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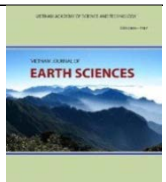

Radiometric survey in geological mapping of parts of basement complex area of Nigeria

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ABSTRACT

Radiometric methods were used to investigate the radioactive properties of rocks in parts of southwestern Nigeria with a view to interpreting the geological structure and abundance of natural radioactive elements in the main type rocks. The airborne radiometric dataset of Ikole Sheet and ground radiometric data recorded from eight traverses in Akoko axis of the study area were processed. Results presented as maps and profiles displayed variations of high and low radioactive concentrations across the area. These maps showed moderate to very high concentrations and very low to low concentrations of the radioelements; uranium (4.5-13.0 ppm); (LLD-low limit of detection -3.0 ppm), Th (25.0-70.0 ppm); (8.5-16.0 ppm) and K (2.0-4.0 %); but the most often observed values are in the range 2.5-7.0 ppm, 22.0-30.0 ppm and 3.0-4.0% for U, Th, and K respectively. High concentrations imply that the rocks are crystalline, undeformed and are rich in feldspar and U-Th bearing minerals. While low radioactivity is attributed to varying geologic framework compositions, weathered materials or fluids formed as a result of intense metamorphism. The radiometric datasets proved valuable in delineating different rock types and serve as a complementary tool in identifying geochemical zoning of rocks in the area.

Keywords: Radiometric; Ikole Sheet; Radioelements; Geological mapping; Rock types.

1. Introduction

The radiometric method involves the measurement of naturally occurring radioactive materials emitting the ionization radiation (α, β, γfrom rocks. In the field, the gamma rays and their adequate energies are detected by a spectrometer coupled with the scintillation detector.Theoretically, the energy of the gamma rays emitted from the natural radionuclides range from zero to 3 MeV, but in the geological survey, the interest lies between 0.2 and 3 MeV. Peaks in the spectrum are attributed to potassium (%K), thorium (eTh) and uranium (eU), the count rate of the whole spectrum is referred to the total count (TC). Such measurements indicate the radioactivity of layers from several cm up to 1.0 m depending on the measurement condition and geology. The rocks near the earth surface are often weathered. During weathering thorium is often freed by the breakdown of minerals and may be remained in Fe or Ti oxides/hydroxides and with clays. Uranium is a reactive metal and easily removed from the origin places. It may be present in rocks as the oxide and silicate minerals, uraninite and uranothorite; as trace

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amounts in other minerals or along grain boundaries possibly as uranium oxides or silicates (Kearey et al., 2002; Milsom, 2003).The radiometric method involves the measurement of naturally occurring radioactive materials emitting the ionization radiation (α, β, γ) from rocks. In the field, the gamma rays and their adequate energies are detected by a spectrometer coupled with the scintillation detector. Theoretically, the energy of the gamma rays emitted from the natural radionuclides range from zero to 3 MeV, but in the geological survey, the interest lies between 0.2 and 3 MeV. Peaks in the spectrum are attributed to potassium (%K), thorium (eTh) and uranium (eU), the count rate of the whole spectrum is referred to the total count (TC). Such measurements indicate the radioactivity of layers from several cm up to 1.0 m depending on the measurement condition and geology. The rocks near the earth surface are often weathered. During weathering thorium is often freed by the breakdown of minerals and may be remained in Fe or Ti oxides/hydroxides and with clays. Uranium is a reactive metal and easily removed from the origin places. It may be present in rocks as the oxide and silicate minerals, uraninite and uranothorite; as trace amounts in other minerals or along grain boundaries possibly as uranium oxides or silicates (Kearey et al., 2002; Milsom, 2003).Some regions in Nigeria are rich in uranium such as within Naraguta and Maijuju Sheets in Plateau State, Igabi, Kajuru, Kachia and kalatu Sheets in Kaduna State as well as Ririwai in Kano State. All the mentioned places are within the ring complex belt of north-central Nigeria. Other areas that show significance uranium anomaly within Schist and Older Granites include Dangulbi and Kwiambana Sheets in Zamfara State, Kakuri and Bishini Sheets in Kaduna State as well as Igboho, Kishi, Meko, Abeokuta, Oyo, Kwara, Ogun, and Ikole Sheets (Arisekola et al., 2013).

The radiometric method is one of the most cost-effective and rapid techniques for geochemical mapping based on the distribution of the radioactive elements: potassium, uranium, and thorium. Nowadays, the method is mainly applied for geological mapping and exploration of other types of economic minerals; geochemical and environmental monitoring such as localization of radioactive contamination from fallout of nuclear accidents and plumes from power plants; allow the interpretation of regional features over large areas, and applicable in several fields of science (IAEA, 1991; 2007). They may be used to estimate and assess the terrestrial radiation dose to the human population and to identify areas of potential natural radiation hazard. Regional surveys also provide a baseline data set against which man-made contamination can be estimated. The airborne datasets can also provide detailed information about the characteristics of the soil and its parent rocks, including surface texture, weathering, leaching, soil depth, moisture, and clay mineralogy (Bierwirth, 1997). It is also possible to determine the amount of anthropogenic radioactivity from the radiation spectrum (Grasty and Multala, 1991).The airborne radiometric data may be less reliable in urban areas because a significant proportion of the ground area is covered with buildings and/or asphalt paving, and the flight altitude is approximately 240 m. In consequence, the number of gamma ray from the earth reach to the detector is low enough, resulting from the measured concentrations of eU, eTh and K for the urban area are very low (Appleton et al., 2008). This study is aimed at giving details in interpretation and distribution of radioelements and characterize them based on gamma airborne and gamma ground surveys.

2. Geologic Setting of the Study Area

The Basement Complex rocks of Nigeria form a part of the African Crystalline Shield which occurs within the Pan African mobile belt that lies between the West African and Congo Cratons and South of the Tuareg Shield which were affected by the Pan-African Orogeny, the last stage deformation of the four Orogenesis in Nigeria (Figure 1) (Oyawoye, 1972, Woakes et al., 1987).

The Basement Complex of Southwestern Nigeria is located in a triangular portion of the Nigerian basement, an extension of the Dahomeyide Shield of the West African Craton. Rocks of the region include Migmatised-Gneiss Complex (MGC) that is characterized by (a) grey foliated gneiss, (b) ultramafic rocks and (c) felsic component comprised of pegmatite, aplite and granitic rocks (Rahaman, 1981). The MGC in Southwestern Nigeria is affected by three major geotectonic events ranging from Early Proterozoic of 2000 Ma to Pan African events of ~600 Ma (Ajibade and Fitches, 1988; Oyinloye, 2011). The rocks of the basement have been affected by medium pressure Barrovian metamorphism (Rahaman et al., 1983; Oyinloye, 2011). The attitudes of tectonic structures in the Nigerian basement have been documented in terms of orientation and magma-induced veins and dykes such as quartz veins and pegmatites (Rahaman et al., 1983; Ajibade et al., 1987). Deformation of the Nigerian basement complex occurred in two phases, a ductile phase, which is responsible for the formation of planar structures (foliations) and a brittle phase resulting in jointing and fractures, many of which have been filled with quartzo-feldspathic veins, dolerite dykes, pegmatite and aplitic veins and dykes (Omosanya et al., 2015).

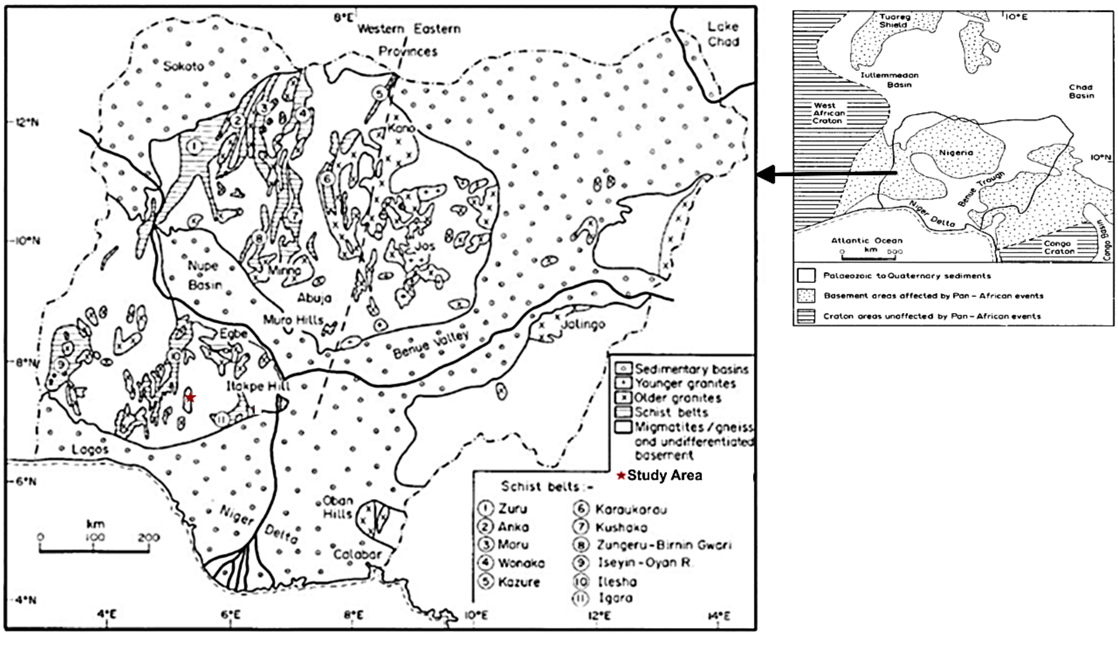


Figure 1. Regional geological setting of Nigeria (modified after Woakes et al., 1987)

The study area (Ikole Sheet 245) lies within latitudes 7°30’N and 8°00’N and longitudes 5°30’E and 6°00’E (Figure 2) of the Greenwich Meridian. The study area is divided into Ikole axis (Ekiti State), Akoko axis (Ondo State) and extends to Kabba (Kogi State) within the Southwestern Basement Complex of Nigeria. The major lithological units of the study area include the migmatite, granite gneiss, charnockite, granite, and other felsic and mafic intrusive (Figure 2). The basement rocks show great variations in grain size and in mineral composition. The rocks are predominantly gneisses, which have been intensively migmatized and essentially consist of feldspar, quartz with small amounts of micaceous minerals. The grain of the rocks varies from very coarse-grained pegmatite to medium-grained gneisses. The basement complex rocks in the area have been subjected to intense regional metamorphism in which shearing stress was the dominant control resulting into widespread magnetization that reflected rapid alternation of granite, biotite gneiss, and biotite-schists, which grade into one another. Selective granitization has resulted in biotite-rich layers in the gneisses being converted into biotite granites, while the leucocratic bands have been converted to aplitic granite. Minor folds are very common in the gneiss and schists and from all available evidence (Jones and Hockey, 1964). The basic geological structure of Southwestern Nigeria is a complementary anticlinorium and synclinorium with northwards plunging axes.

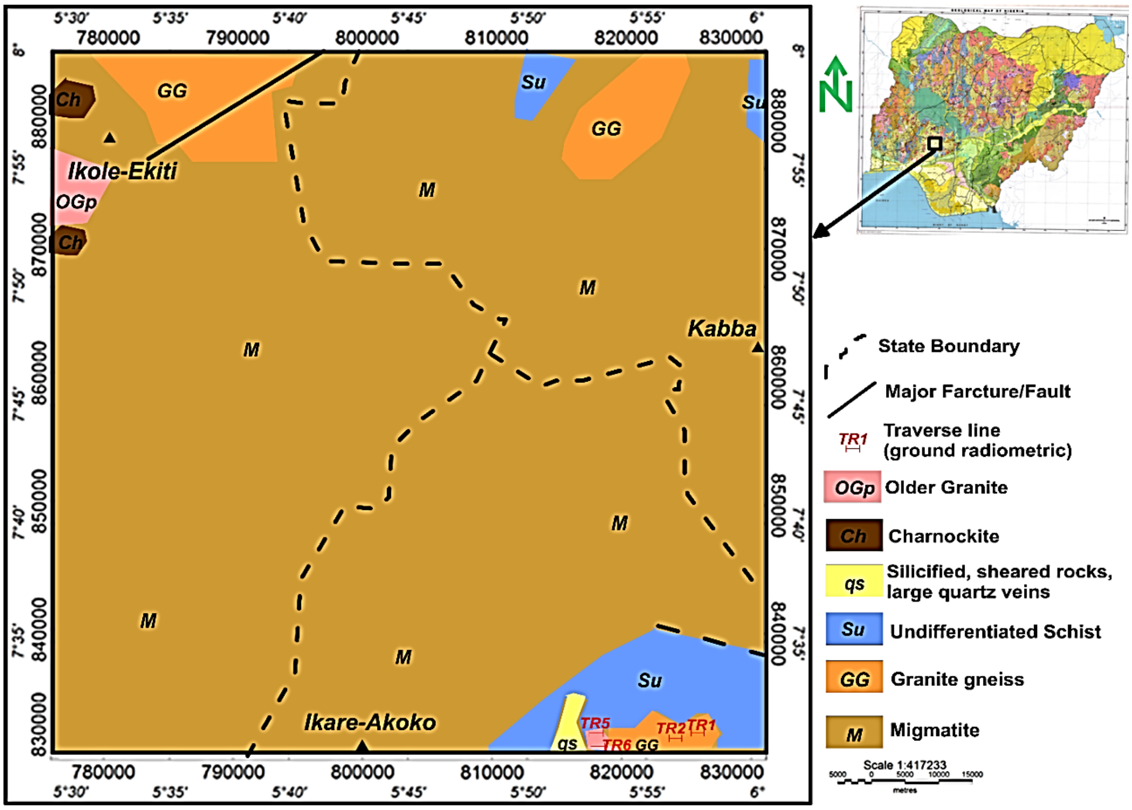
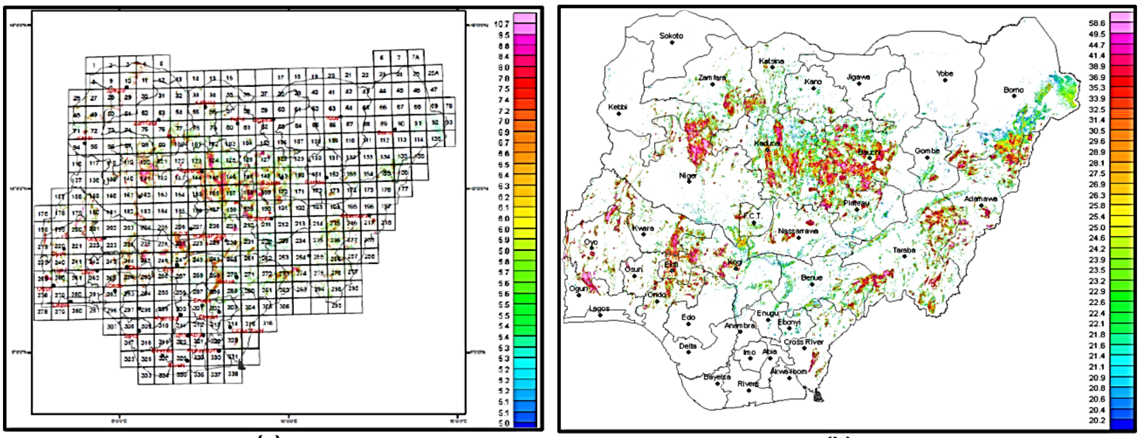


Figure 2. Geological map of the study area showing the various litho-structures (Modified after NGSA, 2009)

3. Materials and Methods

Airborne gamma-ray measurements are a fast way of surveying and monitoring radioactivity of subsurface rocks. For the determining of uranium, thorium and potassium concentrations in the surface rocks using the airborne gamma survey, a range of corrections are usually applied to the data to include removing aircraft noise, cosmic and background radiations; application of stripping corrections derived from calibration data and application of height attenuation corrections by Nigerian Geological Survey Agency (NGSA) - the agency that acquired the airborne data. These are based on protocols described in IAEA (1991) and by Grasty and Minty (1995a, b). The procedure determines the concentrations that would give the observed count rates if uniformly distributed in an infinite horizontal slab source.

The airborne data from NGSA were processed using Oasis MontajTM Software. Appropriate filters were used to remove near surface and background noises that may obscure important signatures originating from the subsurface. Similarly, ground radiometric measurements were carried out along prospective locations within the study area, in order to know the range and variations in measured radioactivity for respective rock types in the area, as well as to ascertain and corroborate the measured radioactivity and interpreted aero-radiometric data. Measurements were taken along eight (8) traverses (TR) on granite-gneiss, charnockite, granite and grey-gneiss (i.e. TR 1-2, 3-4, 5-6, and 7-8 respectively), using a spreading length of 100 m with the station spacing of 5 m each. The acquired eU (ppm), eTh (ppm) and K (%) data were therefore computed and plotted through Microsoft Excel to determine their respective profile signatures. Figure 3 shows the national anomaly map for concentration greater than 5 ppm and 20 ppm for areas with uranium and thorium respectively (Figures 3a and b). These maps give foresight imaginations to what the results of the study area would look like based on the distribution of 238U and 232Th in the country.



(a) (b)

Figure 3. National Anomaly Maps of areas with the concentration greater than 5 ppm and 20 ppm for eU (a) and eTh (b) respectively (Arisekola et al., 2013)

4. Results and Discussion

The radiometric data are first summarized in terms of color images obtained from Minimum Curvature Grids in order to avoid image color bias and to enhance the signal to noise ratio. Results of the gamma-ray measurements are displayed as concentration maps for eU, eTh, %K, and ternary image.

Generally, the maps are depicted as high - moderate-low radioactive concentrations across the whole area. It is evident from the various maps produced that there are rocks with different concentrations of the natural radionuclides. The variation in the study area geology is envisaged through the regional lineament that trend diagonally from the southwestern to northeastern part and divides the study area into approximately equal halves. This regional lineament that extends north-eastward terminates by encountering another NW-SE lineament that distinguishes the boundary of Kabba Complexes from the other complexes. Therefore, the two pronounced lineaments compartmentalized the rocks in the area into three (3) complexes i.e. the Ikole Complexes on the western to northwestern part, Akoko Complexes on the south to the eastern part, and Kabba Complexes occupy the small portion of the area on the northeastern.

Figure 4 shows the Uranium concentration map of varying concentration in ppm. From the northwest of the map up to a little part of the northeastern section (i.e. above the NE-SW lineament (red line) trend) is dominated by moderately high to very high eU concentration ranging from 4.5-13.0 ppm, the edges of the rich to low uranium bearing-minerals are classified within 3.0-4.5 ppm. While below this lineament trend, are areas of very low to low (≤ LLD to 3.0 ppm) with scattered highs of eU concentration denoting in-situ rocks rich in uranium-bearing minerals and some pockets of uranium deposits hosted by some minor faults. The study area reveals very high eU radiation at the northern part (Ikole axis), which could also be attributed to radon gas radiating outwardly through the deep-seated NS trending fault. Though one would expect low eU concentration because of it susceptible nature to weathering like what we have in the southern half of the lineament, this high radiation level confirms the presence of uranium deposit around Ikole-Ekiti in Ekiti State. This characterization further validates the applicability of uranium mapping as a useful tool for litho-structural differentiations.

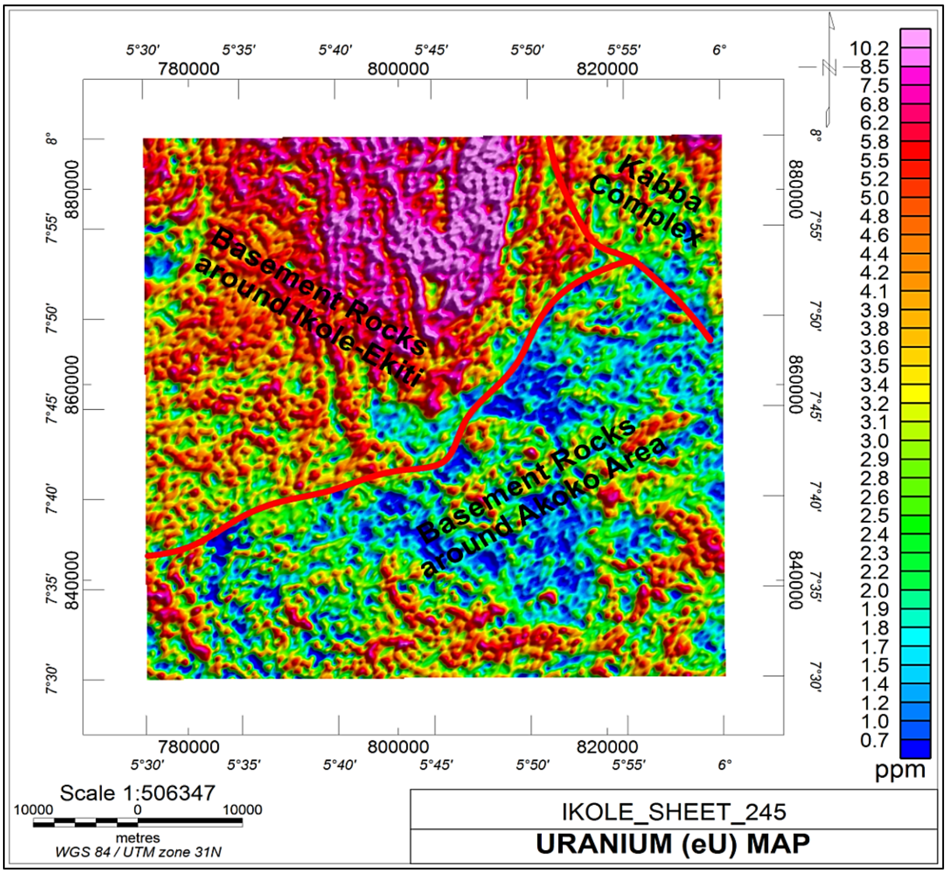


Figure 4. Uranium (eU) Concentration Map

Figure 5 shows Thorium (eTh) concentration map in parts per million (ppm) with somewhat similar attributes and variations to eU map. The high concentration of eTh ranged from 25.0-70.0 ppm corresponding to rocks bearing-rich thorium minerals such as thorite, zircon etc., and 16-25 ppm probably denotes the edges of the mineralized thorium-rich rocks because this range of thorium concentration marks the boundary of the zone of alteration. In addition, the low concentration ranged from 8.5-16.0 ppm representing intra-basement structures such as faults (F-F'), lineaments (R-R' and S-S'), dykes and weathered rocks (D). Less than 8.5 ppm is considered as very low eTh and is attributed to in-filled geologic materials such weathered materials or fluids that are not thorium-rich, while the yellowish color denotes the edges of the anomalous bodies. However, the high anomaly on eTh map compared with depleted of eU map in the southern parts is due to the resistive nature of thorium-rich bearing-minerals to weathering. Interestingly, eTh radiation observed in the study area clearly differentiates the lithology, regional lineament, and faults, as well as identifies the degree of weathering and areas rich in thorium bearing-minerals.

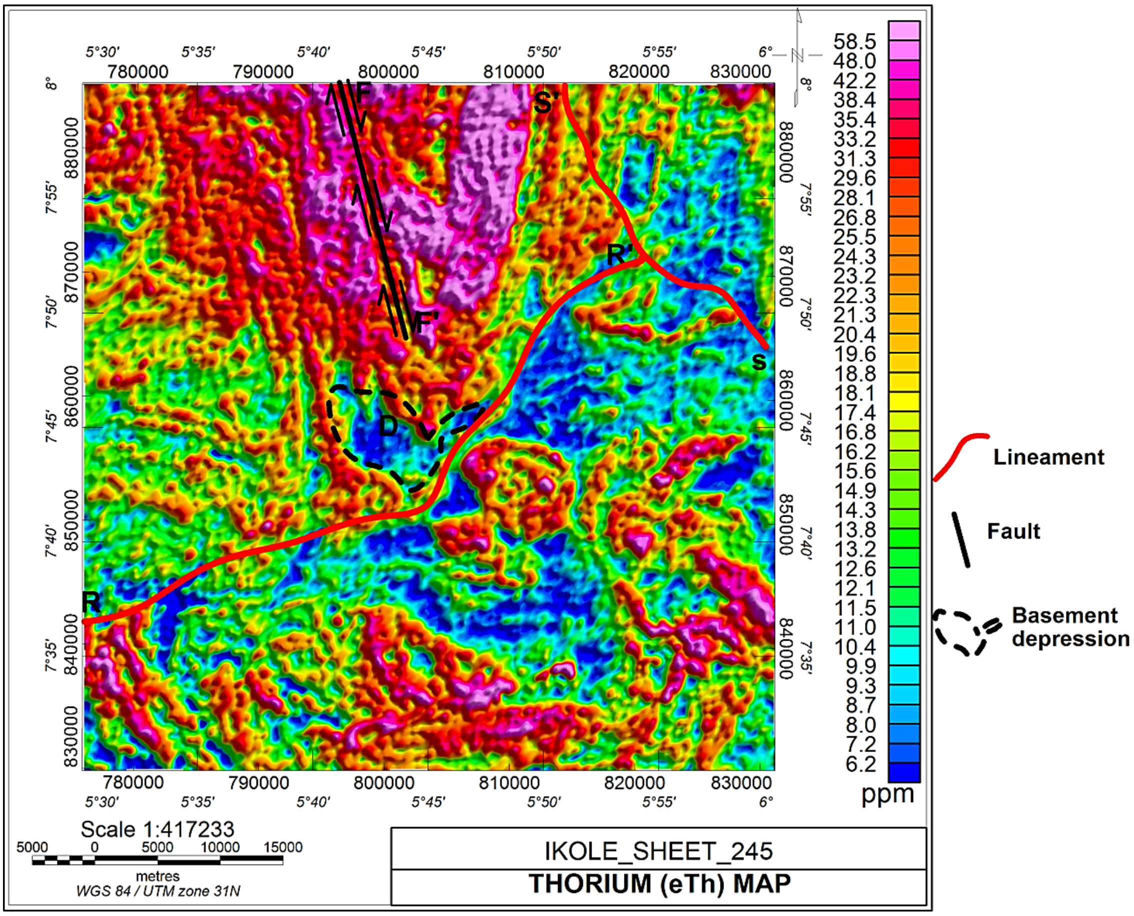


Figure 5. Thorium (eTh) Concentration Map

Figure 6 shows the potassium concentration map in weight percent (Wt. %), depicting high %K of about 2.0-4.0 % over a wide area in the northwestern section of the area. The southern and southeastern parts i.e. below the regional lineament evince varying %K concentration, but concentration increases and becomes more pronounced towards the southern end, the %K concentration also falls to as low as < 2.0 % within some parts of the central, western and eastern sections of the study area. The high % K concentration implies rocks that are highly rich potassium bearing-minerals such as feldspar and on the other hand shows that the rocks are less weathered, as well as with less structural deformities. Conversely, the low %K concentration usually indicates rocks with low potassium bearing-minerals, high weathering and intense metamorphism, which led to the patches/pockets of high concentration seen in most parts of the southern section of the area. The deep-seated fault (F-F') at the northern part (Ikole) has contributed immensely to the low %K concentration seen at the central section due to the accumulated soil and/or fluid of less rich potassium minerals within a likely depression (D) created by the hanging-wall of the fault. The map has also been able to reveal the strike directions of the rocks to be trending generally in NW-SE direction, but some of the rocks still trend NE-SW, NS, NNW-SSE, NNE-SSW and there are fewer rocks trending E-W directions.

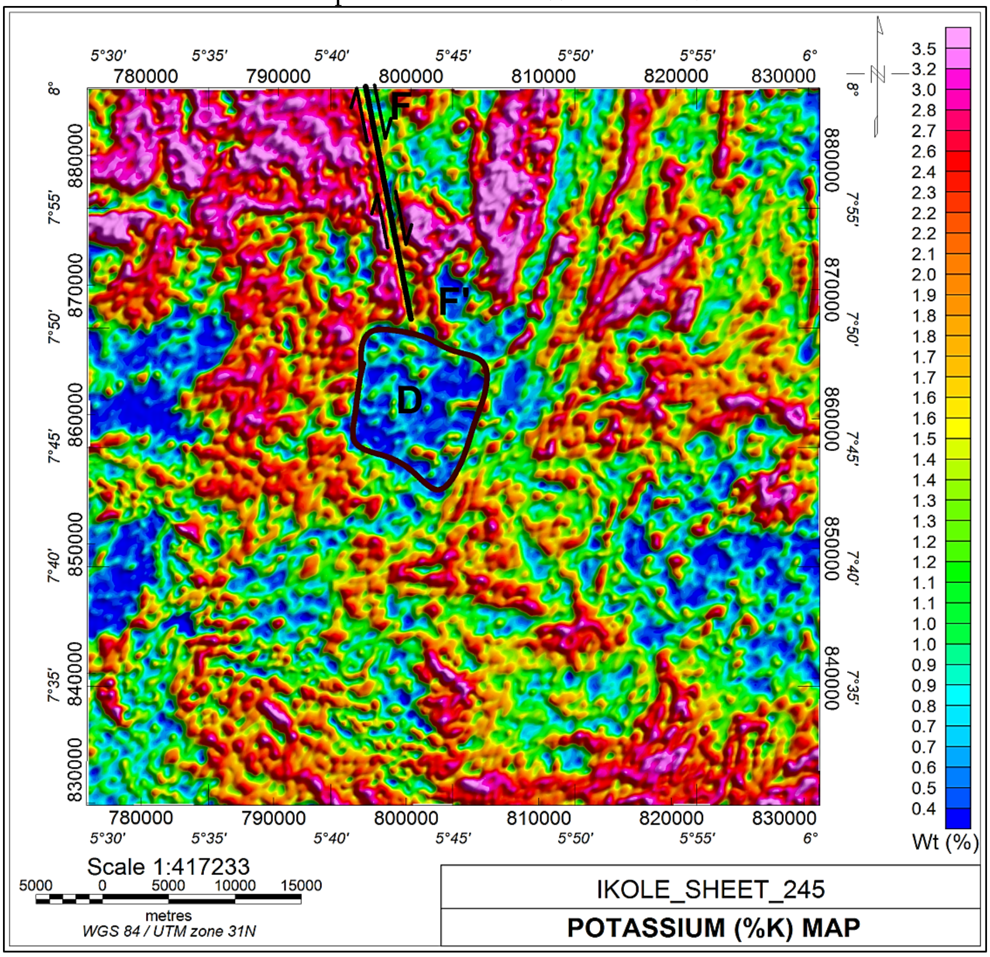


Figure 6. Potassium (%K) Concentration Map

The ground radiometric survey results were processed as further ground truths to ensure that the interpretations of the radioelements from the airborne survey are relatively actual, appropriate and robust. The ground survey provides the opportunity of having direct access and contact with the rocks during measurement than when equipment is few to hundreds of meters above ground level in the airborne survey. The results of the mean values of eU (ppm), eTh (ppm) and K (%) for the eight (8) traverses around Akoko Complexes of the study area were presented in profiles. These values were computed from the large data collected from the field. Figures 7-9 show the profiles for mean eU (ppm), eTh (ppm) and K (%) respectively from traverse (TR) 1-8, to give the clearer pictorial view of radioelements emitted by various rocks.

The profiles show highs and lows indicating the change in the amount of radioelement concentrations present in different rock types. The eU concentration profile (Figure 7) gently increases across traverse 1-2 from about 3 ppm; fall sharply at TR 3 as lowest; peaked back to the concentration of about 7 ppm at traverse 4, and reduces gently in traverse 8. Similar trends are seen on eTh concentration profile (Figure 8) with highs ranging from 22-30 ppm and lows between 14 and 22 ppm. TR 4 and TR 3 envisaged the highest and lowest concentrations respectively as seen in Figure 8. Figure 9 shows the %K concentration profile with highs ranging between 3.0 and 4.0 % (TR 1, 3 and 4) and lows ranging between 2.0 and 2.5 % (TR 2, 5, 6, 7 and 8). TR4 shows that the rock is crystalline, undeformed, rich in K-and-U-Th bearing minerals because of the observed high signatures for the three radioelements. Traverses 3, 5, 6, 7 and 8 depict varying geologic framework compositions, varying degree of metamorphism and weathering in the rocks. The variations in radioelements concentrations observed in granite-gneiss, charnockite, granite and grey-gneiss (i.e. TR 1-2, 3-4, 5-6, and 7-8 respectively) show that the concentrations of the three (3) radioelements are lower for granite-gneiss, granite, and grey-gneiss than charnockite. These imply that the charnockitic rocks tend to show K-and-U-Th bearing minerals enrichment because of the mineralogical composition and fewer deformities in framework crystal lattices. The slight low %K concentration in gneissic and granitic rocks is due to the increased level of biotite. Also, weathering and fracturing of the gneissic rocks have also contributed to the shortfall in the level of observed %K concentration and these variations have contributed to the dispersion of the observed radioelements concentrations.

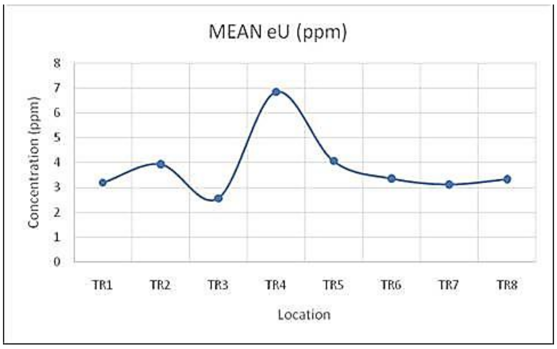


Figure 7. Ground eU concentration profile

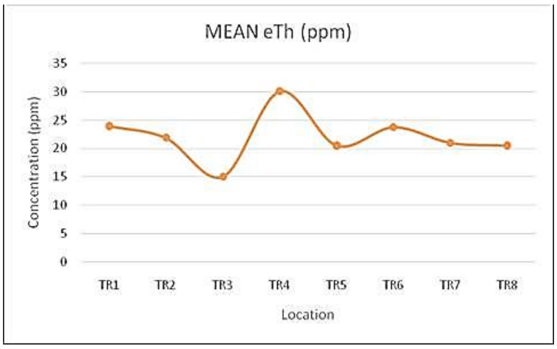


Figure 8. Ground eTh concentration profile

Therefore, from these analyzed airborne and ground radioelements results, it is evident that the rocks have undergone structural deformation that produced varying degrees of fracturing due to metamorphism and intrusions. These geological processes produced the observed varying radioelements concentrations within and around these structures and residues of the weathered rock materials, as well as those radioelements formed alongside the rocks or retained after the metamorphism and intrusions.

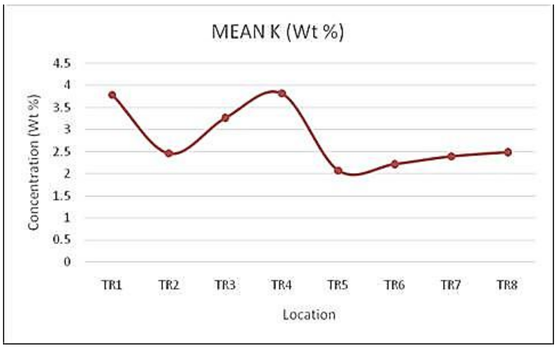


Figure 9. Ground %K concentration profile

5. Conclusions

This study has shown how robust and efficient radiometric method is in lithological and structural mapping, as well as radioelements (eU, eTh, and %K) differentiation and radiochemical mapping based on the interpretation of various concentration maps and profiles of varying compositions from one location to another. It is evident that the lineament is regional and trends diagonally from NE-SW and deep-seated fault trending NS caused by the high degree of metamorphism had restructured the geology of this study area. Also, the degree of metamorphism is highly pronounced in Akoko towards Kabba Complexes than in Ikole Complexes, resulting in high fracturing density and varying lineaments in the rocks. Besides, one could say that the Ikole axis comprises of rocks that are crystalline granitic rocks with less deformation.

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