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An Airborne Radiometric Survey for Lithological Identification of Part of South-Western Nigeria

***[1]Olufemi, S. Tanimola, [1]Ishola, S. Akinola, [1]Oyebolu O. Olalekan, [2]Akinlabi, I. Abiodun, [1]Sulaimon, R. Funmilola and [1]Adebisi, N. Olaonipekun**

[1]Department of Earth Sciences, Olabisi Onabanjo University Ago-Iwoye, P.M.B 2002, Ago-Iwoye, Ogun State, Nigeria
[2]Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

[*]Corresponding Author's Email: olufemi.sunday@oouagoiwoye.edu.ng

ABSTRACT
A gamma ray spectroscopy of an airborne radiometric survey was employed to measure the surface distribution of Potassium (%K), equivalent Uranium (eU) and equivalent Thorium (eTh)) in rocks underlying part of South-western Nigeria. The study aims at employing the alpha-α, beta-β and gamma-γ radiations that emanated from the decay of radioactive elements in the rock units beneath the area to achieve greater accuracy in facies delineation in order to unravel the possible variations in the concentration of naturally occurring radioelements, which is a function of primary geologic processes of mineralizing solution and metamorphic gradient. The data for the study area which lies within latitudes 7°00'N to 7°30'N and longitudes 3°00'E to 3°30'E of Abeokuta sheet 260 SE was obtained from Nigerian Geological Survey Agency (NGSA). The acquired datasets were processed by digitizing maps in numeric fonts which enabled the use of gridding technique by applying color images obtained from Minimum Curvature Grids (MCG). Enhanced composite images, ratio maps, %K, eTh and eU maps were consequently generated. The gridded maps were used to interpret the different rock types as inferred from high and low radiation anomalies with respect to the variation in geology at different locations within the study area. The results of this study defined concentration ranges of %K (-0.2 - 5.0 ppm), eU (0-12 ppm) and eTh (0-115 ppm). Based on the observed variation in the concentration of the three identified radioelements; the radiometric data revealed that the study area is underlain by six (6) major rock types namely, Felsic Volcanics, Gneissic rock, Ultramafic Volcanics, Intermediate Volcanics, Aplites and Pegmatites. The ternary map showed a high intensity of the three radioelements at the Northern part of the study area while the K/eTh ratio maps identified a high hydrothermal activity at the Southwestern part indicating a high potential of rock mineralization. By and large, the distinguishing characteristics of the radioelements in Abeokuta, sheet number 260SE are a promising tool in the search for solid mineral deposits in the study area.

Keywords:
Airborne radiometrics,
Concentration,
Rock types,
Hydrothermal alteration,
Mineralization,
Felsic Volcanics.

INTRODUCTION

Airborne geophysical survey has been a very useful tool used by earth scientists in interpreting the geology of inaccessible areas (Gun, 1975). The principle of aero-radiometric surveys is analogous to the radiometric survey carried out with a hand-held spectrometer but enables larger areas of the Earth's surface to be covered quickly for regional reconnaissance (Ohioma et al., 2017). Since the early days of balloon photography, the broad view of the Earth that the airborne geophysics perspective provides has been well recognized (Telford *et al.*, 1990).

Airborne gamma-ray spectrometry (radiometric) method measures the surface distribution of naturally occurring radioelements (uranium, potassium and thorium).The method is mostly used in areas that are deeply weathered and with thick overburden which usually makes rock delineation difficult. The use of radiation (alpha-α, beta-β and gamma-γ) emanating from the decay of radioactive elements in a rock unit is a way to achieve greater accuracy in facies delineation. They can also be used to estimate and identify regions of natural radiations which may pose potential hazards to the population (Adonu *et al.,* 2023).

Ground and airborne gamma ray surveys make calculations of radiations from natural environment possible. More efforts have been put into the study of natural radiations from the environment since the discovery of radioactivity. Radioactivity is the spontaneous decay of an unstable atomic nucleus usually accompanied by the emission of radiations and the release of energy. The origin of radioactive elements is linked directly with the crystallization of magma. They do not readily combine with silicate minerals in the melt; they are rather deposited by residual fluid of a magmatic upsurge (Jones, 2002). The radiometric method characterizes lithological unit changes due to variations in radioelements concentration between different rock units (Silva *et al.,* 2003; Wemegah *et al.*, 2015; Elkha-teeb and Abdellatif, 2018). Variation in concentration of radioelements is a function of primary geologic processes such as mineralizing solution and metamorphic gradients.

Radiometric surveys are used for geological, geochemical and environmental mapping which allows for the interpretation of regional features over large areas (IAEA, 1991 and 2003). Airborne radiometric data are acquired over a wide gamma energy spectrum and the spectral data are routinely processed to provide estimates of the naturally occurring abundances of the radiogenic materials; potassium, thorium and uranium which can be detected in the top 30 to 50 cm of the surface rocks depending on their responses to gamma ray (Telford *et al.,* 1990; Airo, 2015). The datasets also give accurate information about the properties of soil and its parent rocks, including surface texture, leaching, soil depth, moisture, and clay mineralogy (Bierwirth, 1997).

Gamma ray spectrometers are designed to measure the intensity and energies of gamma rays and hence the abundance of a particular radioactive nuclides. In a sense, the range of gamma ray energies emitted from the natural radionuclides is from 0 to 3 MeV, whereas in the geological survey, the concerned range is between 0.2 and 3 MeV. The highest point in the spectrum is characteristic of potassium (%K), thorium (eTh), and uranium (eU), whereas total count refers to the count rate of the whole spectrum.Potassium (K), an alkali element with simple chemistry is a major component of the Earth's crust (2.35%). The major hosts of potassium in rocks are potassic feldspar (Orthoclase and Microcline with 13%) and Micas (Biotite and Muscovite with 18%). Potassium (K-40) is released from its rock source as K-salts under the combined action of water, carbon dioxide and organic acids.

Thorium (Th) is a minor component of the earth's crust (~ 12ppm). Major Thorium bearing minerals such as Monazite and Zircon are stable during weathering and may accumulate in heavy mineral sand deposits. However, Thorium freed by the breakdown of minerals during weathering may be retained in Fe or Ti oxides/hydroxides and with clays.Uranium (U)on the other hand is a reactive metal with a low average abundance (3 ppm) in the earth's crust. Uranium may be present in rocks as the oxides and silicate minerals, uraninite and uronothorite may also be present as trace amounts in other minerals or along grain boundaries possibly as Uranium oxides or silicates (Kearey *et al.,* 2002; Milson, 2003).

Alteration zones are important as they are indicative of Potassium/Thorium (K/Th) and Uranium/Thorium (U/Th) variations (Airo, 2002). They are favourable zones for mineralization and should be sought for in exploration. Since potassium is normally added to host rocks by mineralizing hydrothermal solutions; it is therefore the most reliable pathfinder in airborne gamma ray surveys in locating hydrothermal ore deposits, especially gold deposits (Hoover and Pierce, 1990).

Basically, the composition and distribution of these radioactive elements vary in different geological environments including mineralized zones. Hence, the radiometric method aids in the location of mineral deposits using the differences in the composition of the three radioelements in relation with the ore and the hosting rocks. The method is also useful in the detection of near surface alteration associated with potassium enrichment or depletion in the hosting environment of deposition (Thomas *et al.,* 2000; Morgan, 2012).

The aim of this study is therefore tointerpret the airborne radiometric data acquired over Abeokuta sheet 260SE with a view to providing a better understanding of radioelements distribution pattern in geological map units by delineating the radioelement concentrations and hence identify the different rock types, as well as alteration zones in the study area.

Study Area

Location, Physiography and Geology of the study Area

The study area (Abeokuta and its environs) is located at the eastern part of Dahomey basin, southwestern Nigeria with latitudes 7^o 00'N to 7^o 30'N and longitudes 3^o 00'E to 3^o30E which corresponds to sheet 260 SE on the Sheet Index map of Nigeria (Ajibade and Fitches, 1988). The sheet covers an area of about 3025km square (55km × 55km) and lies in UTM Zone 31 North (Figure 1). The elevation of the area ranges from 100m to 400m above sea level and the relief of the area is generally low with the gradient in the North-South direction.

Abeokuta is the capital and prominent urban settlement of Ogun state. It is located on the east bank of River Ogun and covers a total area of about 879 square kilometers.

Ogun State is bounded in the west by Benin Republic, in the south by Lagos, in the north by Oyo and Osun, and in the east by Ondo State (Figure 1). River Ogun takes its source from Iganran hills at elevation of about 530m to 540m above mean sea level and flows directly southwards over a distance of about 480km, before it discharges into the Lagos Lagoon (Ajibade, 1979).

The study area lies within the southwestern Basement Complex of Nigeria whose rocks belong to the youngest of the three major provinces of the West Afrcan Craton (Ishola *et al.,* 2016). These rocks were rejuvenated during the Pan-African orogeny about six hundred million years ago. The basement complex rocks of Ogun State make up one-quarter of the surface area of the state while the sedimentary rocks aspect covers about three quarter of the surface area of the state (Figure 2). The topography of the area has an elevation ranging from 100 to 400m above sea level. The relief is generally low with the gradient in the north-south direction (Ishola *et al.,* 2016).

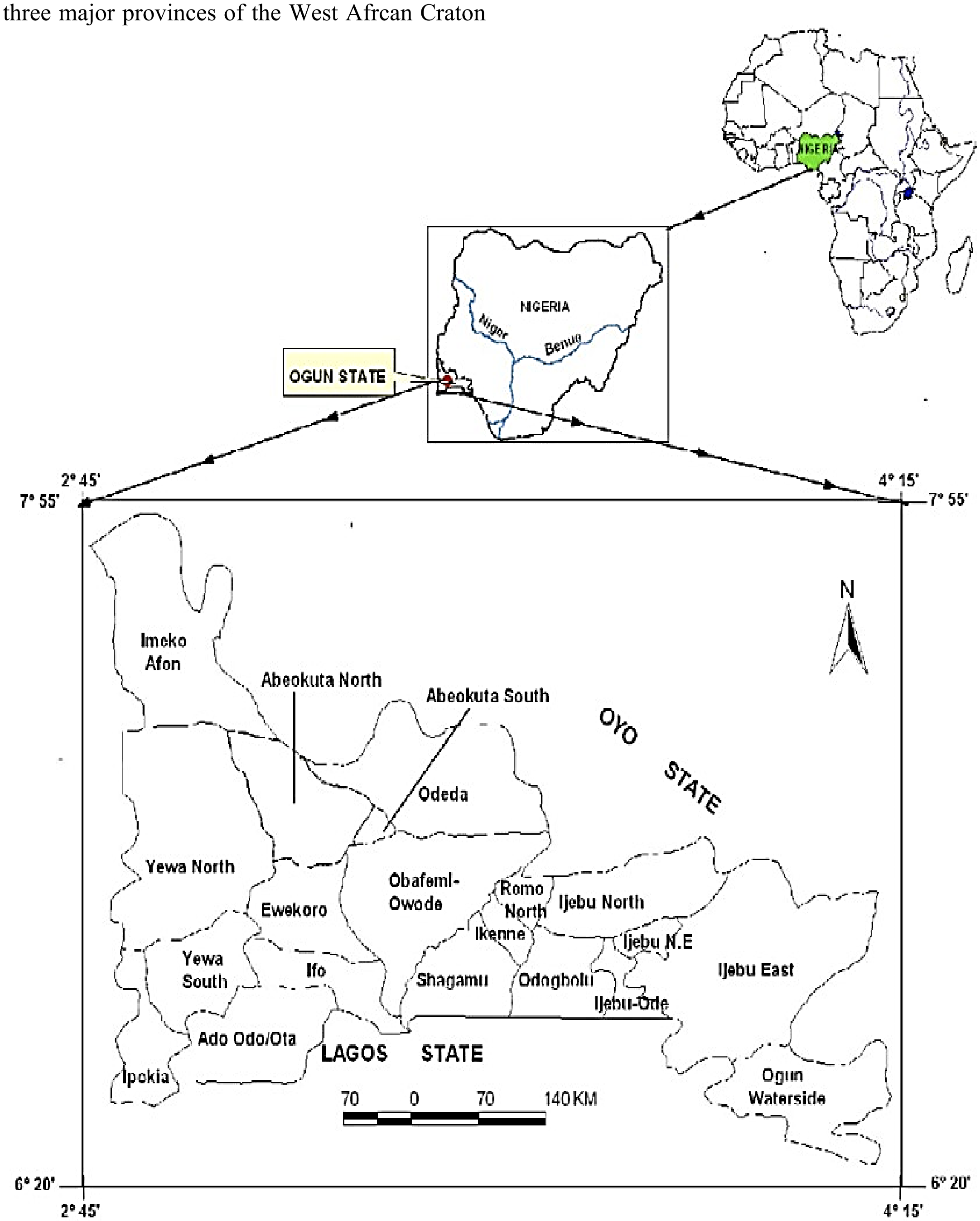

Figure 1: Location map of Abeokuta and its environs showing the major localities with intersected maps of Africa and Nigeria (Olurin *et al.,* 2016)

The older granites occur in and around Abeokuta, and they are Late Precambrian to early Proterozoic in age with magmatic origin (Rahaman, 1976). The most widespread rock group in the study areais Gneiss-migmatite complex dominantly comprising gneisses, with quartzites, calc-silicate rocks, biotite-hornblende schists and amphibolites (Edunjobi et al., 2021).

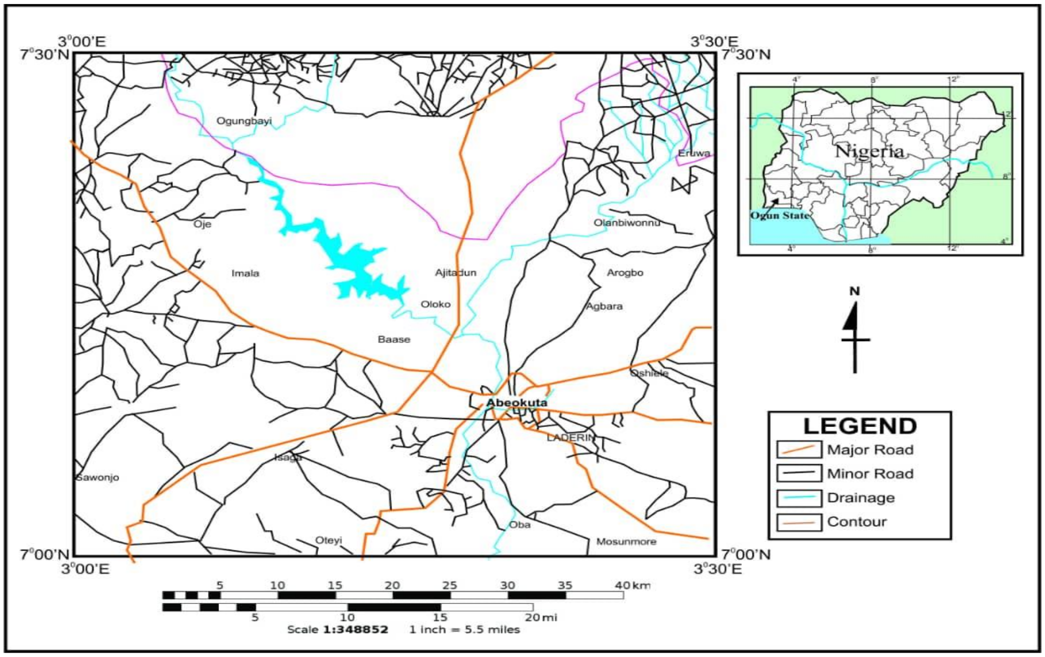

Figure 2: Location map of the study area (Oyebolu *et al.,* 2025a)

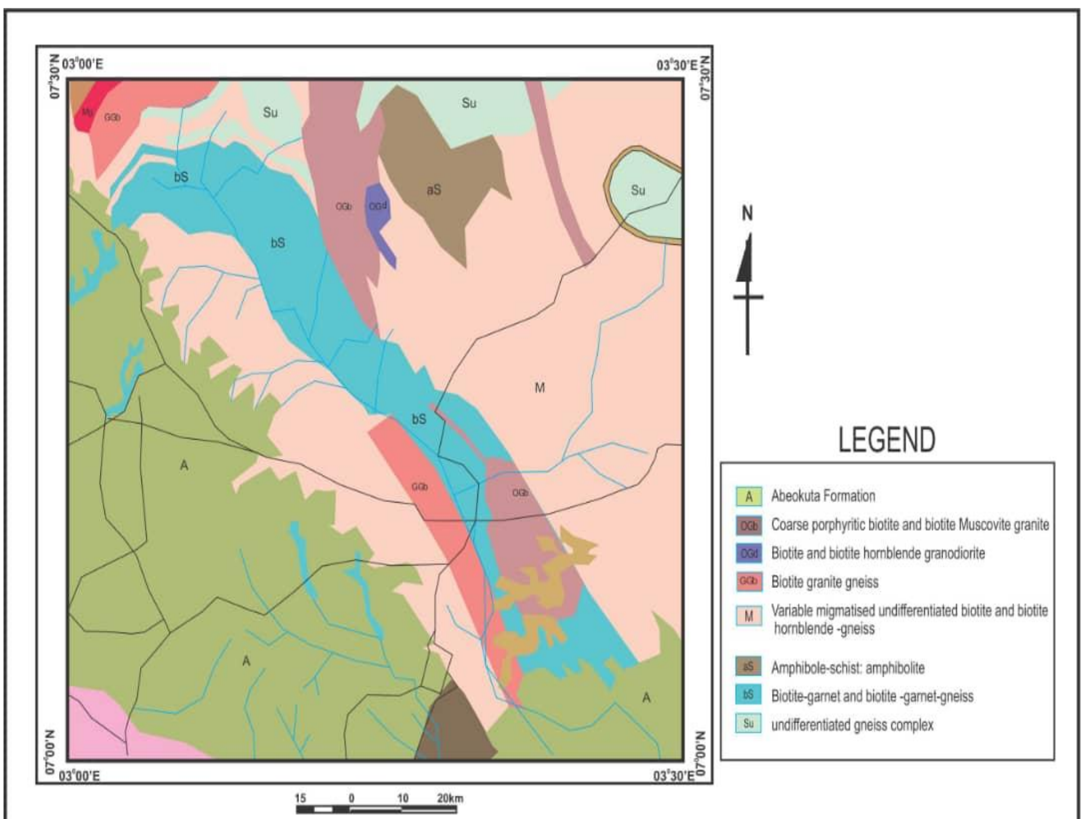

Figure 3: Geology Map of the Study Area (Oyebolu et al., 2025b)

MATERIALS AND METHODS

The dataset used for this study include radiometric data acquired by the Nigeria Geological Survey Agency (NGSA). Mapping of surface structures and lithological units are the functions of radiometric survey since different rock types (igneous, metamorphic and sedimentary) can be recognized based on distinctive signatures (Keary *et al.,* 2013). The airborne radiometric data acquired over Abeokuta, sheet number 260 contain potassium (K), equivalent thorium (eTh) and equivalent uranium (eU) concentrations. The data was obtained at an altitude of 80m with flight line separation of 500m along the southwest direction. The geomagnetic gradient was removed from the aeroradiometric data using International Geomagnetic Reference Field (IGRF).

The data generated were filtered adequately to eliminate background radiation due to cosmic rays and variations resulting from aircraft noise. They were processed by digitizing maps in numeric fonts which enabled the use of gridding technique by applying colour images obtained from Minimum Curvature Grids. This was done to avoid image color bias and enhance the signal to noise ratio. The apparent surface distribution of the radioelements were displayed as concentration maps (depicted as high –moderate-low) for eU, eTh, %K. The K/eTh ratio map was developed to delineate areas that were hydrothermally altered. An increase in %K and a decrease in eTh are indicators of altered zones in different ore deposits (Ostrovskiy, 1975; Lawal, 2020). A Ternary map (combined composite image) of the radioelement abundances (%K, eTh and eU) was then generated which enhanced thedelineation of the lithology (i.e the different rock types) and alteration zones associated with mineralization in the study area.

RESULTS AND DISCUSSION

Weathering modifies the distribution and concentrations of radioelements compared to the original bedrock (Wilford *et al.,* 1997). The characteristics of the gamma rays emitted at the from surface of the earth reflect the properties of the weathered materials and the bedrock mineralogy and geochemistry.

Potassium map (%K)

The Potassium map shows varying concentrations from -0.2 to 5.0 ppm (Figure 4). The Southern part is dominated by low %K concentration ranging from -0.2 to 1.53 ppm while moderate %K concentrations which is classified within 1.53 to 3.26 is observed extensively in the Northwest region. However, some are dispersed in the northeastern and southwestern part. The concentration became higher within a region in the northwest area with values ranging from 3.26 to 4.99 ppm. The very high potassium concentration values suggest porphyritic granite in the region (ICRU, 1994).

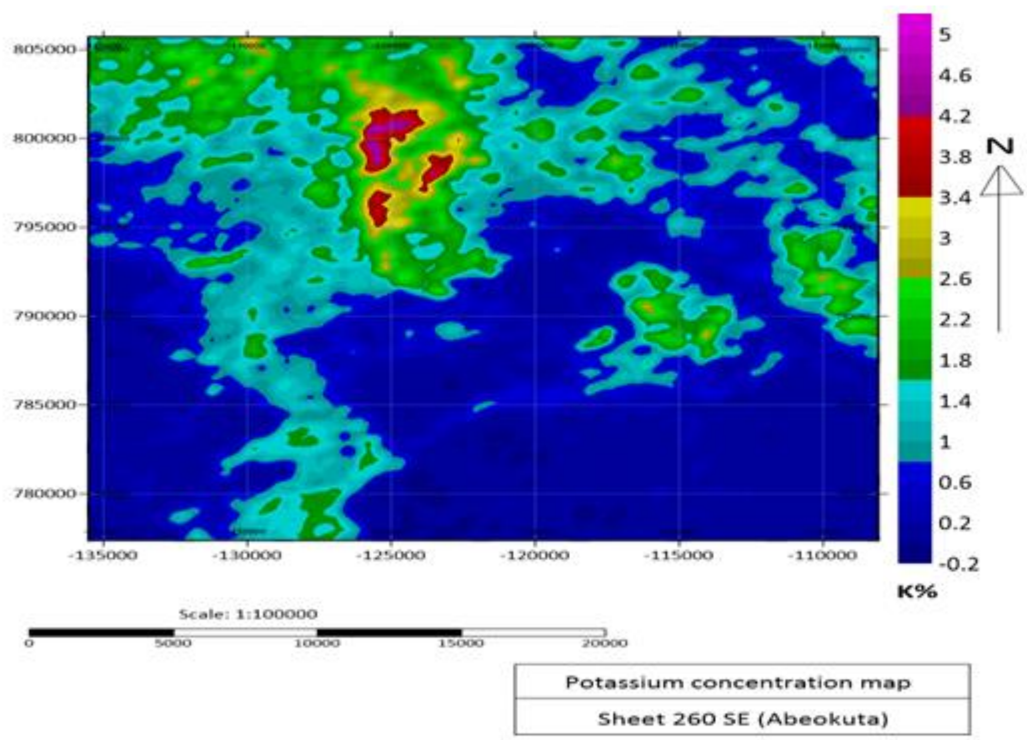

Figure 4: Potassium map of the study area

Thorium map (eTh)
The map of the equivalent concentration of Thorium (Figure 5) delineates the three levels of radioactivity, characteristic of the geological units in the study area. The southern part is extremely dominated by low eTh concentrations ranging from 0 ppm to 38.3 ppm displayed in black, blue and light blue color. Moderate concentration of Thorium is observed in the northeastern part displayed in green- yellow in color. It is classified within the range of 38.3 to 76.6 ppm (green-yellow) were observed in the northeastern part while eTh concentrations ranging from 76.6 ppm to 114.9 ppm (red-purple) were observed in the north-central of the area.

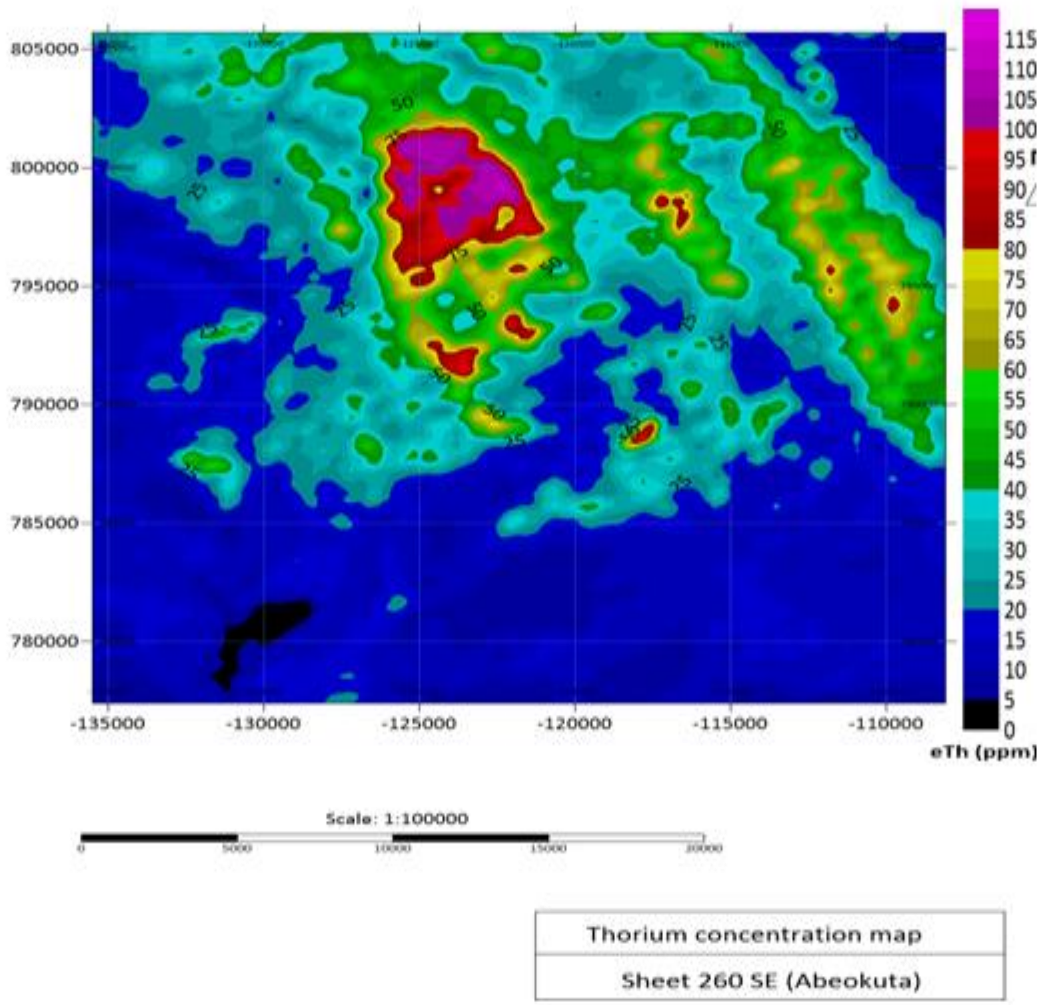

Figure 5: Thorium map of the study area

Uranium map (eU)
The northeastern region of the study area is characterized by moderate Uranium concentrations ranging from 4 ppm to 8 ppm, displayed in green-yellow color (Figure 6) while low concentrations in the range 0 ppm to 4 ppm (black, blue, and light blue) dominate the southern part and northwestern parts. Scatters of high eU concentrations ranging from 8 ppm to 12 ppm were observed at the central part of the northern region and southwestern part of the study area. The mean values derived from the statistical analysis of %K, eU and eTh, suggest that the rock types underlying the study area are Basic intrusives, Metamorphosed Igneous rocks, and Acid intrusives respectively (Killeen, 1979). Both the equivalent thorium (eTh) and equivalent uranium (eU) radioelement maps reveal strong concentrations of the radioelements in the central region of the study area.

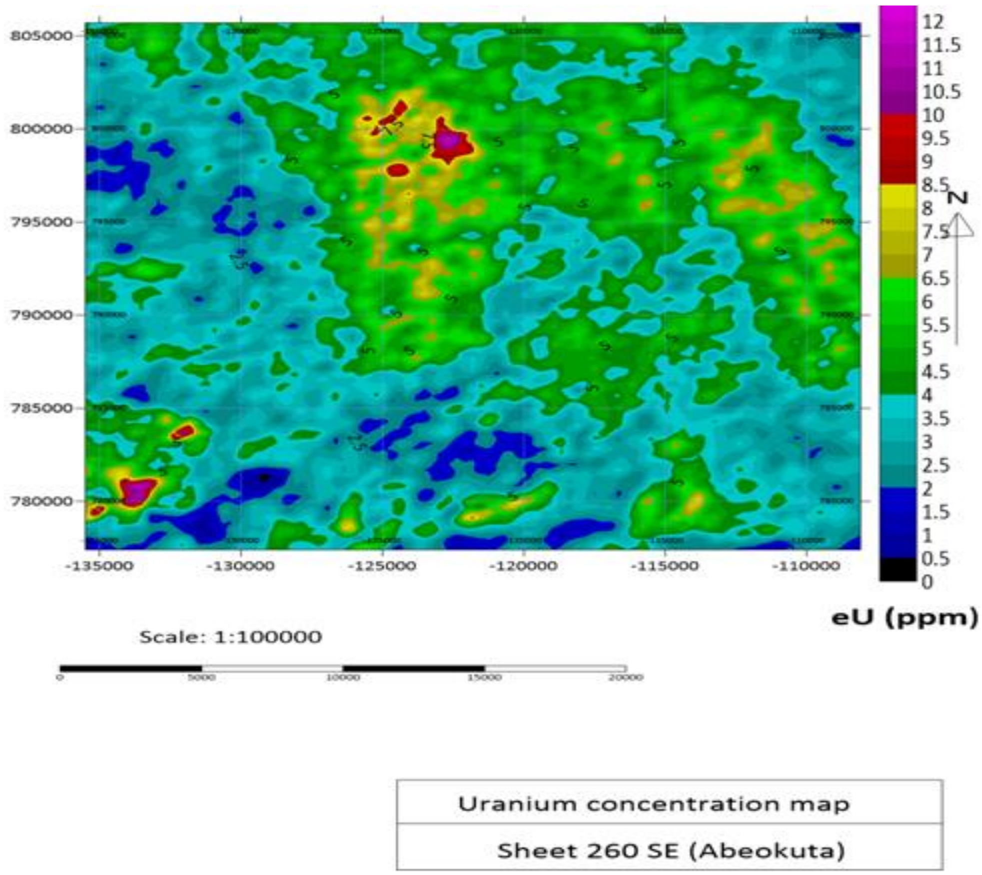

Figure 6: Uranium map of the study area

K/eTh Ratio Map

The K/eTh typically ranges from 0.17 to 0.2 % ppm for unaltered rocks (Hoover *et al.,* 1992). Zones which have K/eTh ratio values remarkably higher than these values are strong indicators of hydrothermal alteration characterized by K enrichment (Elkhateeb and Abdellatif, 2018; Tarshan, 2022). An increase in equivalent potassium and a decrease in equivalent thorium is an indication of altered zones in different ore deposits (Ostrovsky, 1975; Lawal, 2020). The ratio map shows locations with a high concentration of K and areas with a low eTh concentration. Areas of alteration are observed at the southwestern part of the study area with concentration ranging from 0.1 to 0.15 ppm, and this is interpreted as Felsic Igneous rock. The ratio between K and eTh for unaltered rocks varies from 0.17 to 2.0 ppm (Portnov, 1987; Lawal, 2020). Hence, the zones characterized by K-eTh ratio greater than 0.2 ppm values are the strong indicators of hydrothermal alterations. The K/eTh ratio map (Fig. 6), shows that the rocks of the study area are not hydrothermally altered since the K/eTh ratio values are higher than the stated range (Figure 7).

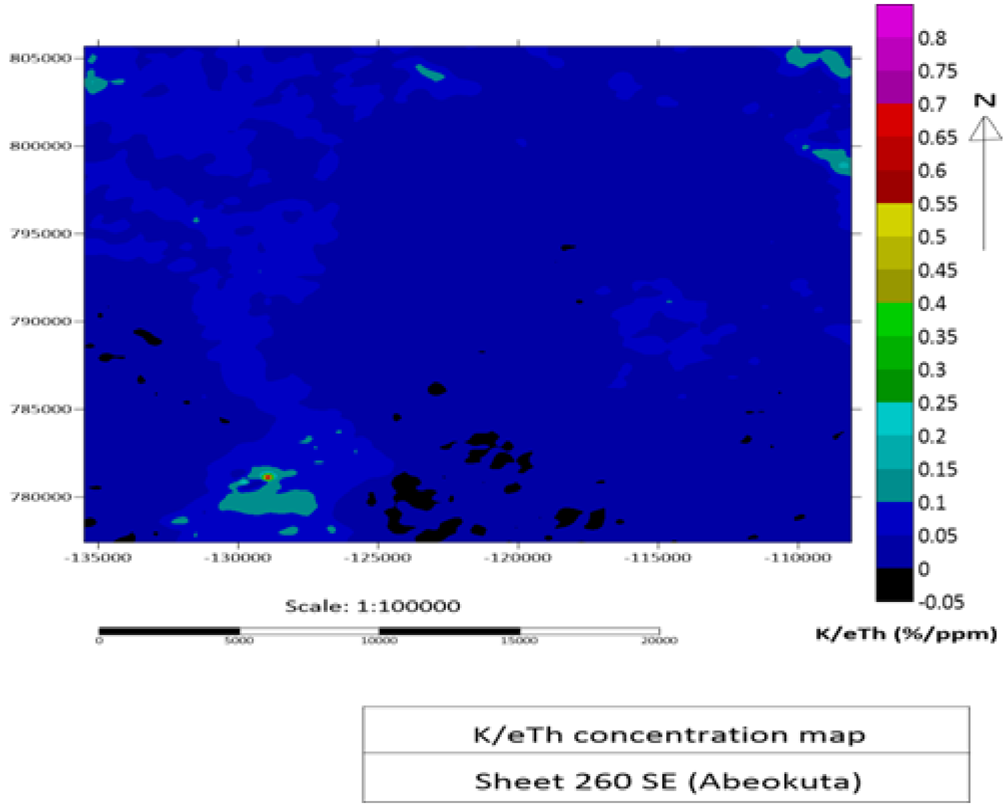

Figure 7: K/eTh ratio map of the study area

Ternary and Interpreted Lithological Units

The ternary image displays the concentrations of the three radioelements relative to one another and in relation to lithology. The study area falls within the basement complex, which is notable of a significant amount of radioelements. A strong intensity is observed at the northern part of the area (Figure 8).

Proposed Geologic Map of the Study Area

In this study, Table 1 reveals the summary of the deductions made based on the Potassium Concentration of the study Area, Table 2: reveals the summary of the deductions made based on the Thorium Concentration Grid of the Study Area while Table 3 reveals the summary of the deductions made based on the Uranium Concentration Grid of the Study Area. From the interpretation and analyses deduced from all the maps, the proposed geological map of the study area inferred from the airborne radiometric data is presented in Figure 9. Six different rock types were delineated comprising: Felsic Volcanics, Gneissic rock, Ultramafic Volcanics, Intermediate Volcanics, Aplites and Pegmatites. The Felsic Volcanics displayed high radiometric activity for Uranium; Gneissic rock is high in Pottassium radioactivity and moderate in Thorium.

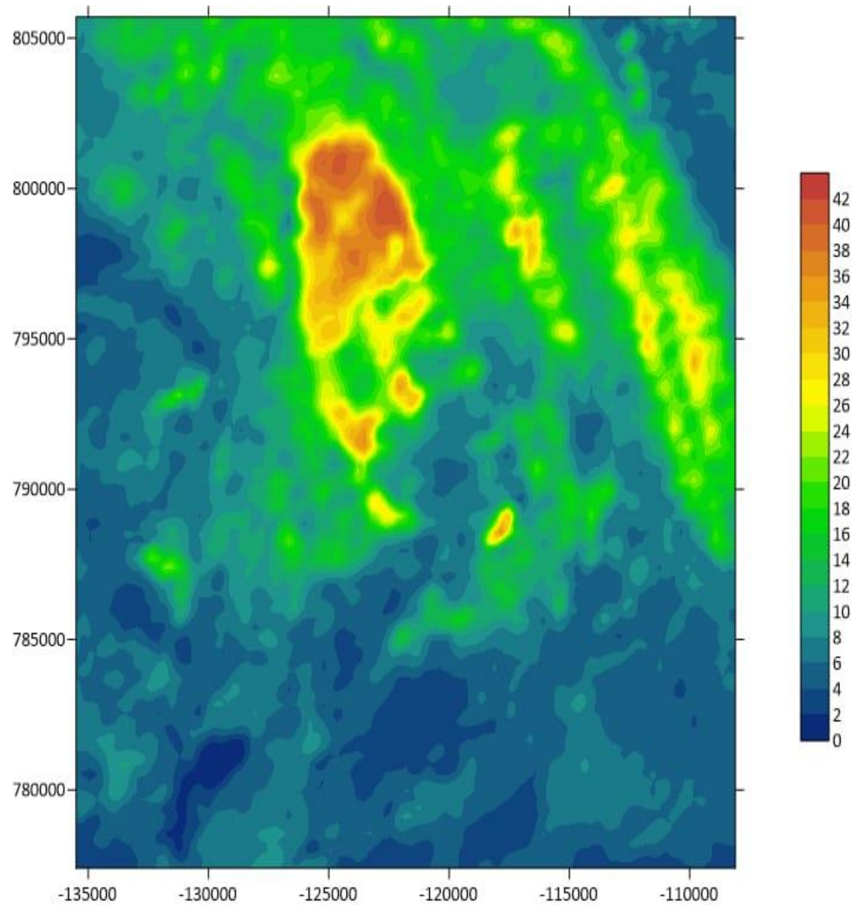

Figure 8: Ternary images of %K, eU and eTh in the study area

Table 1: Potassium Concentration and Lithological Implications of the Study Area

Region on Concentration Map	Concentration	Tentative Interpretation
H1	High	Gneissic rock
H2	Moderate to High	Felsic Volcanics
H3	Low	Ultramafic volcanic

Table 2: Thorium Concentration Grid and Lithological Implications of the Study Area

Region on Concentration Map	Concentration	Tentative Interpretation
V1	Intermediate	Gneissic rocks
V2	Low	Aplites
V3	Very low	Pegmatites

Table 3: Uranium Concentration Grid and Lithological Implications of the Study Area

Region on Concentration Map	Concentration	Tentative Interpretation
M1	High	Felsic Volcanics
M2	Low to moderate	Intermediate Volcanics
M3	Low	Gneissic rock

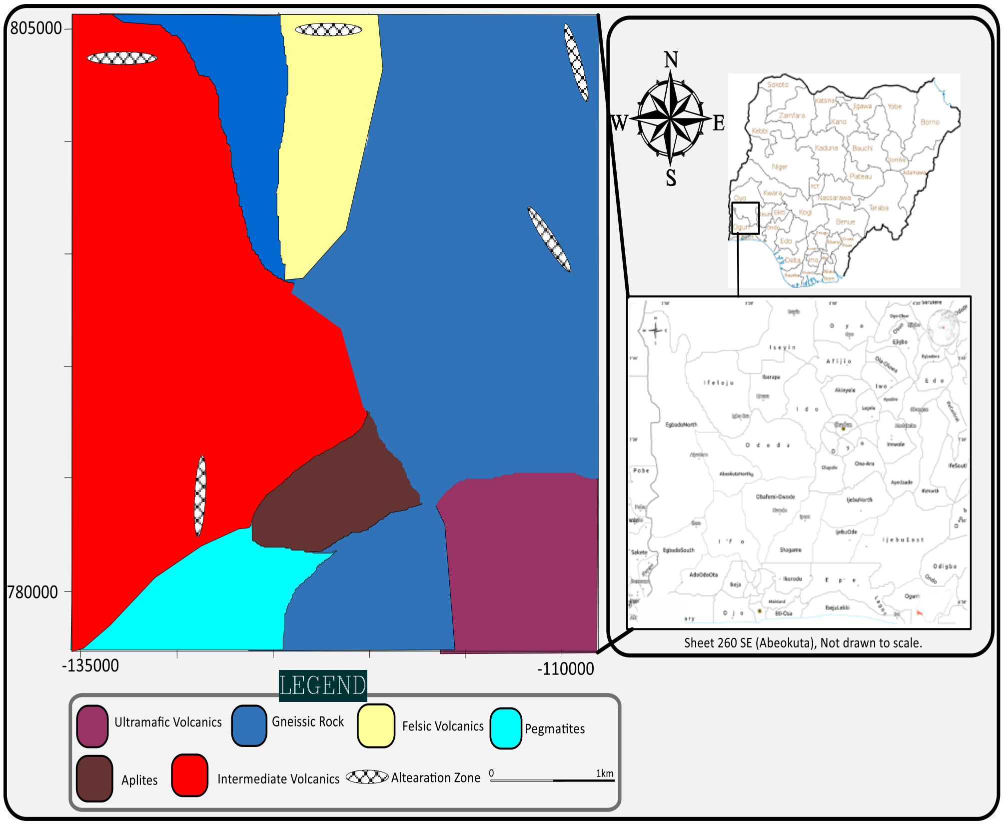

Figure 9: Proposed geological map of the study area

CONCLUSION

Radiometric signatures associated with different rock types were analyzed by interpreting the airborne radiometric datasets in order to identify the different lithological units, mineralization and hydrothermal alteration zones in the study area. Regions with high hydrothermal activities were identified using the K/eTh ratio map developed. Interesting alteration zones were observed at the southwestern part of the study area. The distinguishing characteristics of the radioelements enhanced the delineation of six major rock types namely Felsic Volcanics, Gneissic rock, Ultramafic Volcanics, Intermediate Volcanics, Aplites and Pegmatites, from the airborne radiometric data on Abeokuta Sheet No. 260 and reconstruction of the geologic map of the study area.

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