Geophysical signatures of mineral deposit types in Finland
Edited by Meri-Liisa Airo
Geological Survey of Finland, Special Paper 58, 107–116, 2015

AIRBORNE RADIOMETRIC DATA AS A URANIUM EXPLORATION TOOL – CASE STUDIES FROM SOUTHERN LAPLAND

by

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Lauri, L. S. & Turunen, P. 2015. Airborne radiometric data as a uranium exploration tool – case studies from southern Lapland. G*eological Survey of Finland, Special Paper 58,* 107–116, 5 figures.

Airborne radiometric data registered at low altitudes are used for detecting the presence of potassium, uranium and thorium in the field. Ternary K-Th-U maps combined with either total radioactivity maps or separate U, Th and K-channel maps are especially important in uranium exploration, as they reveal the cause of radioactivity. During the most recent global uranium exploration boom in the 2000s, three new targets (Asentolamminoja, Rumavuoma and Rompas–Rajapalot) were located in southern Lapland. The Asentolamminoja and Rumavuoma targets are discernible as strong aeroradiometric anomalies, whereas the Rompas–Rajapalot target is only weakly delineated by airborne data. The advantage of airborne and ground radiometric measurements is that they are fast and low-cost compared to more time- and money-consuming laboratory analyses.

Keywords (GeoRef Thesaurus, AGI): mineral exploration, uranium ores, radioactivity methods, airborne methods, radioactivity survey maps, Lapland, Finland

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INTRODUCTION

Airborne radiometric data registered at low altitudes are extensively used worldwide in greenfield uranium exploration. Although the radiometric signal only reflects the top 50 cm of ground and does not work in wetland areas, it still offers an effective means to delineate radiometric anomalies that may be verified by ground checking. In addition to total count and U-channel data, ternary K-U-Th maps and U^2/Th ratios are also used in uranium exploration. In the ternary map, three colours, traditionally red for K, blue for U and green for Th, are used to highlight the relative concentration of the three radionuclides. If one of the three elements has an unusually high concentration, the map may be useful in visual inspection. The U^2/Th presentation is based on the tendency of U and Th to co-occur and to have a rather constant relative relationship.

During the most recent global uranium exploration boom in the 2000s, three new targets were located in southern Lapland (Fig. 1), representing the first new uranium prospects found in Finland since the 1980s. The Asentolamminoja target on the SE side of the town of Rovaniemi is a pure uranium target, whereas the Rumavuoma and Rompas–Rajapalot areas in the municipality of Ylitornio are gold-uranium prospects currently under an exploration license by Mawson Oy.

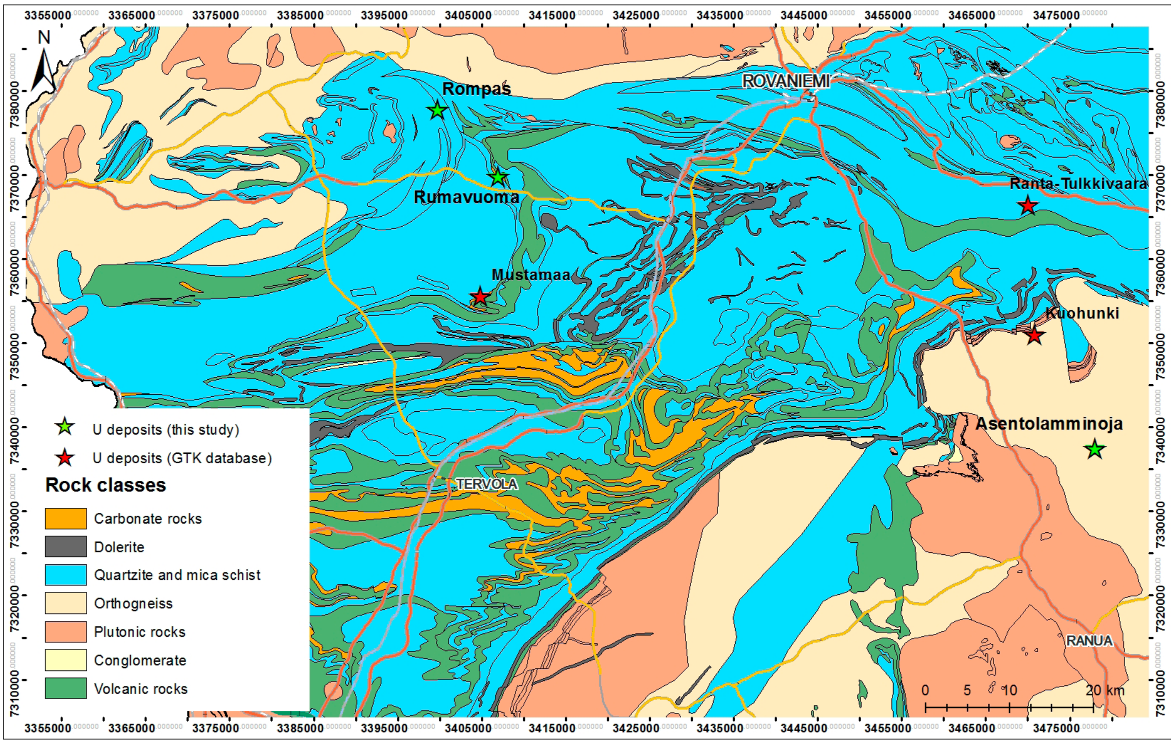

Fig. 1. Simplified bedrock map (extracted from the DigiKP database, GTK) of the study area with the locations of the U deposits marked with stars. Coordinates according to the Finnish National Grid (KKJ). Contains data from the National Land Survey of Finland Topographic Database 03/2013.

ON THE USE OF AERORADIOMETRIC MAPS IN URANIUM EXPLORATION

Gamma spectrometry is used for detecting the presence of potassium, uranium and thorium in the field. These three radionuclides are commonly present in all natural materials, whereas other radioactive elements are more rare compared to them. The ratio of radioactive ^{40}K to total K is constant, and its absolute concentration is straightforwardly measured by means of gamma spectrometry, with ^{40}K being a gamma emitter. On the other hand, because both uranium and thorium are alpha emitters, they must be indirectly detected via the radioactivity of gamma active daughter elements in their decay series. Reliable detection of uranium and thorium contents requires their decay series to be in secular equilibrium. Some geological and anthropogenic processes may alter the secular equilibrium; however, this is rarely a problem in routine exploration. Due to the indirect detection of U and Th, the resulting U and Th contents are commonly referred to as equivalent concentrations, marked as eU and eTh.

The registration frequency in the aeroradiometric gamma detection of the flights of the Geological Survey of Finland (GTK) is 1/s (Hyvönen et al. 2005). The plane moves ca. 60 m during the measurement time period. Most of the gamma pulses measured originate from below the flight line, but also outside of it from a wider zone, and thus the radioactive zone may not be reliably delimited from the flight anomaly. Gamma ray intensity attenuates exponentially as a function of distance, and the measured radioactivity may be estimated to originate from an ellipse elongated in the flight direction. The radioactivity originating below the flight line dominates, but even the pulses beyond the rims of the ellipse, roughly measuring 260 m * 200 m, contribute around 30 % to the total count (Grasty et al. 1979). The aeroradiometric anomaly of a point source is spread to a wide area, resulting in a dim signature, and so the aeroradiometric map is not necessarily the best means of delimiting the area selected for detailed ground follow-up. The intensity of radioactivity and the calculated K, eU and eTh concentrations are projected in the centre of the ellipse.

Flight line separation and flying altitude are equally important parameters in airborne mapping. Target detectability (or ground resolution) decreases as the altitude increases, and ground coverage decreases with decreasing altitude. Also, the observed count rate decreases as flight altitude increases, because gamma rays are absorbed in air exponentially as the air column increases in thickness (Pitkin & Duval 1980). The low information density between the lines could be improved by reducing the line separation. Another method would be to increase the flying clearance from the used 35 m, but this would weaken data quality and resolution. The 200 m flight line separation in GTK's system is the result of several conflicting factors, including the available budget, size of the survey area and size of the target. A speckled map may be a hint of too sparse line spacing, as the lack of line-to-line coherency may yield a non-contourable result.

A portable scintillometer or gamma spectrometer is needed for ground follow-up of airborne radiometric anomalies. If the aeroradiometric map hints a uranium source for the radioactivity, it may be located with a scintillometer that records the total gamma radiation. The target area is scanned with the scintillometer, and the radioactive locations are marked either on a map or with a GPS. The surveys may be combined with the GPS data to produce a large-scale radioactivity map. Ground maps are rarely needed if the target area has a good radiometric coverage from the air, as both air and ground surveys produce largely similar anomaly maps.

Ground gamma spectrometry is comparable to an airborne survey in accuracy and reliability, although it gives more details on a small scale. One cause for this is the statistical property of radioactivity to fluctuate in intensity, even in undisturbed conditions. A single observation has little statistical weight. The accuracy may be improved with longer observation series, and summing time extension is more easily arranged on the ground than in the air.

The radionuclide concentrations measured with the gamma spectrometer must be carefully considered before reaching a conclusion. The higher from the ground the spectrometer is, the larger is the area from which the gamma pulses originate. The spectrometer is calibrated in such a way that the radioactivity is estimated to originate from a half-space. During a survey, the system assumes that even a small sample fills the half space, which results in a too low radionuclide content. A calibration plate measuring an area of 1 m^2 and weighing 1 ton corresponds to ~90% of the total radioactivity of a half-space measured from the plate top (Grasty et al. 1991). In effect, the measured radionuclide concentration is always lower than the total concentration, i.e. eU < U.

The visually most attractive radiation anomalies are often situated on cliffs or on exposed hill tops. If the radiation fades beyond the exposed area, the reason is not necessarily in the rock but in the damping effect of the overburden. The higher the medium density and the larger its thickness, the stronger is the attenuation. Water is in practice the most important radiation attenuator, irrespective of its state. Twelve centimetres of effective water, be it liquid, ice, gas or any combination of these, attenuates the radiation intensity to half, causing wetlands and lakes to appear as blank areas. The fine component in till detains water and attenuates radiation, whereas high porosity sand and gravel eskers allow radon to move up and cause eU anomalies.

Uranium is a complex element in nature. It is soluble in acid water, and as rainwater is always acid, exposed U-bearing cliffs release uranium atoms, which are transported with the water flow. U is easily deposited in alkaline and reducing conditions or in organic substances or clays. Young, redeposited uranium is not, however, gamma active and is not detectable through radiation. The daughters in the U decay series, as separate elements with their own chemical properties, do not leave the original site but continue to be radioactive. It may happen that the original location is devoid of U, but radioactive due to the presence of the daughter elements, and the new site may be rich in U but not radioactive. Geochemical processes have caused a secular disequilibrium within the first depth centimetres, even though at deeper levels the normal state of affairs may be in force.

A detailed account of gamma measurements is found in an IAEA publication (IAEA 2013). The aerogeophysical routine of GTK is thoroughly described by Hautaniemi et al. (2005).

ASENTOLAMMINOJA TARGET

The Asentolamminoja area is situated 55 km SE of the town centre of Rovaniemi (Fig. 1). The bedrock of the area consists of Archaean rocks of the Pudasjärvi complex and 2.44 Ga layered intrusions of the Portimo complex. The distance from the Asentolamminoja area to the unconformity between the Archaean basement complex and the overlying Palaeoproterozoic Peräpohja belt is ca. 15 km.

The Kuohunki uranium target close to the Archaean–Proterozoic unconformity was found and to some extent drilled in the 1980s by GTK (Pyy 1981, Pääkkönen 1983, 1989). The Kuohunki area shows up as a relatively strong anomaly on both U and Th channels on the airborne radiometric maps (Figs 2a, b). On the ternary K-Th-U map, the Kuohunki area is shown to have slightly separate U and Th maxima, with the U-channel anomalies corresponding to glacial boulder trails in the field (Fig. 2c). On the SSE side of Kuohunki, an even stronger U-channel anomaly may be seen 15 km away (Fig. 2c). This anomaly, referred to as the Asentolamminoja prospect, was taken under exploration in 2007 by Areva Resources Finland Oy, the Finnish subsidiary of the French nuclear corporation Areva. When the target area was inspected with field scintillometer and spectrometer measurements, it was revealed to contain numerous radioactive glacial erratic boulders with evidence of hydrothermal alteration (see Mänttäri and Lauri 2008), thus giving the area the nickname of "10 000 boulders". Although no outcrops were found from the main boulder field area, which measures 3 km by 3 km, the boulders are of local origin based on Quaternary geological studies (Sarala 2007, 2008).

Figure 3 shows the results of the aeroradiometric measurements in the Asentolamminoja area. The total intensity in the uppermost figure is the sum of pulses in K, U and Th channels and of secondary pulses the intensity of which exceeds 0.41 MeV. The secondary pulses are generated in the reactions between the primary gamma quanta and atoms in the media – rocks, air, measuring devices – and cosmic radiation. Potassium is ubiquitous and it is responsible for the total field intensity to which the U and Th pulses are summed. The background level is so high that the less intensive U radiation generated by the uranium occurrence in the upper part of the map is seen as a very weak anomaly. The areas with weak anomalies may in general be interpreted to contain small amounts of radioactive nuclides, or be areas where radiation is attenuated by water.

The graph in the middle in Figure 3 is the eU map. The uranium occurrences are much more discernible than in the total gamma map, and they are limited to a smaller area that may be used for targeting the ground follow-up studies.

In the lowermost panel of Figure 3, the eU concentration is normalized with the eTh concentration and the ratio is multiplied by the eU concentration. This process decreases the damping effect of media (e.g., water) and transforms the eU measurement towards the ideal case, in which the bedrock is not covered by soil or water. This is justified by the tendency of U and Th to co-occur. The anomaly marked with a circle in Figure 3 illustrates a danger of this operation. Here, the low eTh content in the denominator has produced a

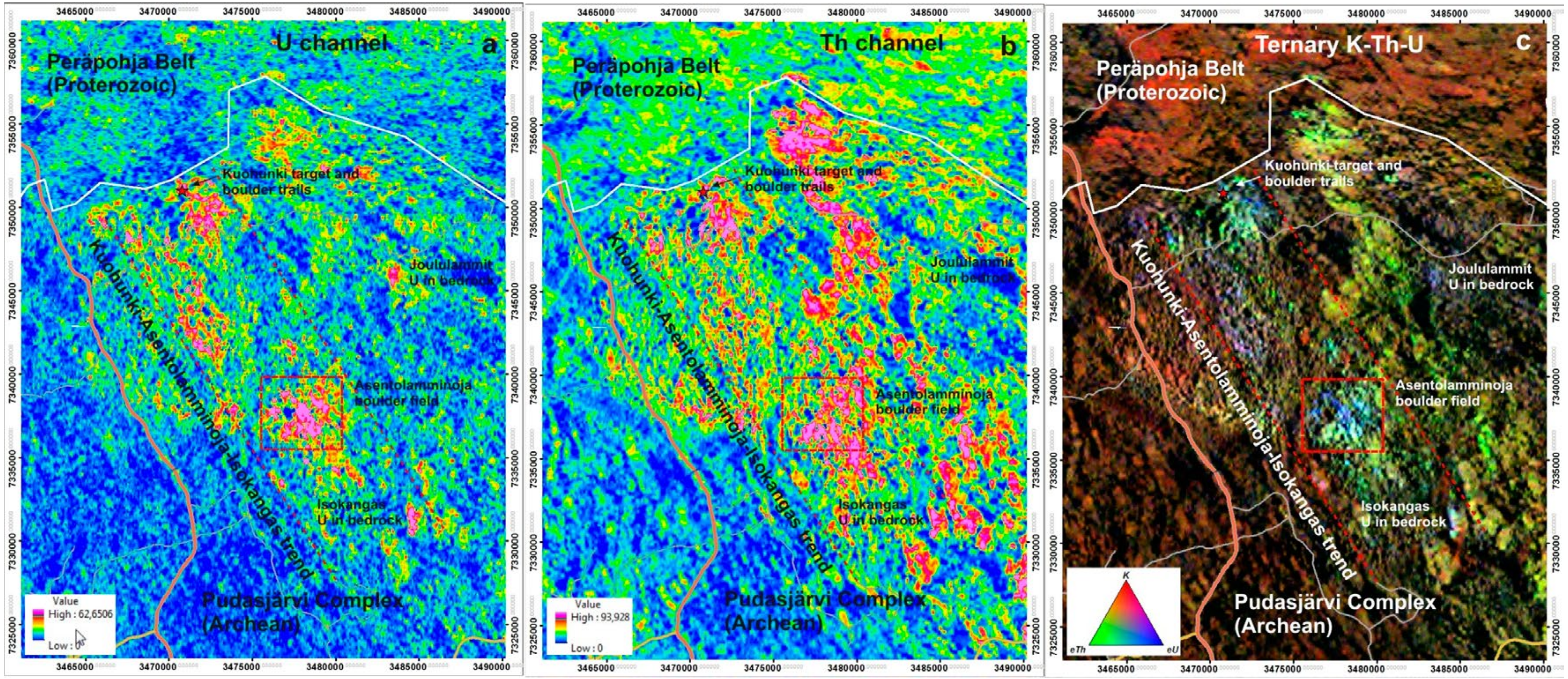

Fig. 2. a) Airborne U-channel map, b) airborne Th-channel map and c) ternary K-Th-U map of the Asentolamminoja area. The Kuohunki-Asentolamminoja-Isokangas trend is marked with red dashed lines and the Asentolamminoja boulder field is delineated with a red dashed square. The Kuohunki U-prospect is marked with a red star. The unconformity between the Archaean Pudasjärvi complex and the Proterozoic Peräpohja belt is marked with a white line. Contains data from the National Land Survey of Finland Topographic Database 03/2013.

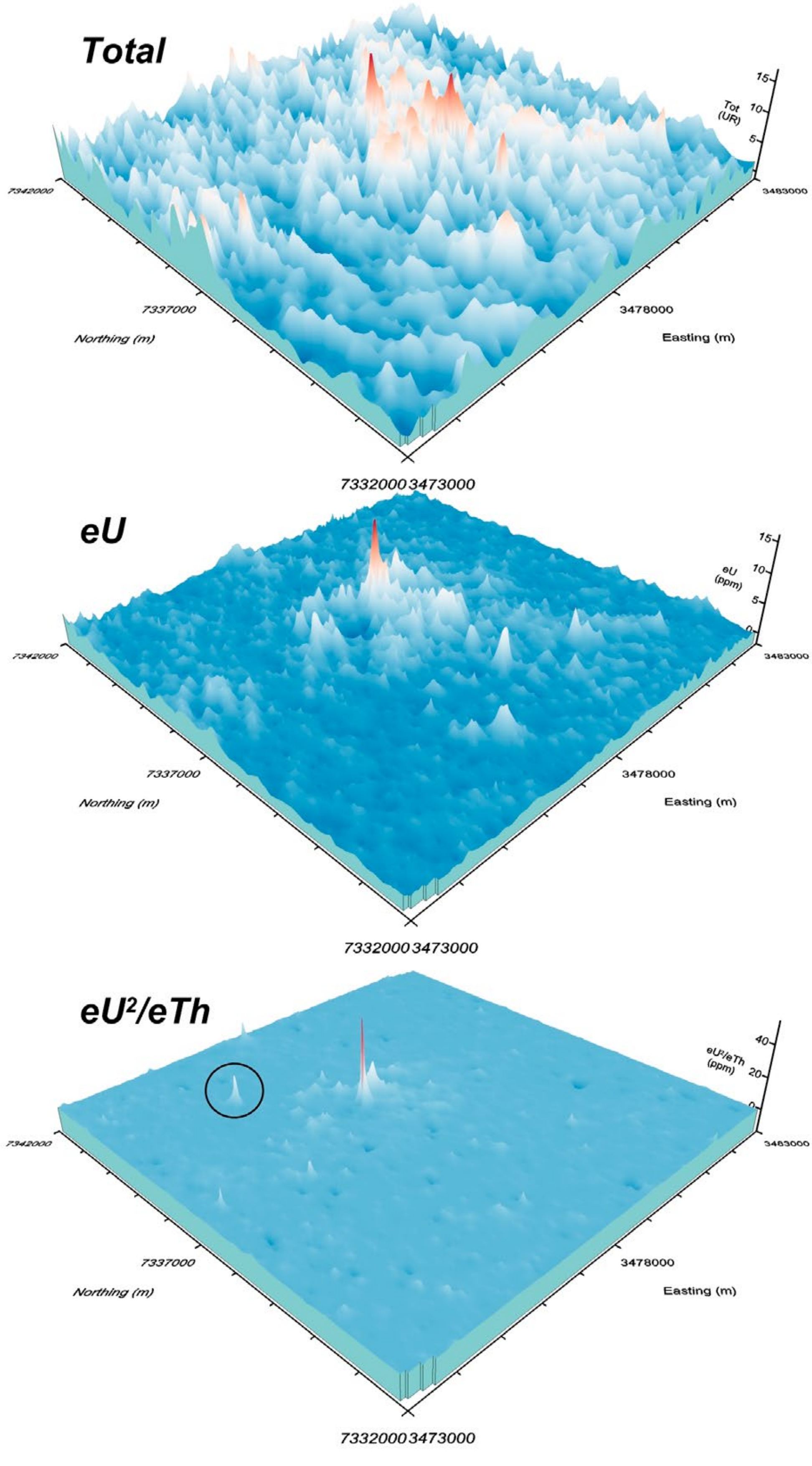

Fig 3. Airborne radiometric maps at Asentolamminoja. Top: Total intensity map. Middle: eU map. Bottom: eU^2/eTh map. The encircled peak is suspected to be a false anomaly.

false anomaly, regardless of eU content. An automatic cut-off technique can be utilized to avoid false anomalies, but a field check may be needed to verify whether the anomaly is real.

The other airborne geophysical (magnetic and electromagnetic) maps of the Asentolamminoja area do not reveal any indications of ore deposits. The weak anomalies on a flat background on aeromagnetic maps were revealed to be caused by peat bogs in ground surveys (Turunen 2008). Radon, a noble gas generated in the radioactive decay series of uranium, is soluble in water and raises the eU concentration in the wetland areas, even though the radioactivity from bedrock is attenuated. Peat is locally formed and to some degree reflects the radioactive nuclide content of the underlying bedrock. Areas covered by peat may be noisy.

Some small but strong U-channel anomalies may be observed on the NE and SE sides of the Asentolamminoja target (Figs 2a, c); these were examined in the field and found to represent small-scale radioactive alteration zones within the bedrock. The alteration type (biotitization, silicification) corresponds to the boulders within the Asentolamminoja boulder field and the Kuohunki drill cores, and most probably represents the same ore-forming system that extends all the way from the Kuohunki area through Asentolamminoja to the Isokangas area 25 km SE of Kuohunki. Although the uranium mineralization is situated within Archaean rocks, the age of the ore-forming process is most probably Proterozoic (Mänttäri & Lauri 2008).

RUMAVUOMA AND ROMPAS

The Rumavuoma and Rompas targets are situated in western Lapland, ca 40 km W of the town centre of Rovaniemi (Fig. 1). The Rumavuoma area appears on the ternary K-Th-U map as a clear uranium-channel anomaly (Fig. 4). The target was originally located in 2007 by ground follow-up of an airborne radiometric anomaly by Antti Pakonen, a former field assistant of GTK. The area was investigated in 2007–2008 by Areva Resources Finland Oy, and after 2010 by Mawson Oy. The Rumavuoma target is an outcropping area that mainly consists of uranium-bearing dolostone. The outcrops are situated within a wetland area, and the exposed outcrops have much higher background radioactivity than the surrounding peat bogs. The radiometric response of the Rumavuoma target is similar to the Mustamaa uranium prospect in the south (Fig. 4). The Mustamaa prospect, found and drilled in the 1970s (Äikäs 1980, Korvuo 1981, 1982), also shows up as a U-channel anomaly ca. 15 km south of the Rumavuoma area in a similar stratigraphic position at the contact between the subaerial Kivalo group and the submarine mica schists of the Martimo formation of the Paakkola group (Fig. 4). However, the Mustamaa prospect belongs to the phosphorite type in the classification of uranium deposits, whereas the Rumavuoma target is more probably a metasomatic type deposit (IAEA 2009).

In field season of 2008, the contact zone of the Kivalo group and the Paakkola group between the Rumavuoma area and the Mustamaa prospect was investigated by Areva Resources Finland Oy, as the contact zone seemed to be interesting in terms of uranium. Based on aeromagnetic data, the area on the NW side of Rumavuoma was included in the prospecting area, as it appeared structurally favourable to ore-forming processes with converging fault zones, although in terms of the aeroradiometric signal, the area did not look very interesting at a first glance. In late September 2008, the field assistants located high-grade uranium boulders in an area now known as North Rompas (Fig. 4), and in the following field season mineralized veins were found in outcrops in a 6-km-long and 300-m-wide area. High-grade uraninite was also found to be associated with native gold. Looking at the ternary K-Th-U map, the Rompas trend is weakly delineated as small uranium-channel anomalies, but it is by no means as spectacularly visible as the much lower grade Rumavuoma and Mustamaa targets (Fig. 4).

At a first glance, Rompas and Rumavuoma appear to differ considerably from each other on the ternary map. At Rompas, the red colour marking potassium dominates and at Rumavuoma uranium glows blue in places. The total radiation level at Rumavuoma is 3.1 UR and at Rompas 6.0 UR, which causes the general picture at Rumavuoma to

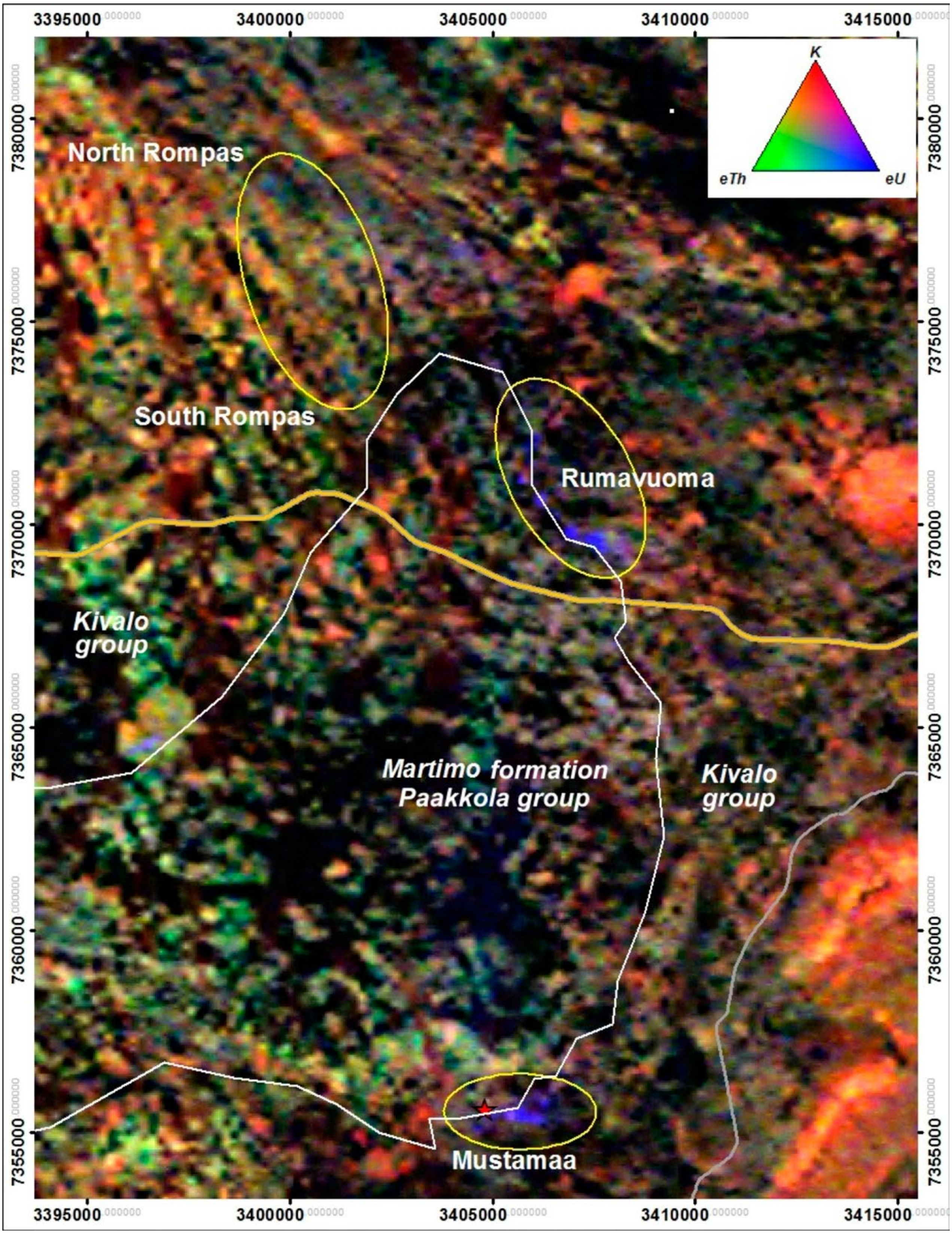

Fig. 4. Ternary K-Th-U map of the Rompas–Rumavuoma–Mustamaa area. White line separates the rocks of the Kivalo group and the Martimo formation of the Paakkola group. Contains data from the National Land Survey of Finland Topographic Database 03/2013.

be darker. The water content in the ground is the reason for the level variation, as an increased water content attenuates the radiation intensity and thus lowers the calculated radionuclide content. While water attenuates the concentrations of K, U and Th, their ratios are less affected. This is seen from the histograms in Figure 5, the data of which have been taken from inside the ellipses marked as Rumavuoma and South-North Rompas in Figure 4.

The maxima in the potassium and thorium distributions at Rumavuoma are lower than at Rompas on the concentration axis. With uranium, the differences between the targets are small, with the largest difference being the wider spread of the uranium distribution towards high concentrations in Rumavuoma, although field studies have shown that Rompas contains more high-grade uranium showings. The eU^2/eTh ratios in the two targets have much in common. It is supposed that the most important reason for the differences between the general ternary images of the two areas is the difference in the ground water content. The final solution to the problem here and elsewhere is provided by a field check.

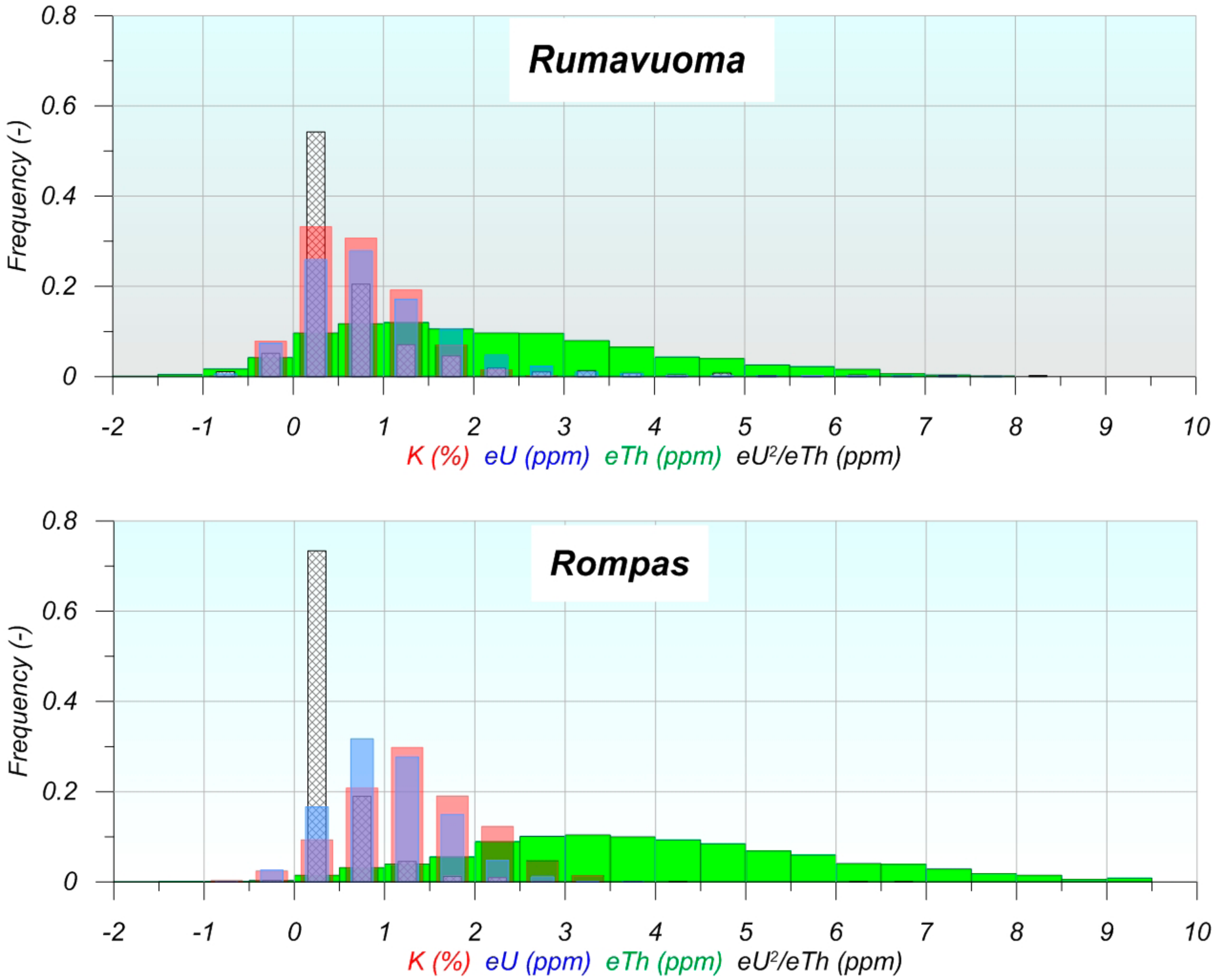

Fig. 5. Radionuclide histograms at Rumavuoma and Rompas.

CONCLUSIONS

Airborne low altitude radiometric data help to delineate areas for ground follow-up exploration with portable devices such as scintillometers and spectrometers. Ternary K-Th-U maps combined with either total radioactivity maps or separate U, Th and K-channel maps are especially important, as they reveal the cause of radioactivity. In terms of uranium exploration, the strong radiometric anomalies caused by granitoid rocks are not as interesting as pure U-channel anomalies. Interesting new targets may still be found when GTK's aeroradiometric data is carefully examined; however, the Rompas case is a good reminder that not all high-grade targets are easily located. The aeroradiometric data may also be used for gold and REE exploration, as uranium is a common element in many Au deposits, as in Rompas, and Th represents a good proxy for REE. The advantage of airborne and ground radiometric measurements is that they are fast and low-cost compared to more time- and money-consuming laboratory analyses.

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