Estimation of Relative Crustal Abundance of Radioelements Using Sum-Normalisation and Elemental Ratio Techniques

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Abstract: ***Airborne gamma-ray spectrometry method was used to estimate relative crustal abundance of radioelements with a view to define target area for possible mineral deposit in some parts of Ilesha schist-belt. This exploration techniques reveal relative concentration of each radioelement using the ratios of elements to sum of elements. Therefore, radioelement concentration contrast between favourable host-rock (granite-gneiss) is a significant pathfinder. eU^2/eTh and eU^2/K ratios anomaly on radiometric maps may be indicative of mineralisation and/or potential localized radioactive deposits. This method, is environmental friendly and easy to use, it is therefore a good tool to rapidly define target area(s) for mineral exploration at a regional scale. The method may also find application in exploring for other types of deposit characterised by an enrichment or depletion in U, K and/or Th.***

Keywords: Estimation, abundance, ratio**s,** radioelement, Relative, sum-normalisation, Techniques

1. Introduction

The basic purpose of radiometric surveys is to determine either the absolute or relative amounts of U, Th, and K in the surface rocks and soils. Radiometric surveys detect and map natural radiometric emanations, call gamma rays, from rocks and soils. At least 20 naturally occurred elements are known to be radioactive [1]. Airborne radiometric data recorded at low altitudes are extensively used worldwide in uranium exploration. All detectable gamma radiation from earth materials come from the natural decay products of only three elements, i.e. uranium, thorium, and potassium. 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. While many naturally occurring elements have radioactive isotopes, only potassium, uranium and thorium decay series, have radioisotopes that produce gamma rays of sufficient energy and intensity to be measured by gamma ray spectrometer. This is because they are relatively abundant in the natural environment. In addition to total count and U-channel data, ternary K-U-Th maps and eU^2/eTh ratios are also used as guide for mineral exploration. Spectral gamma-ray surveying relies on spatial variations in the distribution of earth materials that contain radiation-emitting isotopes. Gamma-ray surveys have traditionally been used either over large areas (generally airborne, kilometer-scale) for mineral prospecting [2] and radiation hazard assessment [3] or down boreholes (at centimeter-scale) for rock petrophysics [4]. In geological studies, gamma-ray transects or mapping have been utilised for many years in the search for mineralised, either for nuclear energy or as a proxy for radon hazard (Kearey *et al*., 2002)[4]. Such studies employ either total count scintillation or spectral detectors in aircraft or vehicles because the K, U or Th bearing rocks and minerals being sought emit high levels of gamma-rays. The application of gamma-ray detectors to superficial sediments has followed two courses of research: airborne, hazard detection or mineralisation studies [5], [6], [7] and surface, archaeological and geotechnical studies [8], [9], [10], [11], [3].

2. Spectral Gamma-Ray Emission

On the Earth's surface, gamma-rays may emanate from natural or anthropogenic sources which can be measured with a gamma-ray detector. Natural sources of gamma-rays include radioactive isotopes in rocks, soils and water or from outer space. Anthropogenic sources include processed isotopes (for example uranium, cesium, californium and others for nuclear power generation and weapons manufacturing). The isotopic source of gamma-rays may be discovered by use of a spectral gamma-ray detector, a device that measures characteristic gamma-ray wavelengths. Estimates of uranium concentration are usually reported as "equivalent uranium" (eU) as these estimates are based on the assumption of equilibrium conditions. In this study, the naturally-occurring gamma-ray radiation of 40K, 238U and 232Th are utilised. The usefulness of spectral gamma-ray data originates with mineralogical variation controlling the rocks in which K, U and Th occur. K is common in many rocks that bear K-feldspar, micas, clays or salts. Uranium (U) and thorium (Th) have a number of host minerals in rocks including clays (including illite and kaolinite), micas (including biotite), feldspars, heavy minerals (including monazite, thorite, uraninite), phosphates (calcium flourapatite).

3. Geology and Description of the Study Area

The basement rocks of Nigeria is part of the extensive PanAfrican Province of West Africa and are delimited in the west by the West African Craton and east by the Congo Craton. Nigeria basement comprises the Migmatite-gneiss complex, the Schist-belts and the Older Granites. The Migmatite Gneiss Complex is the oldest, most widespread and abundant rock type in the basement

[12]. It is of AcheanProterozoic age and a product of long, protracted and possibly polycyclic evolutionary histories. The Nigerian Schist-belts comprise of low-grade metasediments and metamorphosed pelitic and psammitic assemblages that outcrop in a series of N-S trending synformal troughs infolded into the crystalline complex of migmatite-gneiss. The PanAfrican Granites referred to as Older Granites include rocks of wide range of composition varying from tonalite, granodiorite, granite and syenite. The Ijero-pegmatite form an intrusion into the biotite-schist that occupies the central part of the study area. The study area is an extension of the eastern end of Ilesha Schist-belt and falls within the Basement Complex of southwestern Nigeria. The study area is located within latitude 7°41' 00" - 7°46' 30" N and longitude 4°57' 15" - 5°2' 30" E (Fig. 1). According to [13], Ilesha schist belt is characterized by abundance of rocks which harbor metallic and non-metallic minerals, rare metals and gemstones among other minerals.

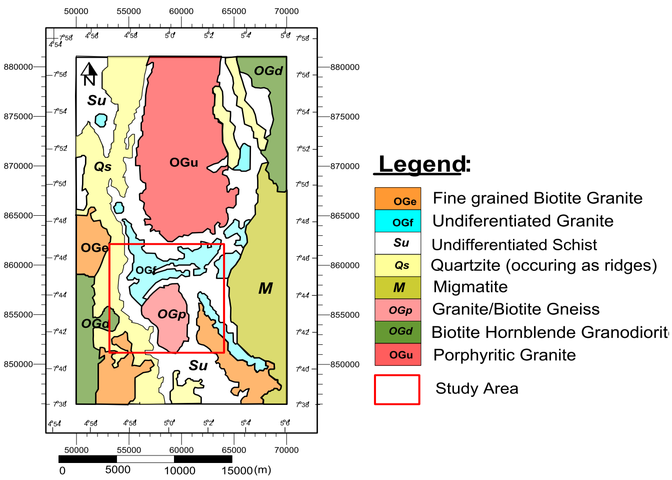

Figure 1: Geological Map of the Study Area

4. Materials and Method of Study

Specialised gridding techniques provided in the Geosoft and Golden software (Oasis montaj^{TM} and Suffer 12^{TM}) were used to enhance airborne radiometric datato observed radioactive distribution of the primary radioelements (potassium, uranium and thorium) and generate images and maps for easy identification and characterisation of radiometric signatures associated with relative crustal abundance, trends of structures and pattern of geologic units. Grid and Image tool in Geosoft software are used to create radionuclide-count grids, element sum/ratios and images. The ratio images were created with the intention of removing lithological differences and effects in the data caused by variations in the radiometric concentration. According to [14]. Lithological differences tend to be removed because radioelement concentrations frequently vary as lithology change. To help identify zones or area with high concentration of radioelements, elemental ratio grids (eU^2/K, eU^2/eTh) were created to determine its relative abundance and good spatial distribution in rocks. Sum-normalization ratio was used to compute the concentrations of K, Th and U prior to imaging as follows:

$K_n = K/ K + eU + eTh$

$U_n = eU/ K + eU + eTh$

$Th_n = eTh/ K + eU + eTh$

This converts the radioelement concentrations to relative abundance. Sum-normalisation is useful in reducing the effects of the attenuation of gamma rays by vegetation or soil moisture.

5. Results and Discussions

5.1 K, eTh and eU Radioelement Concentration

Variations in radioelement concentrations indicate primary geological processes: mineralizing solutions, metamorphic processes and secondary geological processes (supergene alteration and leaching). Potassium is an abundant and widespread element in the earth's crust and a major component of granitic rock (predominantly in muscovite and biotite) but virtually absent from dunite and peridotites [15], [16]. Uranium is the only fissionable material occurring in nature. It is useful in explosive devices and in the generation of power. Thorium isotope (Th-232) must be converted into fissionable isotope U-233 to be utilized as a source of power. Uranium and thorium are found in many mineral species; some of which contain appreciable amounts of these elements. There is high potassium count (0.7 – 3.5%) around regions underlain by granite-gneiss and migmatite-gneiss, while areas underlain by quartzite and undifferentiated schist are low (0.2 – 0.7%) in potassium concentration (Fig. 2). The concentration of Thorium is high (17.9 – 61.6 ppm) across the study area except in regions underlain by quartzite, granite and biotite hornblende where it is low (3.9 – 17.9) (Fig. 3). The spatial distribution of uranium concentration is similar to that of thorium (Fig. 4). It is high (4.3 – 20.2) at region underlain by granite-gneiss (around the central) but generally low (0.6 to 4.3 ppm) in other parts of the study area. High count of all the three radioelements: K (0.7 – 3.5%), eTh (17.9 – 61.6 ppm) and eU (4.3 – 20.2) response is observe at area underlain by granite-gneiss rock.

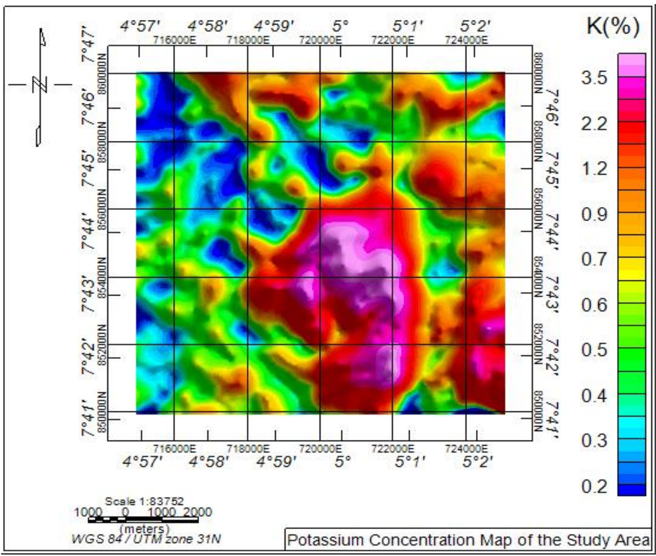

Figure 2: Potassium Concentration Map of the Study Area

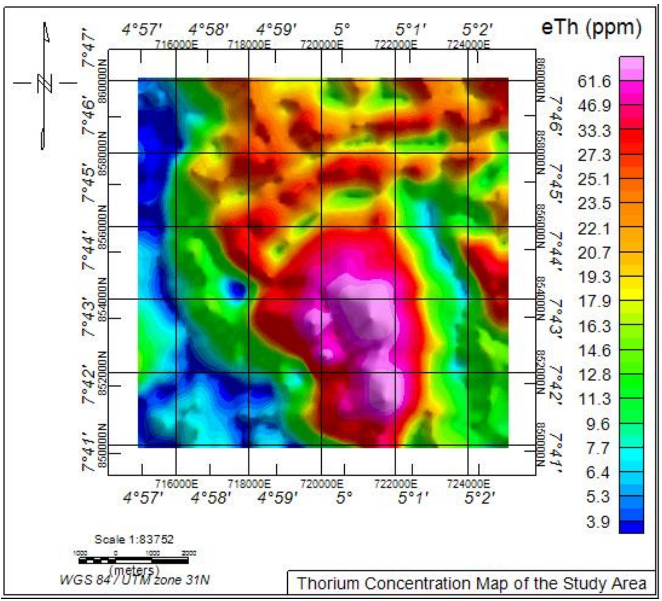

Figure 3: Thorium Concentration Map of the Study Area

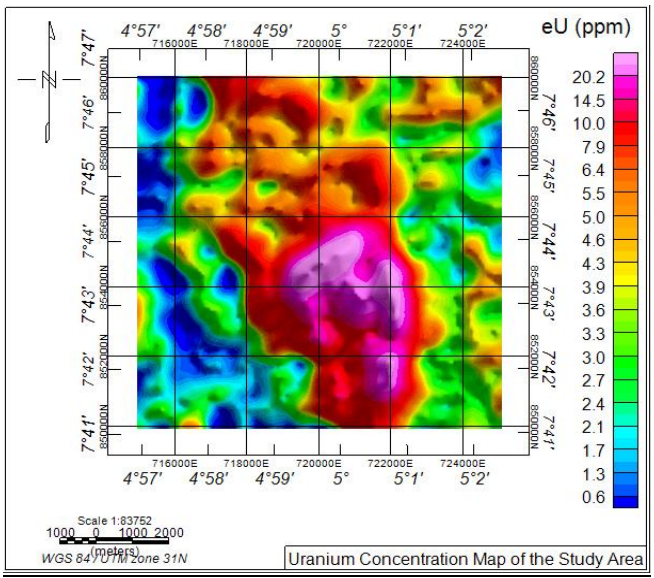

Figure 4: Uranium Concentration Map of the Study Area

5.2 Elemental Ratio Maps

Figures 5 and 6 are elemental ratio (eU^2/eTh and eU^2/K)maps which show relative concentration of radio elements as computed from airborne spectrometric data. Variations in radioelement concentrations reflect the environmental conditions, mineralisation/geological processes and relative crustal abundance of radioelements in rocks. eU^2/eTh and eU^2/K ratio anomaly on radiometric maps may be indicative of potential for localised mineral deposits**.** Figure 5 is a map which displays values (eU^2/K-ratio) displayed to reveal relative abundance of uranium to potassium concentration in rocks within the study area. Uranium is relatively abundant (0 – 250) across the study area, but higher (250 – 650) at some isolated locations in areas underlain by granite-gneiss around the center and towards the northwestern and north central region underlain by schistose rock. The profile drawn along cross-section line (AB) across the map shows varying amplitude with high peaks recorded at regions underlain by granite-gneiss (around the center). Figure 6 shows eU^2/eTh-ratio map which is displayed to reveal relative abundance of uranium to thorium concentration in rocks within the study area. Uranium is relatively abundant (-1 – 9) across the study area, but higher (9 – 24) at areas underlain by granite-gneiss around the center. The profile plotted along cross-section line (AB) across the map shows varying amplitude with high amplitude noted at regions underlain by granite-gneiss around the center. This map clearly defines area with high concentration of radioelement and potential area for mineral exploration.

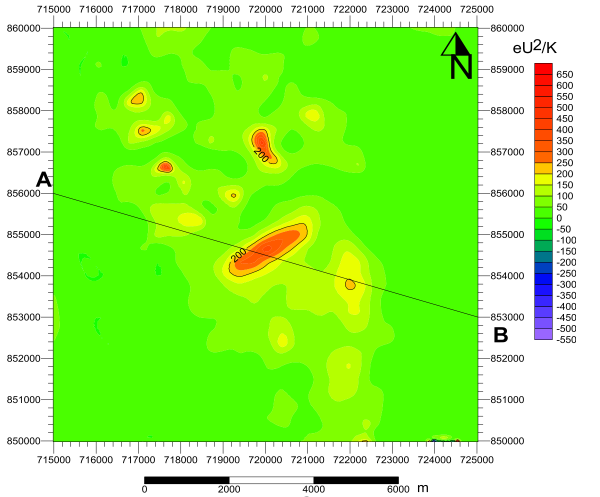

Figure 5: Elemental ratio (eU^2/K) map of the Study Area.

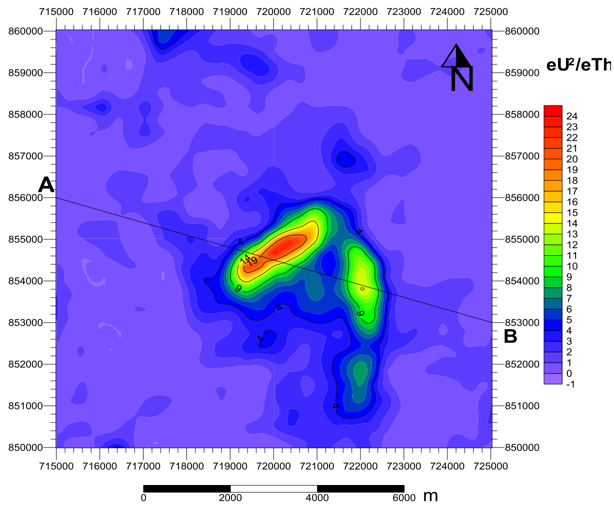

Figure 6: Elemental ratio (eU^2/eTh) map of the Study Area

5.3 Sum-Normalisation Ratio Maps

Sum-normalisation (K/K + eTh + eU, Th/K + eTh + eU and eU/K + eTh + eU) maps below were produced from ratio of elements to sum of elements within the study area. These maps help to determine areas with relatively crustal abundance of radioactive elements and high mineralisation potential. High concentration of radioelement (prominent anomaly) suggest possible presence of mineralised deposit. K/K + eTh + eU ratio map (Fig. 7) shows relatively high (0.08 – 0.19) concentration of K in mineral-bearing rocks in some parts and low (- 0.03 – 0.08) in the remaining parts of the study area. It is mainly high in areas underlain by migmatite-gneiss, granite-gneiss and quartzite rocks. 2D profile plotted along line AB across this map reveals varying concentration of potassium along the cross-section line.

Uranium elements is mobile, while thorium is relatively immobile, both of which are present in trace amounts in most mineral-bearing rocks [17]. The eTh/K + eTh + eU ratio map (Fig. 8) shows relatively high concentration (0.8 – 1.2) of eTh in major parts of the study area and relatively low concentration (0.4 – 0.8) in other parts. It is mainly high in areas underlain by quartzite, migmatite-gneiss and undifferentiated-schist, but low in areas underlain by granite-gneiss and biotite-gneiss. The profile line (AB) across the map reveals varying concentration of thorium along the cross-sectional line. The eU/K + eTh + eU-ratio map (Fig. 9) reveal varying concentrations of uranium radioelement across the study area. It is relatively high across the study area (0.1 – 0.55) owing to its mobility. Higher values (0.25 – 0.55) are recorded in areas underlain by granite-gneiss, but relatively low (- 0.25 – 0.1) in region underlain by migmatite and along region underlain by quartzite rock. The signature of eU/K+eTh+eU is indirectly proportional to that of eTh/K + eTh + eU. The profile line (AB) across the map reveals variations in relative-eU amplitude, it is relatively higher across granite-gneiss.

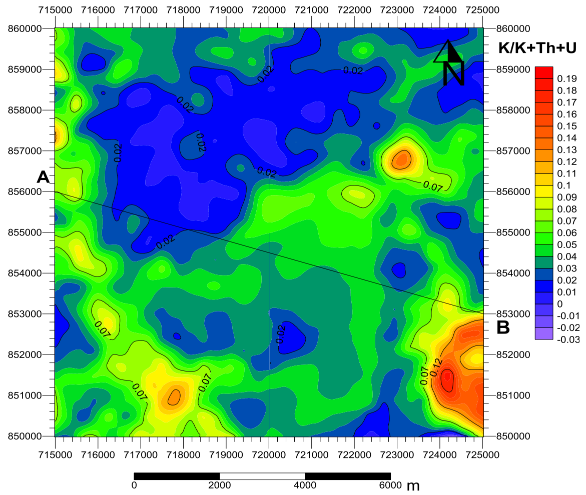

Figure 7: Sum-Normalisation Ratio (K/K+Th+U) Map of the Study Area

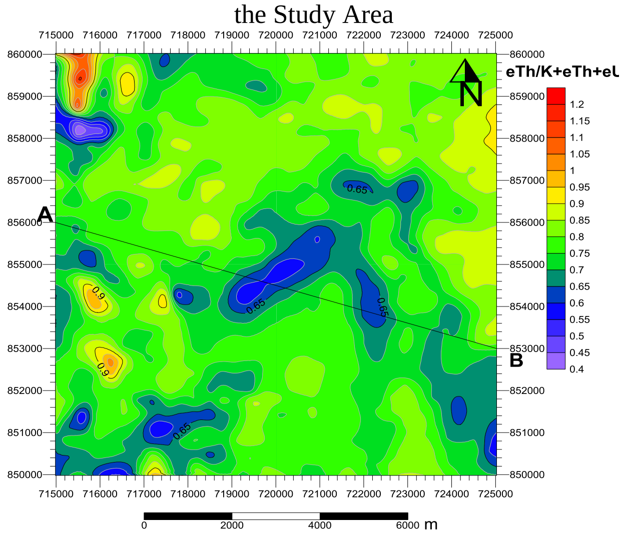

Figure 8: Sum-Normalisation Ratio (eTh/K+eTh+eU) Map of the Study Area

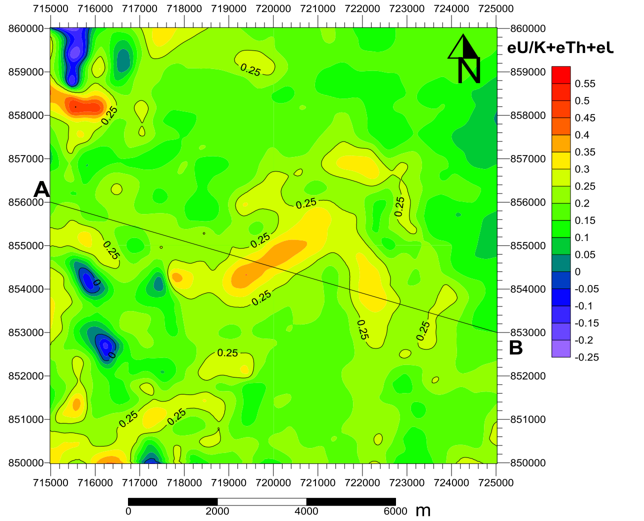

Figure 9: Sum-Normalisation Ratio (eU/K+eTh+eU) Map of the Study Area

5.4. 2D Cross-Section profiles of Suspected Radiometric Anomalies

Figure 10 is a 2D cross-section profile across suspected elemental and sum-normalisation ratio anomaly (eU^2/K, eU^2/eTh, K/K + Th + U, eTh/K + eTh + eU and eU/K + eTh + eU) maps within the study area. The total length of these sections is 10,500 m and is oriented approximately in NW – SE direction. The radioelements concentrations ratio profiles reveals varying amplitudes which suggest changes in lithology, mineral constituents and possible presence of concealed geological features with contrasting physical and/or chemical properties at different segments along the profile. The quantitative interpretation was carried out using Surfer 12 (a geophysical interpretation software) which enables us to characterise and estimate relative abundance of radioelements concentration across the study area. These profiles show plots of radioelement anomaly ratio against distance. It reveals high and low anomalous deflections at different parts of the 2D sections. Radiometric ratio anomaly profiles reveal relatively high values (20, 320 and 0.36) for eU^2/eTh, eU^2/K and eU / K + eTh + eU respectively while eTh/K + eTh + eU and K/K + eTh + eU profiles reveal low values (0.6 and 0.0375) between distances 4,000 and 6,000 m. This implies high and low relative uranium concentration respectively. The remaining parts of the profile reveals relatively low uranium concentration apart from interval between 6,500 – 8,500 m where the response is moderately high. Figure 11, is a shaded-relief map of the study area. It was produced from values of eU^2/eTh ratio which shows relative abundance of uranium to thorium ratio within the study area. The high amplitude shown on the map shows area with relatively high crustal abundance of radioelements within the study area.

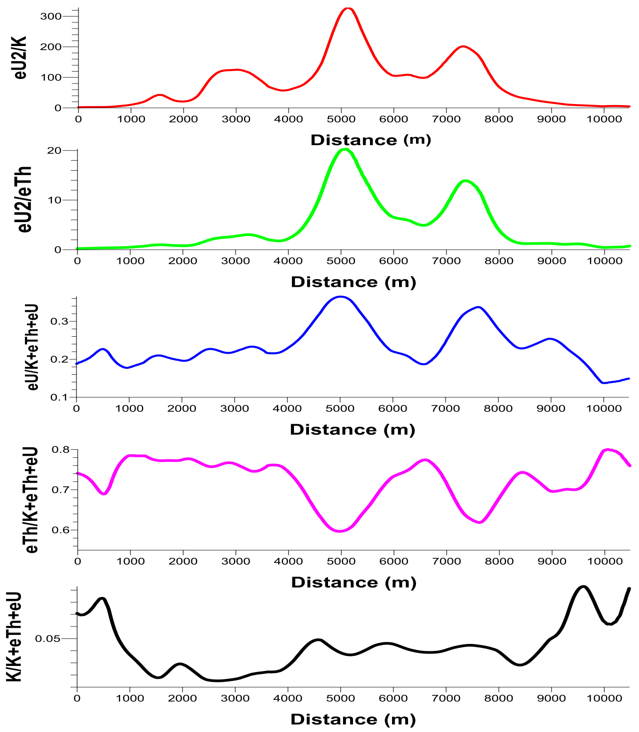

Figure 10: 2D-Cross-Section across Suspected Radiometric Anomalous Zone

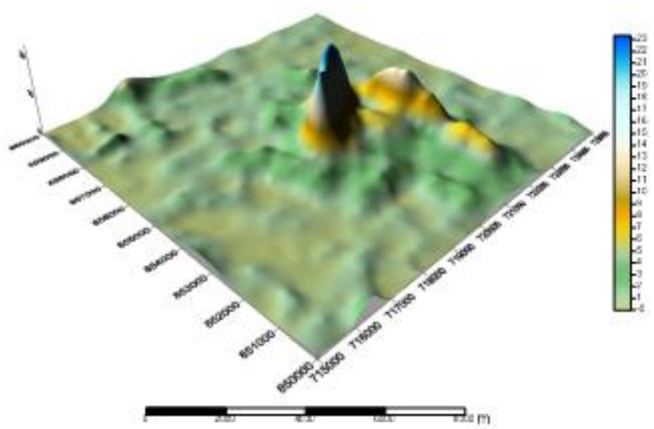

Figure 11: Shaded-relief map of the study area.

6. Conclusions and Recommendations

Analysis of airborne radiometric data help to delineate target areas for follow-up ground exploration survey with portable devices such as gamma ray spectrometers. Elemental or sum-normalisation ratio map can be combined with either total radioactivity count maps or single (U, Th and K) channel maps to reveal the cause(s) of radioactivity. Granitic rocks are associated with very strong radiometric anomalies, most especially the potassium and uranium channels. Ratio images (eU^2/eTh, eU^2/K, K/K + eTh + eU, eTh/K + eTh + eU and eU/K + eTh + eU) are radioactive pathfinders and a useful tool for mineral exploration. High amplitudes in eU^2/eTh, eU^2/K and eU/K + eTh + eU maps and profiles correspond to high relative abundance of radioelement while low amplitudes in K/K + eTh + eU and eTh/K + eTh + eU maps and profiles imply relatively low abundance. Exploration may solely be for radioactive mineral or other mineral found to co-exist with uranium minerals. The advantage of airborne and ground radiometric measurements is that they are fast and cheap compared to more time- and money-consuming laboratory analyses. The map of eU^2/eTh ratio shows relative abundance of radioelement ratio (uranium to thorium) within the study area.

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