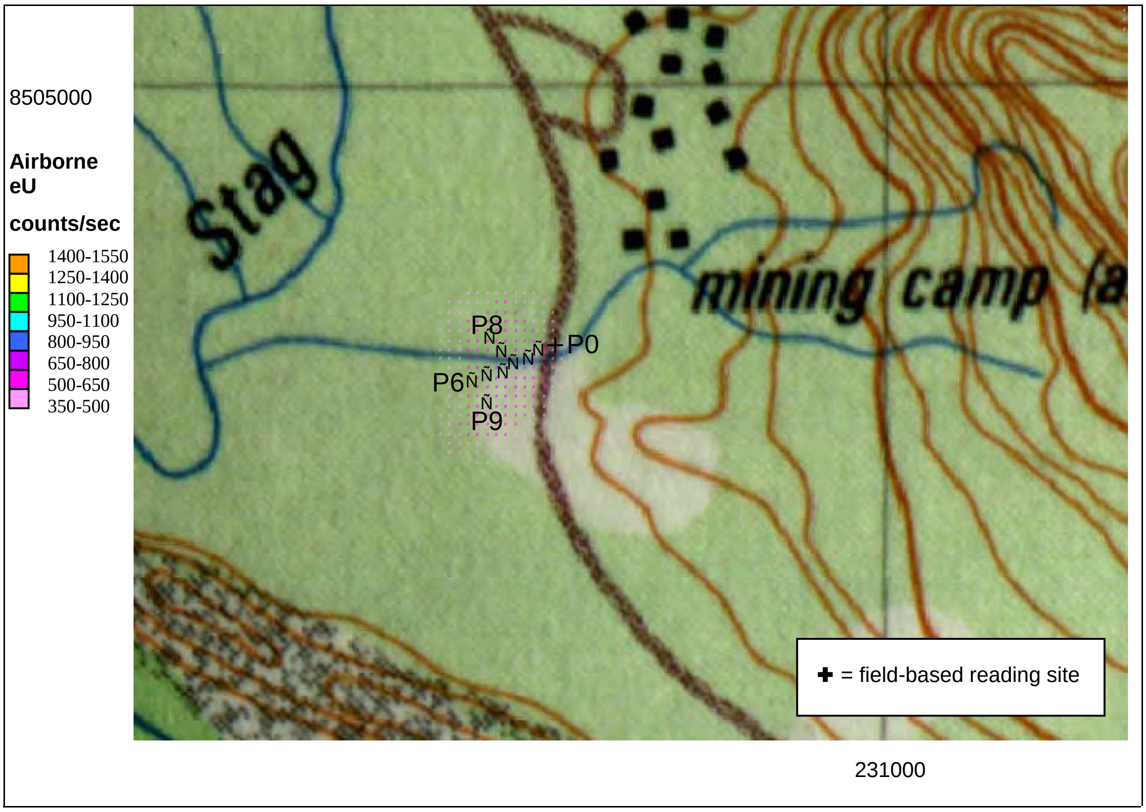


Figure 14. "Uranium Signal" counts at "Weighbridge" overlain on the topographical map (AGD84).

The Weighbridge site is an old "burial" or dumping ground of mining waste. Rubbish and scrap metal can be clearly seen around the general area. P0 was recorded near the road of the old burial site, with 20m spaced positions recorded in a SW direction up to P6. P7 – P8 was recorded perpendicular to P4 in a NW direction. Spectrometer values at P4 were high (2455 Bq/kg), which is likely due to material buried beneath this site, as there was no obvious drainage line and counts along the transect varied within the 20m sampling points. P9 was a random reading over a rock with a precipitating yellow mineral, likely a secondary ore mineral, recording 2707 Bq/kg. The area is easily accessed as it is by the Gimbat road and is an unfenced area.

Table 5.

Transect L4 at Weighbridge

Line and Position	GPS easting	GPS northing	Image easting	Image northing	Image value (counts s-1)	Spectrometer value eU (Bq/kg)
	Coordinates in AGD84 Due to 12m image pixels, the image coordinates will differ slightly to the field GPS coordinates					
L4P0	230590	8504648	230596	8504652	332	332
L4P1	230567	8504630	230572	8504628	503	448
L4P2	230554	8504619	230560	8504616	588	186
L4P3	230535	8504613	230536	8504616	697	1264
L4P4	230521	8504602	230524	8504604	740	2455
L4P5	230501	8504597	230500	8504597	727	532
L4P6	230482	8504589	230488	8504592	668	371
L4P7	230520	8504627	230524	8504628	680	1787
L4P8	230505	8504644	230500	8504640	613	795
L4P9	230500	8504562	230500	8504556	667	2707

vi. Scinto VI

Figure 15 shows the transect (Line 5) made at Scinto VI, the sampling points (to the nearest pixel) and count rates greater than 350 counts/s of the airborne image overlain on a subset of the topographic map. Table 6 gives the GPS coordinates and corresponding closest image coordinates as well as the airborne gamma image value of the eU channel (counts/s) and the ground-based spectrometer reading in Bq/kg.

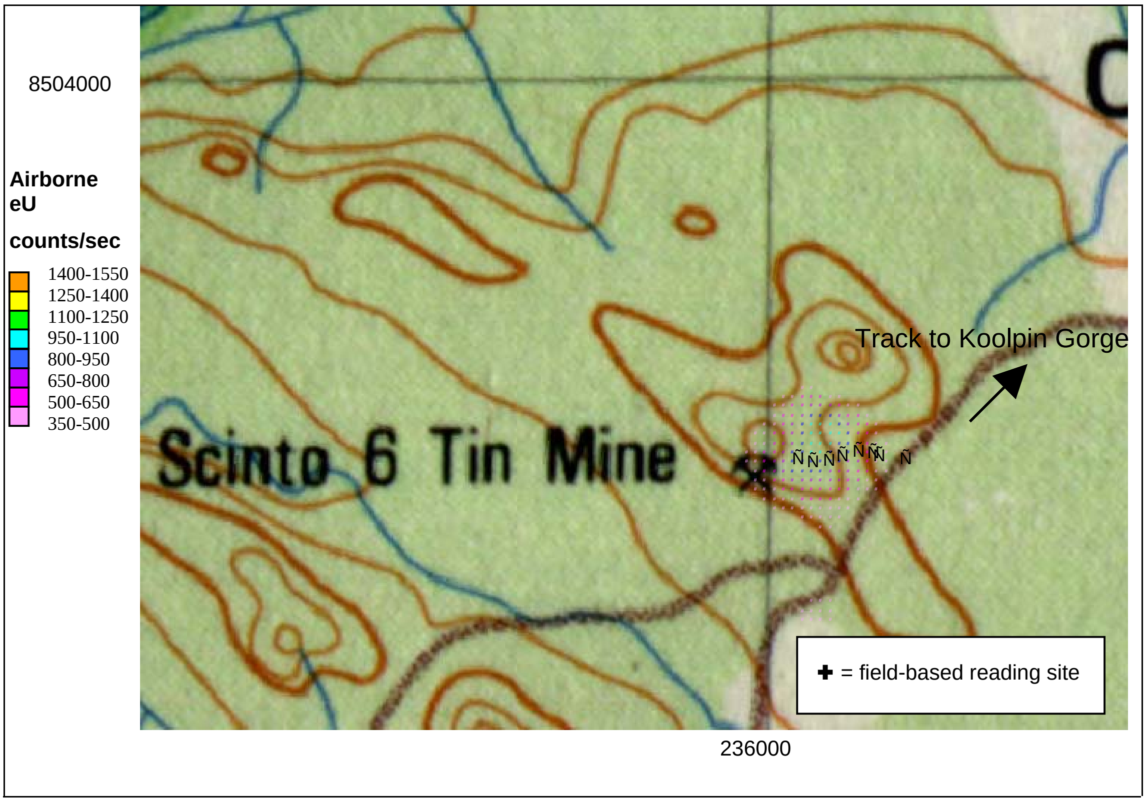


Figure 15. "Uranium Signal" counts at Scinto VI overlain on the topographical map (AGD84).

The transect at Scinto VI began within the main mine pit where the readings were too high to allow the NaI spectrometer to stabilise the spectrum. Position 1 (P1) was recorded 20m from the central pit, P2 just outside the pit area (approximately 5m from the warning sign) and P3-P7 in an easterly direction downslope towards the Koolpin Gorge Track. P6 and P7 were recorded in flatter area than the slopes of P3-P5. P8 was recorded on the east side of the track to Koolpin Gorge. Field-based measurements seen in Table 6 illustrate that the radiation around the pit is the highest of measurements made. Based on the spectrometer field readings, there is some evidence of localised erosion occurring from the mine pit, towards the track to Koolpin Gorge. Previous research on erosion at Scinto VI (Hancock *et al* 2000) has found that the waste rock dump surrounding the pit at Scinto VI is armoured through depletion of fines during runoff, although erosion is localised.

Table 6.

Transect L5 at Scinto VI.

Line and Position	GPS easting	GPS northing	Image easting	Image northing	Image value (counts s-1)	Spectrometer value eU (Bq/kg)
	Coordinates in AGD84 Due to 12m image pixels, the image coordinates will differ slightly to the field GPS coordinates					
L5P0	236010	8503506	236008	8503500	657	Too high
L5P1	236041	8503506	236044	8503500	908	1725.42
L5P2	236059	8503502	236056	8503500	903	611.36
L5P3	236081	8503504	236080	8503500	870	411.02
L5P4	236097	8503510	236092	8503512	893	368.07
L5P5	236119	8503515	236116	8503512	701	340.24
L5P6	236138	8503514	236140	8503512	495	539.73
L5P7	236146	8503511	236152	8503512	404	560.17
L5P8	236180	8503507	236176	8503512	285	363.52

vii Other Mine Sites

Due to access difficulties both cultural and physical, field-based measurements have not been performed at Coronation Hill or Saddle Ridge. The topographic map with airborne counts of Coronation Hill overlaid is provided in figure 16 and Saddle Ridge in figure 17 for reference.

The Battery burial site was visited and found to range between 0.2 and 1 μGy/hr. No detailed field-based surveys were recorded here due to time constraints.

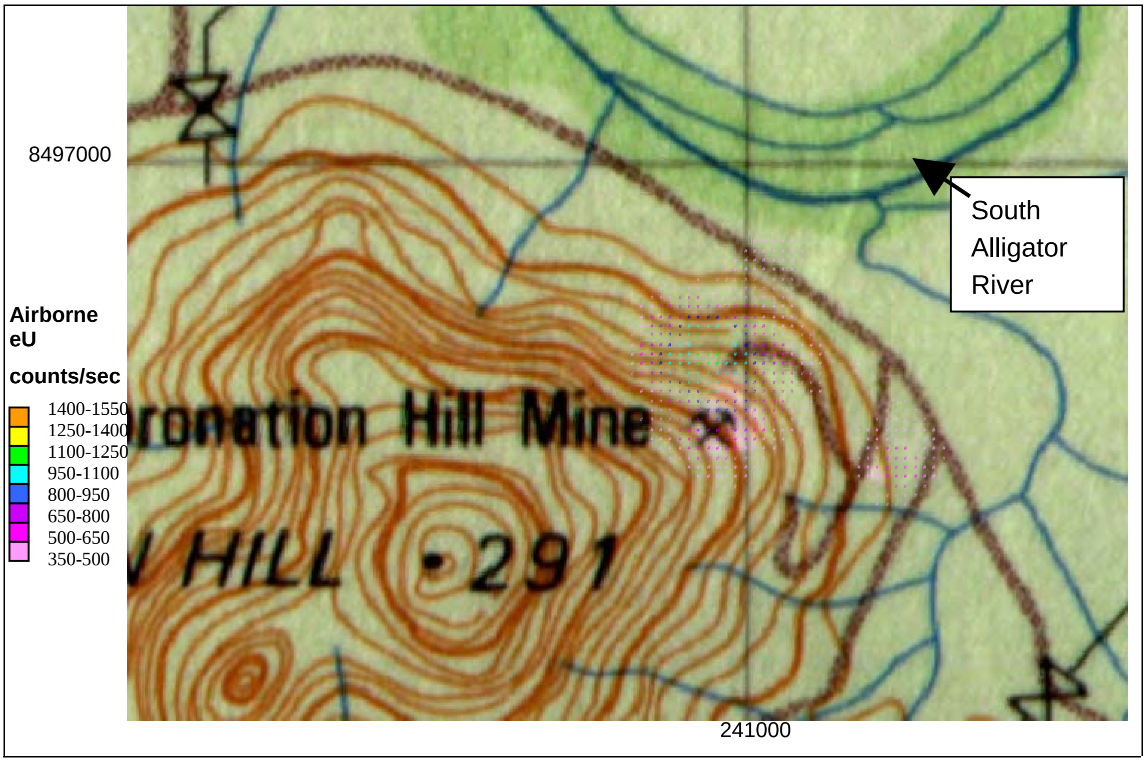


Figure 16. "Uranium Signal" counts at Coronation Hill overlain on the topographical map (AGD84).

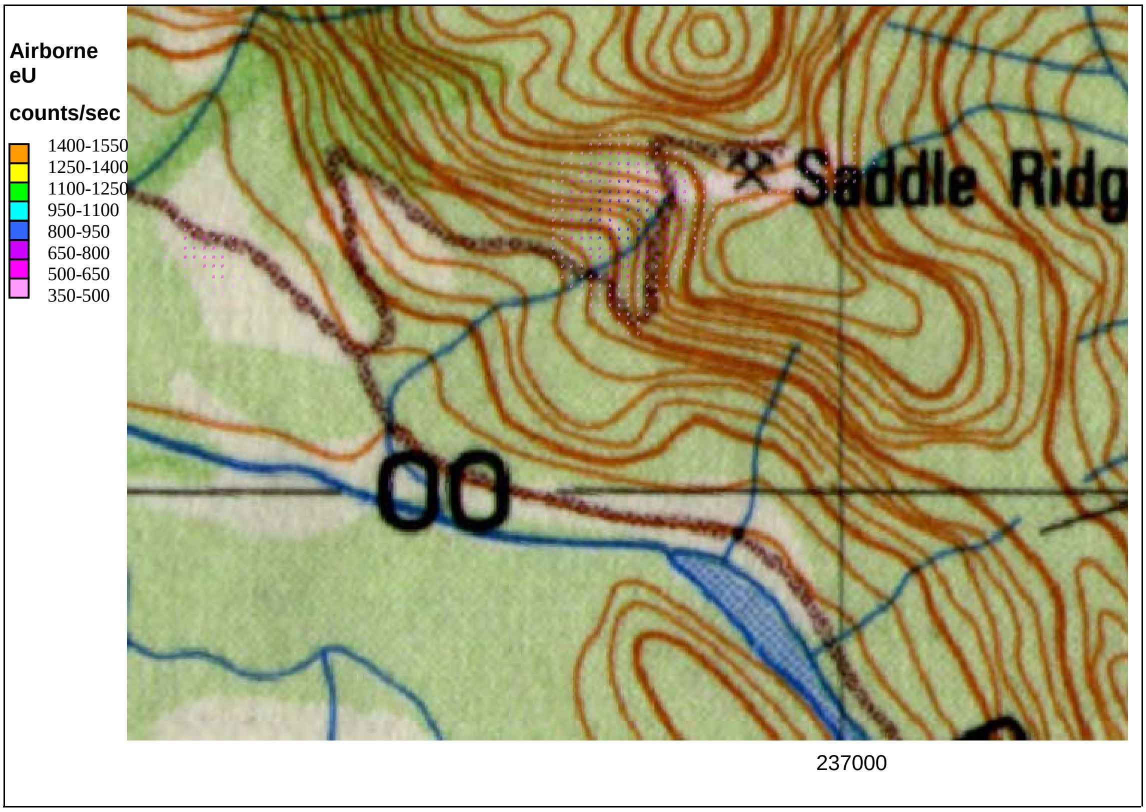
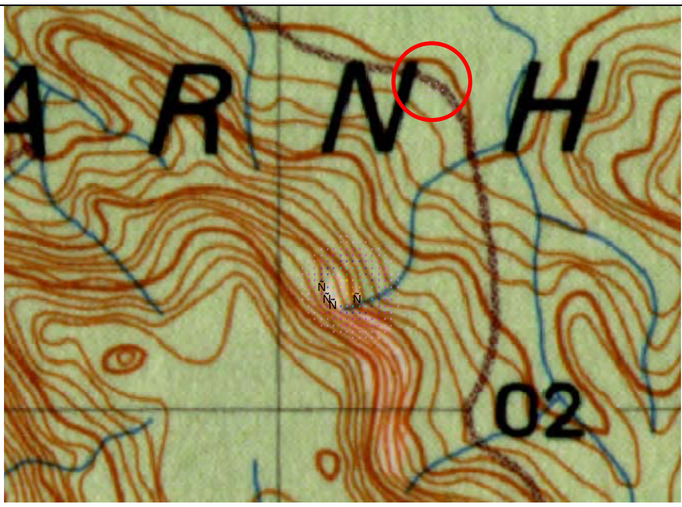
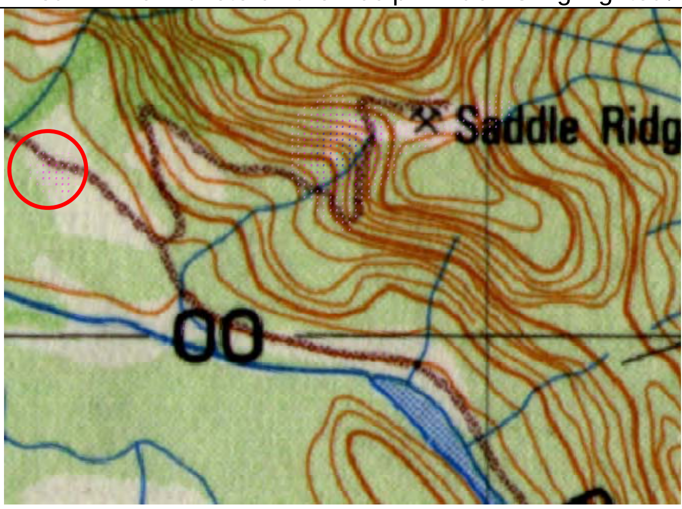


Figure 17. "Uranium Signal" counts at Saddle Ridge overlain on the topographical map (AGD84).

Three areas were identified from the airborne gamma survey, which do not correspond to known abandoned mining locations. These include an area on the Koolpin track NNE of Pallete with airborne gamma eU values up to 409 counts/s, and an area W of Saddle Ridge with airborne gamma eU values up to 567 counts/s. These areas are illustrated in figures 10 and 17, respectively. The areas are highlighted by a red circle in figure 18, for reference. The area west of Saddle Ridge is located in close proximity to a known uranium mineral occurrence, Clear Springs (NT Department of Mines and Energy, 1999). The area corresponds to a marked track on the topographic map. The track was most likely used for transport of ore during mining. This area may also have been a storage area for ore during mining (Waggitt, *Pers comm.*).



Area NNE of Pallete on the Koolpin Track is highlighted.



Area W of Saddle Ridge is highlighted.

Figure 18. Non-mine airborne gamma readings overlaid on topographical maps.

Another site highlighted by the airborne gamma survey which did not correspond to a known abandoned mine site location is an area NE of the Battery site on the road to

Gimbat, with airborne gamma eU values up to 655 counts/s. This area was field verified. Figure 19 shows the position of the two sampling points (to the nearest pixel), with count rates greater than 350 counts/s of the airborne image overlain on a subset of the topographic map. Table 7 gives the GPS coordinates and corresponding closest image coordinates as well as the airborne gamma image value of the eU channel (counts/s) and the ground-based spectrometer reading in Bq/kg. This area is located in close proximity to known uranium mineral occurrence/prospect, sometimes referred to as Flying Fox or Stockpile (NT Department of Mines and Energy, 1999). It may be that this area is a natural anomaly or is associated with prospecting (or stockpiling of ore from nearby mines) during the 1950’s and 1960’s. The area appears as non-disturbed woodland with grassy understory, and is very accessible.

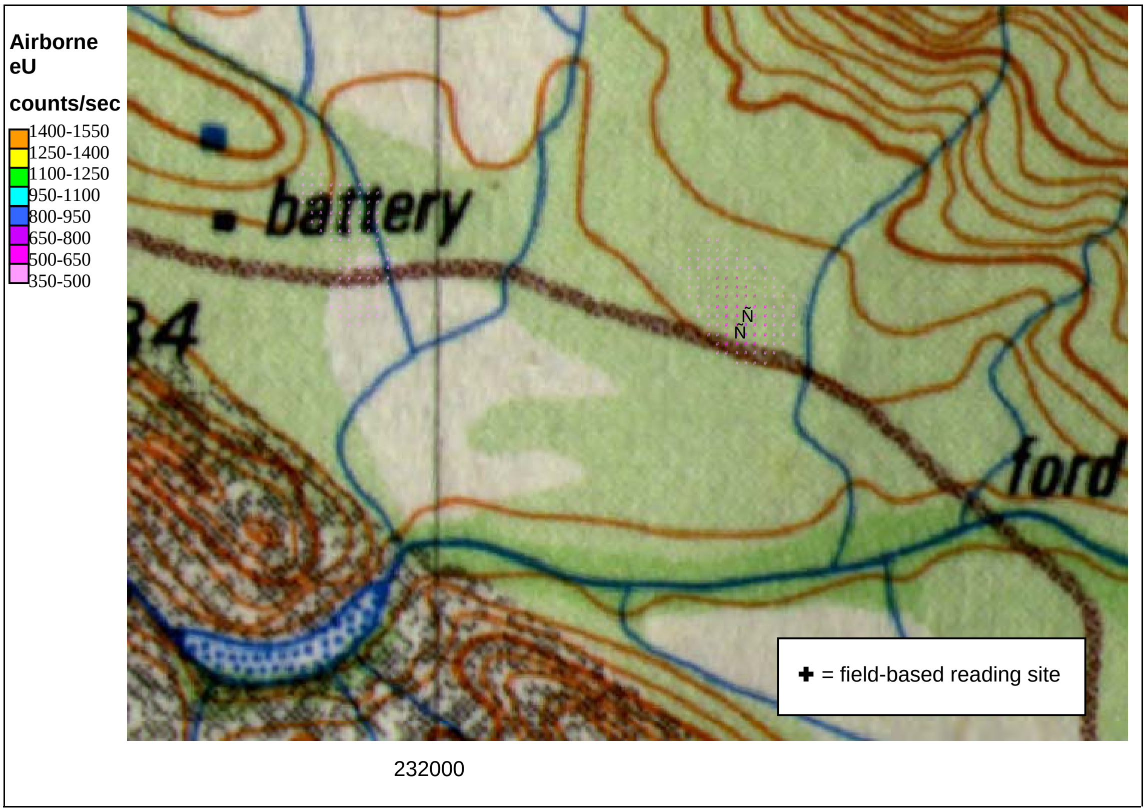


Figure 19. "Uranium Signal" counts overlain on the topographical map (AGD84).

Table 7.

Transect L8 at a non-mining location

Line and Position	GPS easting	GPS northing	Image easting	Image northing	Image value (counts s-1)	Spectrometer value eU (Bq/kg)
	Coordinates in AGD84 Due to 12m image pixels, the image coordinates will differ slightly to the field GPS coordinates					
L8P0	232390	8503565	232396	8503560	655	2456
L8P1	232400	8503586	232396	8503584	624	965

Comparison of image values with field-based measurements

Figure 20 illustrates the image value at the sampling site point as plotted along the transects (Figure 20a), the ground-based measurement in Bq/kg (Figure 20b) and, the relationship between the airborne counts of the eU channel (counts/s) against the ground-based measurements (Bq/kg) (Figure 20c) for all lines and positions.

Referring to figure 20, it can be seen that the airborne gamma counts are much less varied than the field-based measurements. This is not surprising considering the airborne survey flying height is 50m and each counts is at 50m intervals compared to the 1m height of the field spectrometer at 20m sampling intervals. In addition, the counts received by the airborne detector will not be an exact 50m x 50m footprint, which will vary depending upon the actual aircraft height and geographic location at the time. Within a 50m x 50m "footprint" area, it may be that a particular area has a much elevated concentration of the radionuclide of interest compared with the average over the rest of the area. If this elevated area does not cover the whole of the footprint, the count rate recorded in the imagery will be an average of these levels to provide a single digital number. These differences may be a result of small areal high readings on the ground (such as the small drill residues at Pallete), or variations over a larger area (such as Weighbridge burial site where highly variable count readings are expressed in field based measurements, whereas the airborne image shows similar counts across the area).

Other factors contributing to the differences in the airborne counts compared to the ground-based measurements include moisture content of the soil at the time of survey comparisons and the topography over which the counts are received. Most of the mine sites in the upper South Alligator River area are associated with steep topography, where often the sites were mined through part of a hillside. This may result in a decreased signal from the airborne survey. For these reasons, the airborne survey alone should not be used for the estimation of actual soil concentrations or dose rates at specific locations.

Figure 20a. Airborne eU image (counts/s) plotted along transects

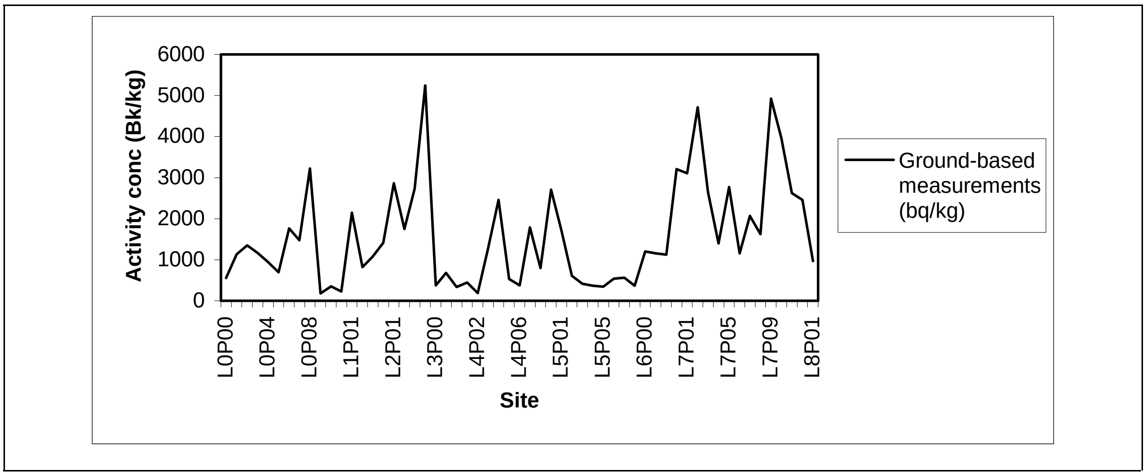


Figure 20b. Ground based measurements of activity (Bq/kg) plotted along transects

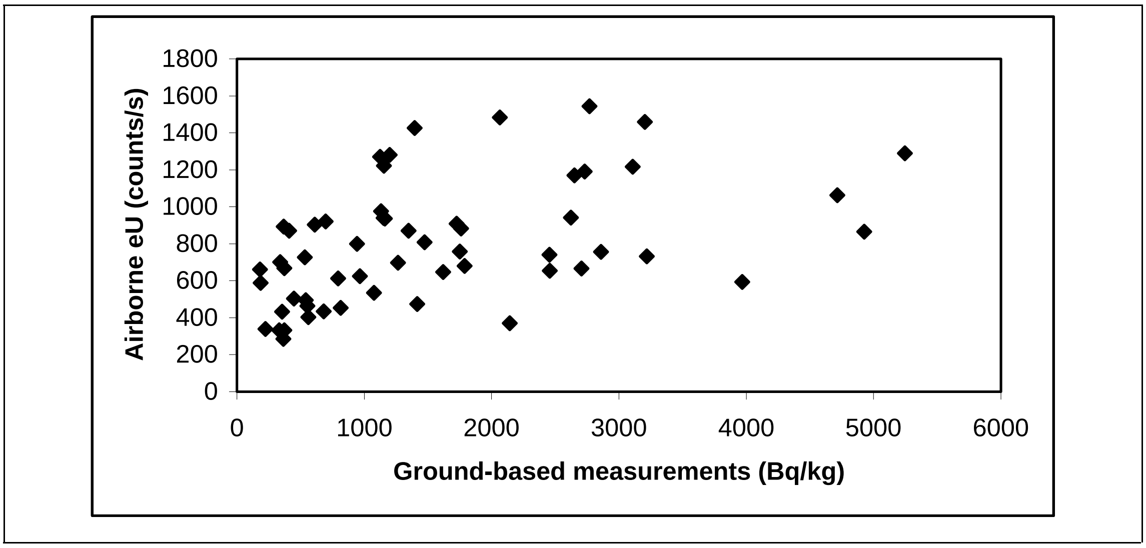


Figure 20c. Airborne eU count rates plotted against ground-based measurements.

Comparison of dose rates measured

In order to compare the dose rates measured around the abandoned mine sites with the measurements taken over the tailings area to the SE of the road (near Rockhole Mine Creek), discussed in a report by Tims *et al* (2000), it is necessary to convert the ground based measurements (Bq/kg) into absorbed dose rate (μGy.h^{-1}). The terrestrial component of the absorbed dose rate, *D*, which is due to γ rays from ^{40}K, eU and eTh activity may be approximated by the following function:

$$D = a_1K + a_2eU + a_3eTh$$

where *K*, *eU* and *eTh* represent activity concentrations in the ground (Bq kg^{-1}), and a_i are the appropriate dose rate coefficients. UNSCEAR (1993) quote average values for a_1, a_2 and a_3 of 0.0414, 0.461 and 0.623 nGy hr^{-1} per Bq kg^{-1}, respectively.

Tims *et al* (2000) radiological survey reports terrestrial gamma dose rate at sites along and either side of the road to Gunlom falls and to the southwest of the South Alligator mill vicinity. They classed their results into one of four categories. Category 1 was largely in the range 0 – 0.14 μGy.h^{-1}, and categories 2, 3, and 4, in the general ranges of 0.14 – 0.40 μGy.h^{-1}, 0.40 – 1.0 μGy.h^{-1}, and 1.0 – 6.0 μGy.h^{-1}, respectively (maximum dose rate recorded was 6 μGy.h^{-1} where exposed tailings were clearly visible).

Table 8 illustrates the dose rate (μGy.h^{-1}) for the positions along the transects recorded in the areas described in this report. Based on the category division of Tims *et al* (2000), there were 17 readings recorded over category 4 areas, 22 readings over category 3, 17 readings correspond to category 2, and 2 readings in category 1. It should be noted that the location of transects was designed to identify areas of highest activities and to validate and correlate the airborne counts and were thus chosen over areas where a variation in counts would be expected as shown by the airborne results. Note that another four readings would be expected to also fall in Category 4, although these ground-based readings were too high to gain a spectrometer reading. The area near the old Battery was found to be fenced and field-based readings ranged between 0.2 and 1 μG/hour (category 3).

Table 8. Field-based Dose Rates ($\mu Gy.h^{-1}$)

Mine Site	Transect/ Position	**Dose Rate (uGy/hr)**	Category	Mine Site	Transect/ Position	**Dose Rate (uGy/hr)**	Category
Scinto V	L0P0	0.29	2	**El Sherana**	L3P0	0.25	2
	L0P1	0.60	3		L3P1	0.42	3
	L0P2	0.66	3		L7P0	1.61	4
	L0P3	0.59	3		L7P1	1.55	4
	L0P4	0.47	3		L7P2	2.35	4
	L0P5	0.38	2		L7P3	1.45	4
	L0P6	0.87	3		L7P4	0.88	3
	L0P7	0.73	3		L7P5	1.56	4
	L0P8	1.57	4		L7P6	0.65	3
	L0P9	0.13	1		L7P7	1.15	4
	L0P10	0.18	2		L7P8	0.93	3
	L6P0	0.62	3		L7P9	2.52	4
	L6P1	0.61	3		L7P10	1.98	4
	L6P2	0.58	3		L7P11	1.33	4
Flying Fox prospect	L8P0	1.18	4	**Weighbridge**	L4P0	0.19	2
	L8P1	0.48	3		L4P1	0.24	2
Pallete	L2P1	1.44	4		L4P2	0.11	2
	L2P2	0.88	3		L4P3	0.62	3
	L2P3	0.84	3		L4P4	1.17	4
	L2P4	1.36	4		L4P5	0.28	2
	L2P5	2.59	4		L4P6	0.20	2
Scinto VI	L5P1	0.85	3		L4P7	0.85	3
	L5P2	0.31	2		L4P8	0.38	2
	L5P3	0.22	2		L4P9	1.29	4
	L5P4	0.21	2	**Koolpin**	L1P0	0.14	2
	L5P5	0.20	2		L1P1	1.06	4
	L5P6	0.28	2		L1P2	0.41	3
	L5P7	0.29	2		L1P3	0.56	3
	L5P8	0.22	2		L1P4	0.74	3

Conclusion

The airborne survey was found to be particularly useful for highlighting regions of higher count rates and determining the location of field-based surveys. All higher counts in the airborne survey correlated to known abandoned mine locations. Also, field-based measurements follow the general trend of the airborne survey i.e. areas of the highest airborne count rates (Rockhole tailings, El Sherana mine, Palette mine) generally exhibited highest individual readings during ground truthing. Due to the 50m sampling of the airborne survey, however, it is not trivial to compare the signal with actual soil concentrations. However, it is possible to estimate with a first approximation an average dose rate for specific locations. For further information on dose estimates, refer to Bollhöfer *et al* (2001).

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