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Interpretation of airborne radiometric data of flamingo field, Southwestern Nigeria

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Abstract

The airborne radiometric data of the flamingo field, Southwest Nigeria has been analyzed and interpreted with the aim of evaluating the surface geology and structural features that are critical for mineral resource exploration. The objectives of the study are to delineate the alteration zones by correlating interpreted data with the lithological units, and to describe the relationship between the airborne radiometric anomalies and the subsurface structural trends. To achieve this, the data was subjected to rigorous qualitative and quantitative interpretation. Maximum and minimum concentration values for Total count (TC (Unit of radiation (Ur)) rate, Potassium (K), equivalent of Thorium (eTh) and that of Uranium (eU) were estimated. The results of the study show that the value of Ur, K, eTh %, and eU in flamingo field range from 2.408 to 41.017, 0.162 to 3.238 (%), 0.846 to 33.104 (ppm) and 0.169 to 7.232 (ppm), respectively. Locations of the associated anomalies which serve as alteration zones were obtained and values obtained from this expression clearly reveals that majority of the rock units for most of the radio elements in the area are below one hundred percent, while few others such as carbonaceous/slate phyllite, meta siltstone, undifferentiated schist and granite gneiss have values above 100%, especially for potassium and thorium elements. Also, the produced composite radioelements and image maps reveals bright some zones within the field which is a revelation of anomalous alteration zones. More so, the most prominent trend in the field correspond to the Northeast – Southwest and Northwest – Southeast directions which plays an important role in the structural framework of the study area.

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1. Introduction

Airborne radiometric survey is the survey used in the geological characterizations and enhancing radioelement patterns with individual rock units [1]. In specific term, Paoletti and Pinto [2] reported that the method can used to contribute to a better technical know-how of the sub-surface and surface geology, to describe the distribution of natural and human caused radiations, to recognize area disposed to high indoor radioactive element levels, to observe pollution in ground and wastewater arising from industries and waste sites and to investigate radioactive heat production (RHP) in crystalline basement rocks. The survey measures the distribution of naturally occurring ra-

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dioactive elements such as Potassium, equivalence Thorium, and equivalent Uranium. These elements vary measurably and significantly with lithologies [3].

In addition, Darenely and Ford [4] reported that among airborne geophysical techniques, Radiometric technique is the only method which provides information that can be interpreted directly in terms of the surface geological. But interpreting radiometric distribution for mapping near-surface and surface features assumes that different rock types are made up of certain amounts of rock forming minerals. These rocks forming minerals are based on the quantities of each radioactive elements [3]. Meanwhile, a lot of researchers have interpreted radiometric data for lithological variation, mineral exploration, dose rate evaluation etc. among them is Shives *et al*. [5] who used Radiometric data to detect potassic alteration zones in recognition of alteration relating to mineralization in part of Canada.

Paoletti and Pinto [2] identified certain features in Vesuvian volcanic area when they analyzed and interpreted magnetic and radiometric data which revealed new insight into the volcanological characteristics of the region. The radiometric data reveals that potassium and total count show good radiometric signatures of the most recent volcanic products in the area. Youssef and Elkhodary [1] interpreted Airborne gamma ray spectrometric data of Aswan city of Egypt. Their study revealed the presence of four relatively high uraniferous zones with structural lineament trending Northwest, Northeast and East-northeast. They also obtained dose rate which ranges from 0.57 to 1.3 mSvyr^{-1} and concluded that these dose rate remain safe in the area because it is less than the maximum permissible from the natural gamma radiation source.

Faruwa *et al*. [6] analyzed and interpreted Airborne radiometric data over Okitipupa Southwestern Nigeria. The study revealed that the average level of Natural background radiations is within what is generally considered not harmful. Adabanija *et al*. [7] investigated the background radiation level and radiogenic heat potential of crystalline basement rocks in Okene using gamma ray spectrometric data. Their results revealed radiogenic heat production which varies with lithology while background radiation annual dose equivalent was greater than the global average value of 60 nGy/h. Qassas *et al.* [8] interpreted (both qualitative and quantitative) airborne gamma-ray spectrometric data of Wadi Queih and Wadi Safaga in the central Desert of Egypt. They obtained radiometric composite maps which delineate the locations of high anomalous area that are indications of zones made up of Uranium. Lawal [9] integrated aeromagnetic and aero radiometric data in order to delineate lithologies and hydrothermal alteration zones in part of Southwestern Nigeria, In his work, he was able to outline the lineament structures and hydrothermal alteration zones that served as potential mineralized zones in the area. And recently, Akingboye [10] carried out an insitu gamma ray spectrometry over part of Akungba -Akoko area of Southwestern Nigeria. Their results show an average RHP value of 2.03 μWm^{-3}, absorbed dose rate of 87.98 nGyh^{-1} which is within the permissible range, although the annual gonad dose equivalent and excess life risk were above their permissible limits.

As of now, there are no sufficient information on the mineralization potential and alteration pattern of the flamingo field of the southwestern Nigeria. Therefore, analyzing and interpreting radiometric data from this area is critical in order to address the existing knowledge gap. This study aims to address the questions surrounding the mineralization potential, alternation zone and lithologic distribution in flamingo field using radiometric data. In addition to the above, airborne gamma radiometric data can be studied and analyzed to evaluate shallow potential mineral deposits and buried construction aggregates [11, 12] that are often found in close association with anomalous radiometric signatures. Consequently, this study is critical to the potential economic evaluation of the Flaming Field. flamingo field is used to describe an area in the southwestern Nigeria which cut across a part of Ekiti, Oyo, Osun, and Ogun States as shown in Figure 1.

The cities and communities covered by the field include Ejigbo, Ikirun, Otan-ile, Ibokun, Iwo, Ilesha, Olupon, Awgawfun. The area has a human population of over 1,000,000. The major occupations of the people are farming, fishing, and trading. Low-scale scattered mining activities are going on in the place. The operators of the mine site explore trial-and-error techniques and indiscriminate excavation of near surface soil and rocks to search for minerals such as tin, tantalite, columbite and some gemstones. Findings from this study will contribute to the successful mineral exploration and reduce environmental degradation in the area.

2. Geological settings of the study area

Geologically, flamingo field falls within Precambrian basement complex of Nigeria which has been described by many geologists including [9, 13–16]. This area essentially falls within the Migmatite Gneiss complex and the Schist belt. The lithological units in the area include migmatite, gneiss, schist, and quartzite which occupy about 60% of the landmass. The gneiss includes granite gneiss, banded gneiss, migmatite gneiss, and banded iron formation. The schist belt is generally localized to the south-western part of Nigeria is made up of Younger Metasediments found majorly in the central region of the area as shown on the geological map (Figure 1). In addition, the Ifewara fault system which is of the four important fault systems in Nigeria was found to have stretch through the study area. Studies have shown that this schist belt is generally associated with both metallic and non-metallic minerals.

3. Materials and method

3.1. Data acquisition

3.1.1. The topographical data

The Topographical data used to study this area is part of the high-resolution Shuttle Radar Topographical Mission (SRTM) acquired with a spatial resolution of 30 x 30 m. The data was obtained from the website of United State Geological Survey www.usgs.org. The elevation in this area ranges from 129. 2 to 944.3 m (Figure 1). The lowest values are represented by

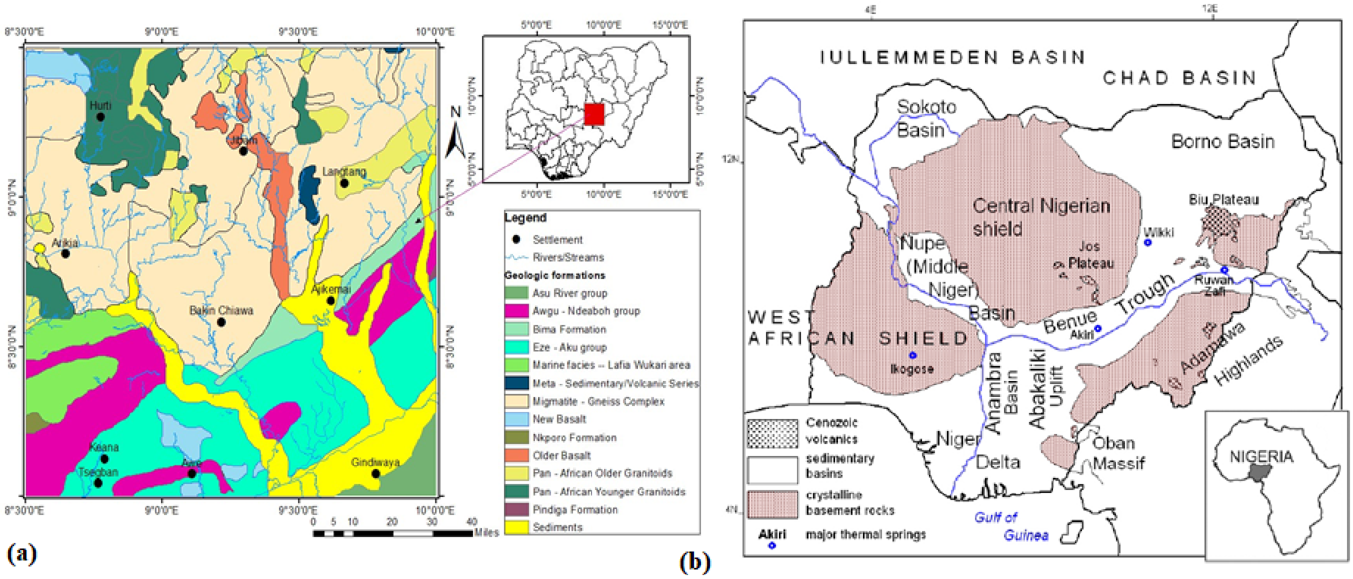

Figure 1. (a) Map of Nigeria showing the location of flamingo field [14], and (b) Geological map of the study regions digitized from [17].

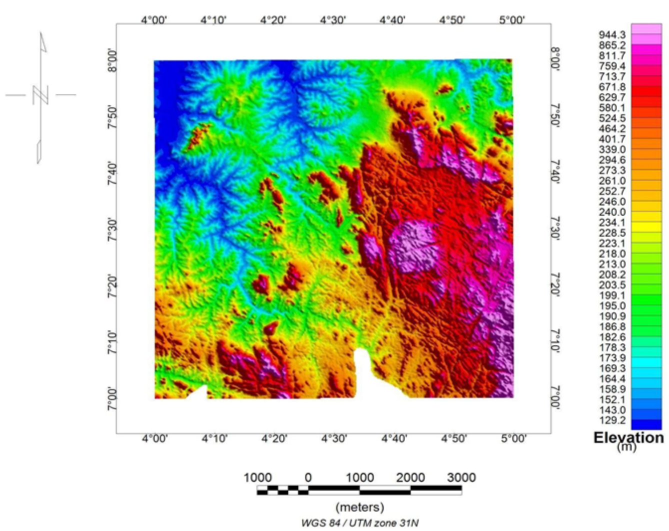

Figure 2. Elevation map of the area.

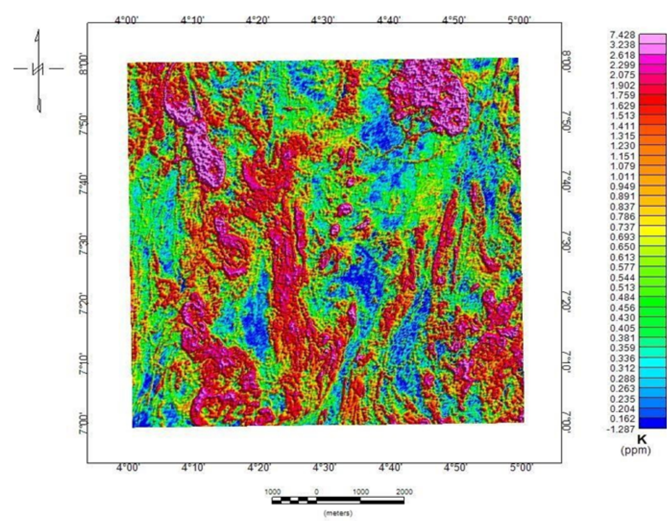

Figure 3. Map of Potassium contour plot (K%).

blue color in the Northwestern part while the highest value occupies the larger percentage of the area with a range of color from light green to magenta. The areas with higher values are hilly and consist of sandy clay, gravel, alluvial soil etc., while areas with lower values are gentle undulating and steep. The area is marked by two different climatic conditions namely the rainy season which lasts from February to November with an average temperature of 28 – 42 degrees Celsius. This range of temperature depends on the rainfall for a specific year.

3.2. Aero-radiometric data

Airborne radiometric data was obtained from the Nigerian Geological Survey Agency [17]. The data were acquired between 2004 and 2010 by NGSA via an aircraft flown at 80 m height and 500 m line spacing, 80 m mean terrain clearance [17]. The data acquisition was jointly financed by the Federal government of Nigeria and world bank as part of the sustainable development goal for mineral exploration program. This exercise was carried out by Fugro Airborne Surveys limited Johannesburg, South Africa. Corrections including background radiation resulting from aircraft and cosmic rays' contamination, variations caused by changes in the altitude of aircraft relative to the ground were performed on the data after the acquisition. Further corrections on the data include Compton scattered gamma rays in potassium and uranium energy window. In view of the above, the corrected Airborne Radiometric data provides an estimate of the apparent surface concentration of potassium (K) measured in (%), Thorium (Th) measured in ppm and Uranium with the unit measured in ppm.

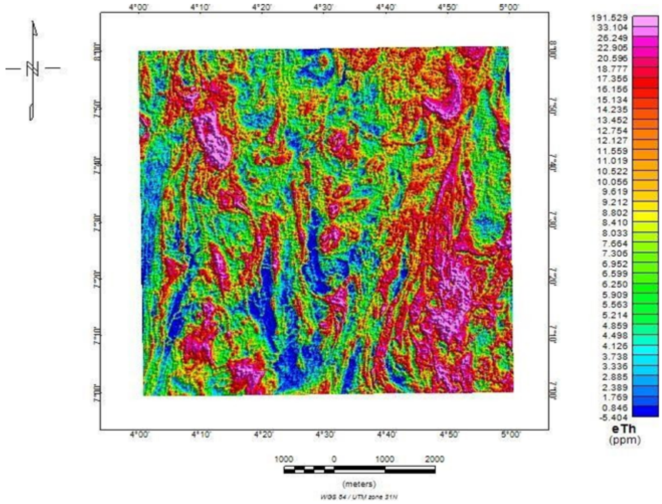

Figure 4. Map of equivalent Thorium contour plot (eTh ppm).

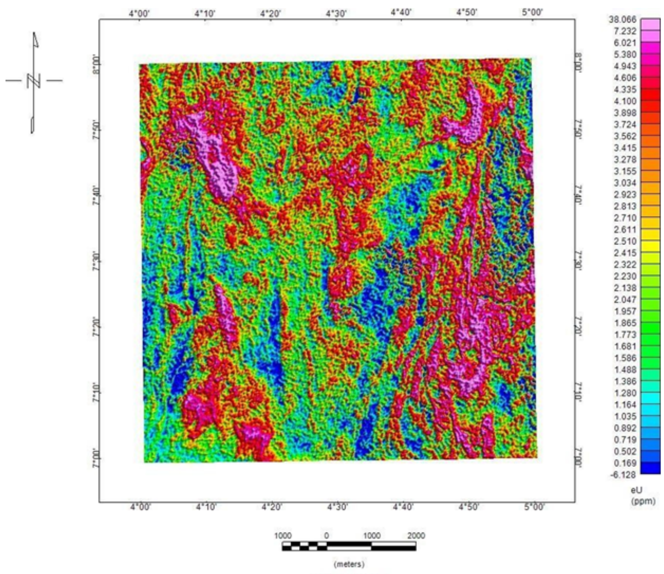

Figure 5. Map of equivalent Uranium contour plot (eU ppm).

3.3. *Data analysis and interpretation*

The corrected Airborne radiometric data were plotted and presented as contour maps using the Oasis Montaj (Geosoft inc. 2017). The same data were subjected to qualitative and quantitative interpretation. For qualitative interpretation, we obtained contour maps of the surface distribution of these elements that is the Potassium (K), equivalent Thorium (eTh ppm), equivalent Uranium (eU ppm) and lastly the Total-count (TC Ur). Also, the K/eTh, K/eU, eTh/K, eTh/eU, eU/K and eU/eTh ratios and the ternary image were obtained and interpreted. For the quantitative interpretation, statistical characteristics units were obtained in other to determine the minimum, maximum, arithmetic mean, standard deviation, and coefficient of variability which will be used to check the normality of each rock unit.

4. Results and discussion

The Radioelements (K%, eTh ppm, eU ppm) and Total Count Map (TCM (Ur)) (Figures 3 – 6) reveals the distributions of radiometric levels, their relationship with various rock units which reflects several geological features. The statistical summary of these data is shown in Table 1. Also observed on the maps are high and low radiometric values in different parts of the study area which shows that activity of the radioactive elements recorded varies from different types of rock compositions. More so, gradients are observed on the maps which are enough to describe lithological contacts from the changes in radiation level.

After a careful examination of the maps, three radiometric levels can be interpreted as follows: high level, intermediate level and low level. The high level (represented by pink color) has values ranging from 1.0 to 7.428 % for K, 10.6 to 181.628 ppm for eTh, 2.923 to 38.066 ppm eU and 13.200 to 214.617 Ur for TC. These values were found to be dominant in Northeast, Northwest, Southwest, North central and southeast respectively. The prominent structural trends in the area are along the Northeast – Southwest, Northwest – Southeast, East – west and South – west directions.

Although, Northwest – Southeast were found to be most predominant, and this can be attributed to the orientation of the mineral deposits present in the study area. The rocks associated with these radioelement values are younger granites, ring complex, metamorphic rocks, and schist felsite [1, 4].

Followed by the high level is the intermediate values (represented by green color) which range from 0.381 to 0.949 % for K, 4.862 to 10.066 ppm for eTh, 1.488 to 2.611 ppm for eU and 7.526 to 12.702 Ur for the TC. These values are found in the North – East, South – West, North – Central and parts of South – east. Rocks associated with these values are meta volcanics, metagabbro, meta sediments that include pebbly schist. These rocks are derivatives of older granites that are acidic in nature, and they trend majorly in North – South and North – east direction [6].

And lastly, the low-level values (represented by blue color), which ranges from – 1.287 to 0.357 for K, – 6.404 to 4.869 ppm for eTh, – 6.128 to 1.386 ppm for eU and – 7.127 to 7.086 Ur for TC. These values were found to be scattered across the study area with predominance in Southwest, Northwest and Northcentral parts of study region. Rocks associated with these area metavolcanics, ophiolitic metagabbro, metasediment, undifferentiated schists formation include phyllities which trend majorly in Northeast – Southeast and Northwest – Southeast direction [8].

5. Ratio maps of the radiometric elements

In other to further understand the variability of rocks in radiometric elements of the study area, ratio of radioelements and their composite maps of the obtained concentration of radio elemental nuclides were produced and discussed. The K/eTh ratio map shown in Figure 7 gives information about the spatial

Table 1. Statistical summary of the aero-radioelement data of parts of Southwest, Nigeria.

Variables	Minimum	Maximum	Range	Mean (X)	Standard deviation (S.D)	CV (%)
TC (Ur)	- 7.12656121	214.617375	221.7439362	14.6185012	11.5873457	79.2649365
K (%)	- 1.28667092	7.42842007	8.71509099	0.99258256	0.83631021	84.2559847
eTh (ppm)	- 5.40410948	191.529449	196.9335585	10.8451767	9.83152007	90.6533876
eU (ppm)	-6.1283617	38.0664101	44.1947718	2.77709791	1.88434187	67.8529145

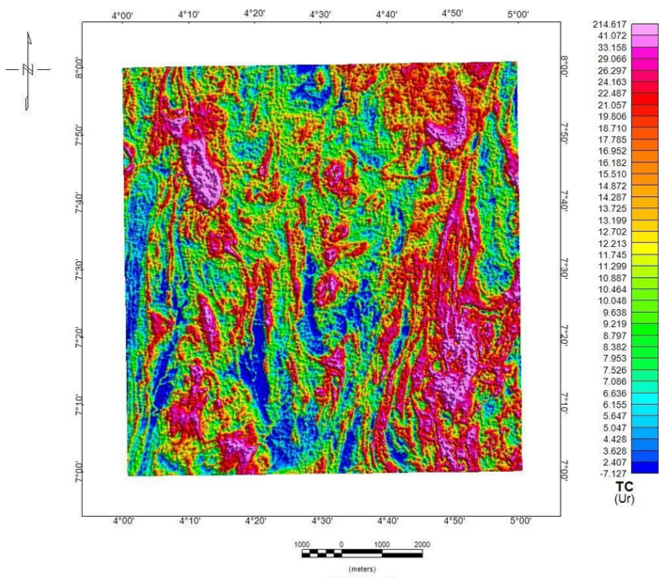

Figure 6. Map of Total count contour plot (TC (Ur)).

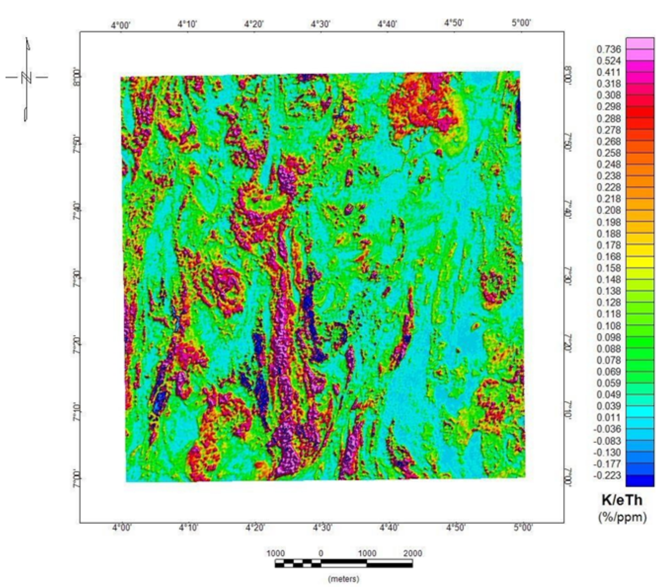

Figure 7. Map of ratio of Potassium/equivalent Thorium contour plot (K/Th (%/ppm)).

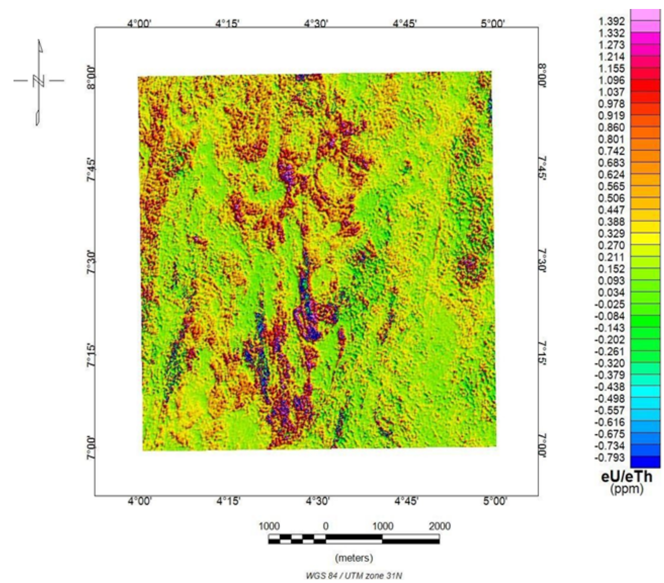

Figure 8. Map of ratio of equivalent Uranium/equivalent Thorium contour plot (eU/eTh (ppm)).

distribution of K – eTh concentrations resulting from the nature and degree of alterations many rocks in the study area have been subjected to. Lawal [9] reported that high % K and low concentration of eTh are associated with alterations in many minerals/ore deposits. Therefore, area associated with high % of K and low concentration of eTh are shown in color red to pink with values ranging from < 0.208 to > 0.736 %/ppm. These values are regarded as strong indicators of mineral deposits. These indicators are found in parts of Northeast, Northwest, Southwest and prominent in the Northcentral region of the study area. Rocks associated with these values are younger granites, ring complex, metamorphic rocks, and schist felsities. On the other hand, areas associated with low % in K and high concentration of eTh are shown in blue color with values ranging from < – 0.223 to > 0.049%/ppm. These values are regarded as low indicator and are prominent in the Southwest and Northcentral region of the study area. They trend majorly in the North south direction. Rocks associated with these values are metasediments, meta gabbro, and undifferentiated schist. The eU/eTh ratio map shown in Figure 8 reveals high concentration of eU and low concentration of eTh shown in pink and green colours respectively with values ranging from < 0.278 to

> 1.578 ppm. These values are found in the Northwest, North central and Southwest and they trend Northwest – Southeast and North – East direction. These values depict the mobility and leachability of Uranium over Thorium [8]. Rocks found in these regions are granite gneisses, biotite, granite, and younger granite ring complex.

On the other hand, the areas associated eU and high eTh concentration are shown in blue color with their values ranging from < – 0.793 to > 0.329 ppm. These values are prominent in the North central, Southeast, Northeast and part of Northwest, and they also trend majorly in the North south direction. Rocks associated with this area include Pegmatites, Dolerite, fine grained biotite, and they are regarded as areas of depletion due to high concentration of eTh [10]. Meanwhile, Akingboye *et al.* [10] reported that when values of eU/eTh concentration are higher than 0.26 ppm, it suggests abundance of eTh than eU in the rocks present in the crust. This can be explained in terms of the stability of eTh concentration over eU content [8].

The results presented in Figure 9 is the map of eU/K which describes Uranium enrichment in rocks in the area. The spatial values of eU/K range from < – 2.399 (in blue color) to > 18.583 ppm/% (pink color). The high values which range from 4.869 to > 18.583 ppm/% is delineated as the area viable for uranium enrichment. This enrichment is prominent in the Northeast, Southeast, Southwest parts of the flamingo field trending in Northeast – Southwest. The lithologies associated with this area are meta gabbro and meta volcanics. The area with low values of eU/K (blue color) are found in parts of Northeast, Southeast, North central and Southwest parts of flamingo field. In addition, the eTh/K map shown in Figure 10 revealed similar characteristics, pattern, and structural features to the eU/K map shown in Figure 9, and shows three pattern of eTh/K ratios. (i) High level ratio which has values ranging from 17.076 to > 72. 678 ppm/% and represented by pink colour. The rocks associated with this pattern are the younger granites, ring complex, metamorphic rocks, and schist felsities. (ii) Moderate level pattern which has values ranging from 5.756 to 17.076 ppm/% and (iii) lastly, the low-level pattern which has values ranging from < – 15.358 to 5.756 ppm/% (blue color). The rocks associated with these values include metasediments, meta gabbro, undifferentiated schist [8].

5.1. Ternary map

In this section, two ternary composite maps were obtained. They are three radio element composite map (i.e., K, eTh and eU) (Figure 11) and the uranium composite map (i.e eU, eU/k and eU/eTh) (Figure 12). Figure 11 was obtained by mixing the three colors in equal proportions using red for K, green for eTh and blue for eU and colors such as white, red, black, blue and green were found on the map. These colors are sparsely correlated with the geological unit. White color found in the Northwest, Northeast, North central and southwest region of the study area are high concentrated region is characterize by strong radio element responses. Younger granites are the most dominant rocks in the region. The black colors found in parts of Northwest, Northeast, North central and Southwest are low

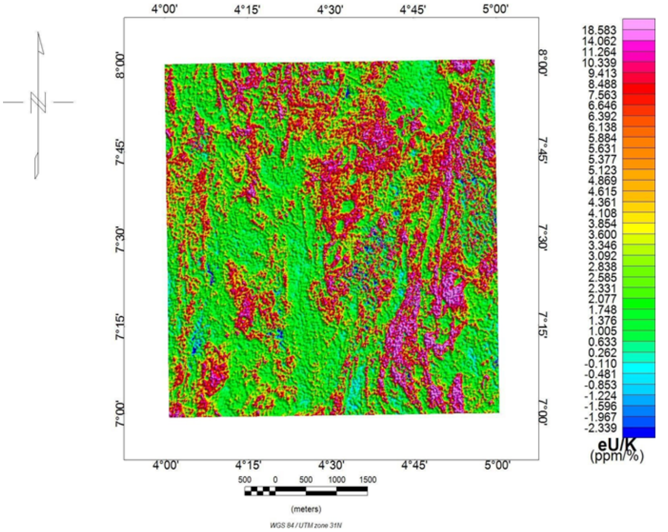

Figure 9. Map of ratio of equivalent Uranium/Potassium contour plot (eU/K (%/ppm)).

concentrated regions characterized by weak radio element responses. Meta volcanic, meta gabbro rocks are prevalent in this part of the area. Other colors include red which shows high % content of K with low eTh and eU, green color which shows high content of eTh with low in % of K and eU and lastly, blue color which shows high concentration of eU with low in % of K and eTh respectively. The map has been used extensively in the distribution of surface radioelements, for rocks contact mapping and identification of widespread lithological contrast which have been found to be useful for mineral exploration in several research work [1, 8, 10]. On the other hand, Figure 12 present a combination of eU in red color, eU/eTh in green and eU/K in blue. The map gives information about the delineation of enrichment zones for eU concentration. The bright-white color on the map reveals anomalous zone of uranium concentration which is an indication of high level of the ratios of eU/eTh and eU/K at that region. The map also reveals that Uranium migration occurred in these segments of the study area. low concentration of Uranium as shown in black/dark color is a representation of meta sediments, meta volcanics etc.

5.2. Quantitative interpretation

The interpretation is based on statistical analysis applied to the aero radiometric data of parts of Southwest Nigeria. The applied statistical parameters include Minimum, Maximum, Range, mean, standard deviation and coefficient of variation (in percentages) [1, 8] which is used to check if rocks in the area exhibit normal distributions or not. The expression for the coefficient of variation is given in equation (1) as:

$$CV\% = (SD/X) \times 100. \quad (1)$$

The result of this analysis is revealed in Table 2.

Table 2. Statistical summary of the aero-radioelement data treatment for various rock units of parts of southwest, Nigeria.

Rock Unit	Statistical Values	K (%)	eTh (ppm)	eU (ppm)	TC (Ur)
Coarse Granite Biotite (Ogm) (1145)	Min	0.1	-0.01	-0.4	1.5
	Max	5	34.3	7	42.9
	Mean (X)	0.9	8.3	2.6	11.9
	Standard Deviation (SD)	0.6	5.6	1.1	6.4
	CV (%)	66.7	67.4	42.3	53.7
Coarse homblende Granite (OGh) (575)	Min	-0.01	2.7	-0.2	3.7
	Max	3.5	63.8	11.8	75.2
	Mean (X)	1.2	20.1	3.8	25
	Standard Deviation (SD)	0.8	12.7	2	14.5
	CV (%)	66.7	63.1	52.6	58
Fine Grained biotite (Ogf) (837)	Min	-0.01	-1.1	-0.9	0.2
	Max	2.8	38.2	7.7	43.5
	Mean (X)	0.8	9.6	2.3	12.3
	Standard Deviation (SD)	0.6	7.4	1.5	8.3
	CV (%)	75	77	65.2	67.4
Undifferentiated Schict (Su) (1291)	Min	0.1	-0.2	-0.9	0.3
	Max	6.1	47.9	11	58.1
	Mean (X)	1.1	9.5	3.2	13.8
	Standard Deviation (SD)	1.3	7.2	2.1	9.8
	CV (%)	118.2	75.7	65.6	71
Carbonatceous/Slate Phylite and Meta Siltstone (Sp) (1411)	Min	0	-0.7	0	0.2
	Max	5.2	74.3	12.9	90.4
	Mean (X)	0.9	9.8	2.7	13.5
	Standard Deviation (SD)	0.9	11	1.7	13.2
	CV (%)	100	112.2	62.9	97.8

5.3. Pan – African older granite series

The Pan – African older granite has highest number of rock units in the area. The rock units include Pegmatite, Dolerite, Biotite granodiorite, medium to Coarse – grained biotite granite, Coarse homblende granite, fine grained biotite, and Coarse granite biotite. All the units in these series have values of coefficient of variability to be lower than one hundred percent (100%) for all parameters of radiometric data considered. The fine-grained biotite has the highest value of coefficient of variability with values 75, 77, 65.2 and 67.4 for K, eTh, eU and TC, respectively. This shows that the rock unit have the lowest degree of homogeneity. On the other hand, the Biotite granodiorite has the lowest values of coefficient of variability with values of 55.6, 68.3, 48.0 & 51 for K, eTh, eU and TC, respectively. It shows that the rock units have the highest degree of homogeneity.

5.4. Meta – sediments/Meta – volcanic series

The rock units in this series include Band iron formation, Schist, Amphibole schist and carbonaceous/shale phylide and

Table 3. Statistical summary of the aero-radioelement data treatment for various rock units of parts of southwest, Nigeria.

Amphibole Schist (Sa) (1332)	Min	0.1	-1.8	-0.6	-1
	Max	3.5	31.3	6.5	37.7
	Mean (X)	0.9	6.7	2.1	9.7
	Standard Deviation (SD)	0.7	6	1.4	7.4
	CV (%)	77.8	89.5	66.7	76.2
Mylonites (aMy) (944)	Min	0	-1.9	-0.9	-2.4
	Max	3.2	27.3	5.7	35
	Mean (X)	0.8	6.6	2.2	9.6
	Standard Deviation (SD)	0.7	5.3	1.3	6.7
	CV (%)	87.5	80.3	59.1	69.8
Band gneiss (bG) (425)	Min	-0.001	-0.3	-2	1.3
	Max	3.2	32.3	7.4	40
	Mean (X)	1.2	11.8	2.5	15.5
	Standard Deviation (SD)	0.6	7.1	1.5	7.9
	CV (%)	50	60.1	60	51
Granite gneiss (GG) (334)	Min	-0.01	2.1	0.6	3.6
	Max	4.6	29.7	9.9	40.9
	Mean (X)	1.1	16.7	4.1	21.9
	Standard Deviation (SD)	1.1	5.6	1.9	7.8
	CV (%)	100	33.5	46.3	35.6
Granulite and gneiss (Ge)	Min	0.01	2	-0.7	2.1
	Max	3.5	31.5	7.5	38.7
	Mean (X)	1	13.3	3.3	17.6
	Standard Deviation (SD)	0.7	5.9	1.7	7.5
	CV (%)	70	44.4	52	43
Banded Iron Formation (Bif) (402)	Min	0.1	1	-0.4	2.3
	Max	4.6	34.2	9.5	46.2
	Mean (X)	1.2	10.7	3.4	15.2
	Standard Deviation (SD)	1.1	6.9	1.9	9.2
	CV (%)	92	64.4	55.8	60.5
Biotite granite (Ogf) (837)	Min	-0.01	-1.1	-0.9	0.2
	Max	2.8	38.2	7.7	43.5
	Mean (X)	0.8	9.6	2.3	12.8
	Standard Deviation (SD)	0.6	7.4	1.5	8.3
	CV (%)	75	77.1	65.2	64.8
Coarse homblende granite (Ogh) (575)	Min	-0.01	2.7	-0.2	3.7
	Max	3.5	63.8	11.8	75.2
	Mean (X)	1.2	20.1	3.8	25
	Standard Deviation (SD)	0.8	12.7	2	14.5
	CV (%)	66.7	63.1	53	58

Medium to Coarse granite biotite (Ogm) (1145)	Min	0.1	-0.01	-0.4	1.5
	Max	5	34.3	7	42.9
	Mean (X)	0.9	8.3	2.6	11.9
	Standard Deviation (SD)	0.6	5.6	1.1	6.4
	CV (%)	66.7	67.4	42.3	53.7
Bioite homblende gneiss (Bgh) (1390)	Min	-0.01	0.4	-1.1	0.1
	Max	2.6	45.5	9.5	52.7
	Mean (X)	0.8	12.9	2.9	16.5
	Standard Deviation (SD)	0.5	9	1.8	10.3
	CV (%)	62.5	69.8	62.1	62.4
Pegmatite (P) (922)	Min	-0.01	-3.8	-1.4	-4.6
	Max	3.1	21.1	5.3	25.1
	Mean (X)	0.9	5.5	1.8	8.1
	Standard Deviation (SD)	0.6	3.7	1.2	4.8
	CV (%)	66.7	67.2	66.7	59.2
Dolerite (D) (948)	Min	0.1	0.9	0.6	3.5
	Max	4.1	74.1	12.7	90.5
	Mean (X)	1	11.6	3.4	16.2
	Standard Deviation (SD)	0.7	8.8	2	10.9
	CV (%)	70	75.9	58.8	67.2
Biotite granodiorite (Ogd) (458)	Min	0.2	-0.2	-0.8	1.4
	Max	2.2	25.6	5.6	31.2
	Mean (X)	0.9	6.3	2.5	9.6
	Standard Deviation (SD)	0.5	4.3	1.2	4.9
	CV (%)	55.6	68.3	48	51

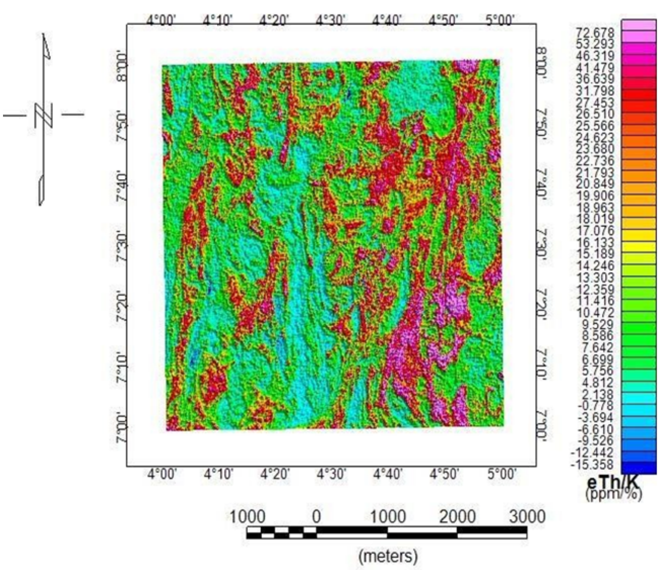

Figure 10. Map of ratio of equivalent Thorium/Potassium contour plot (eTh/K (%/ppm)).

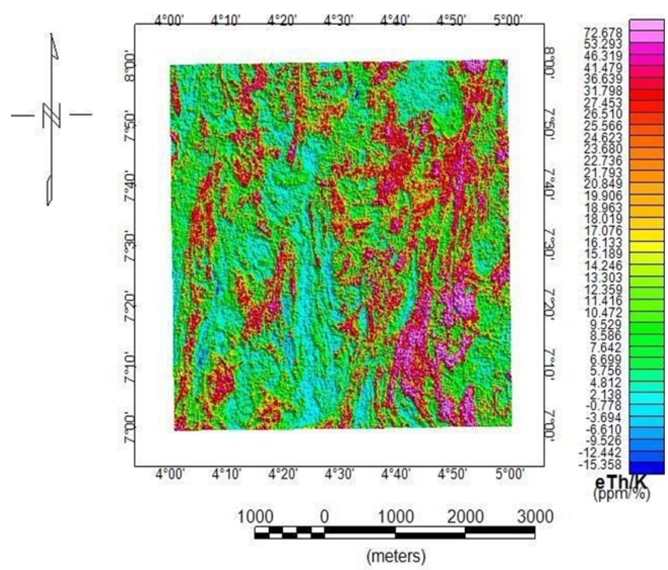

Figure 11. Ternary Contour Map of the three Aero-radioelement of the study area.

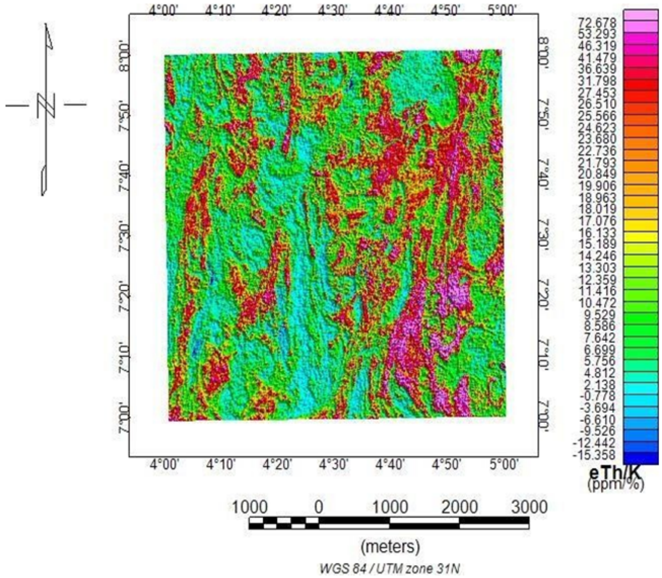

Figure 12. Composite Uranium Map of the study area.

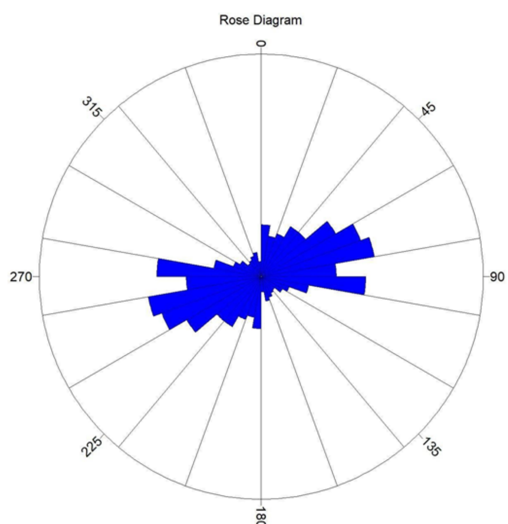

Figure 13. Main structural lineaments in Ross diagrams form obtained from the geological map.

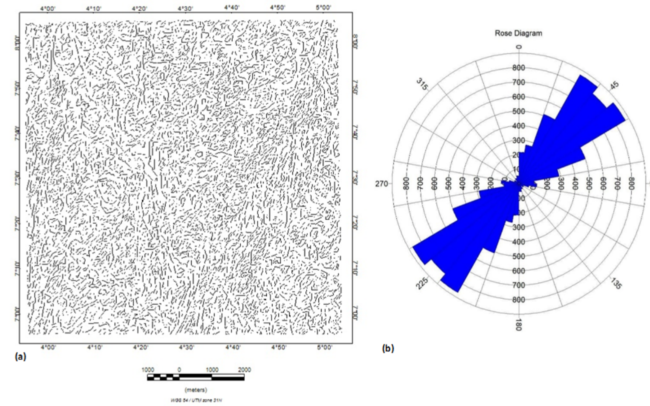

Figure 14. (a) Main structural lineaments obtained from the Potassium map (b) Its Ross diagram.

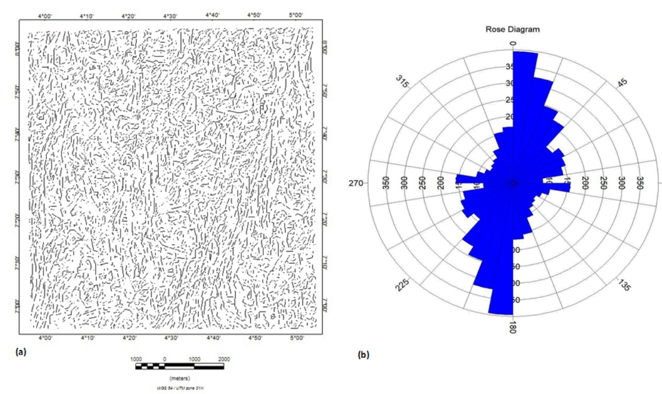

Figure 15. Main structural lineaments obtained from the TC map (b) Its Ross diagram.

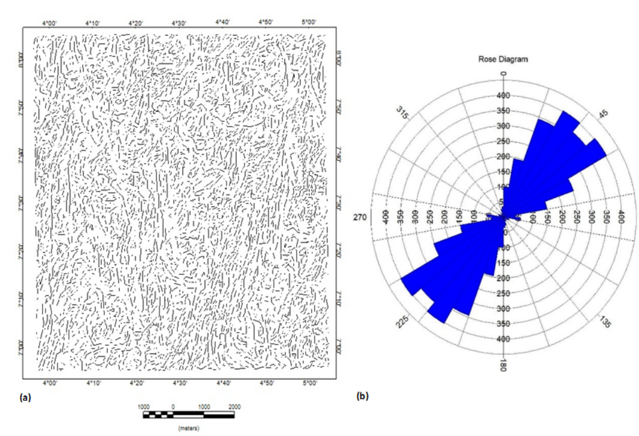

Figure 16. Main structural lineaments obtained from the Thorium map (b) Its Ross diagram.

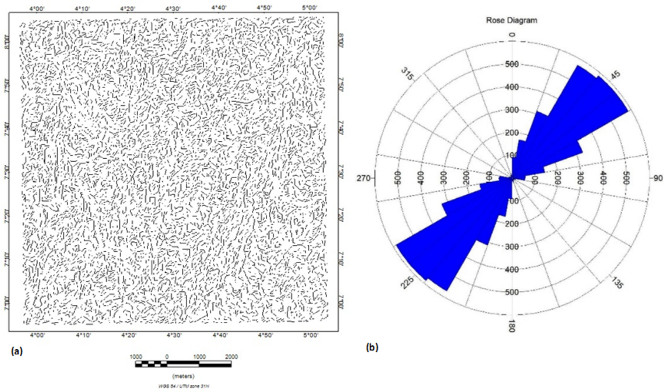

Figure 17. Main structural lineaments obtained from the Uranium map (b) Its Ross diagram.

meta silt stone. Among the rock units found in this region, both undifferentiated schist and carbonate/meta siltstone have CV values greater than 100% in potassium and thorium radio element while Band iron formation and Amhibole schist have values less than 100 % in their CV. This shows that rock units in the undifferentiated schist and carbonate/meta siltstone does not tends to normality in their distribution and other rock units tends to normality in their distribution.

5.5. Migmatic gneiss complex series

The rock units in this series include Biotite homblende gneiss, granulite and gneiss, granite gneiss and Band gneiss. All the rock units in these series have values of coefficient of variability lower than one hundred percent (100%) for all parameters of radiometric data considered except for potassium in the granite gneiss that has a value equal to 100%. It shows that all the rock units in this series tends to normality in their distributions for the radio elements considered except for potassium. Other series include catallactic and Jurassic rock units. All the rock units in these series have values of coefficient of variability lower than one hundred percent (100%) for all parameters of radiometric data considered and they tend to exhibit a normal distribution in all the radio elements considered.

5.6. Interpretation of lineament structures

In other to understand the trends of structural features present within the area, lineament structures were deduced from the aero radiometric maps of TC, eU, K and eTh respectively. These lineament structures when compared with the surface geology (figure (1)) showed a good correlation. The lineament structures were later used to produce sets of rose diagrams (Figures 13 – 17) which is a representation of numerical values of percentages of lineaments and the distributions of azimuth length of the study area. In addition to its use in mineral exploration, these lineament features are important for groundwater exploration in the basement complex of Nigeria and for near surface engineering structures such as dams [18]. Figures (13 – 17) presents detailed trends of the lineament structures observed as faults, joints on the geological map of the study region. The structural trends observed from the rose diagram are categorized into two; firstly, major lines which trends Northeast – Southwest, Northwest – Southeast, North – south and East – west directions. Secondly, the minor lines which trends East–North – east to west-north- west direction. From the interpretation of aero radiometric point of view, these trends are considered important for mineral prospectivity. In view of the above, this research findings confirm that flamingo field has high potential for mineral prospectivity. The prolific area in the area are the ones associated with Pan – African older granite Series or rocks with derivatives of older granites that are acidic in nature. A follow up investigation that will include an in-situ geochemical, geophysical, and geological analysis is necessary especially in areas where the Northeast – Southwest and Northwest – Southeast intersect.

6. Conclusion

Aero radiometric data of the flamingo field in southwestern Nigeria has been analyzed and interpreted to evaluate near surface geology, structural features, and mineral prospectivity potential of the region. The objectives of the study were to evaluate the alteration zones, correlate interpreted radiometric data with the lithological units, and reveal the relationship between the airborne radiometric anomalies and their structural trends. Results of the study showed that each of the radio element map can be divided into three classic patterns with unique lithologic association: (i) the lower values were found to be associated with metavolcanics, ophiolitic metagabbro, metasediment, undifferentiated schists formation. (ii) the intermediate values were found to be associated with meta volcanics, metagabbro, meta sediments including pebbly schist, and (iii) the highest values were found to be associated with the younger granites ring complex, metamorphic rocks and schist felsite. Further, the results showed that areas with prominent intersections of fractures and joints have high potential for mineral prospectivity. flamingo field is characterised by a variety of radio element with values ranging from 1.0 to 7.428 % for K, 10.6 to 181.628 ppm for eTh, 2.923 to 38.066 ppm eU and 13.200 to 214.617 Ur for TC. Normal distribution was observed in all the rock units present in the area except for undifferentiated schist and carbonate/meta siltstone which has a coefficient variability value greater than 100 % for potassium and thorium radio elements. The prominent structural trends delineated were along the Northeast – Southwest and Northwest – Southeast directions. The trends are critical to understanding the structural evolution of flamingo field and the entire region. The near surface structures delineated in this area are also important for groundwater exploration and site selection for engineering infrastructure such as dams. Generally, the inverted maps showed that zones of high radio elements concentration are potential areas for mineral prospectivity which have been subjected to series of deformations throughout geological ages. Findings from this study address the knowledge gap in the relationship between radioelement concentration and lithologic distribution in the flamingo field, and it will serve a benchmark for detailed studies on mineral prospectivity in the area.

Data availabilty

The datasets generated during and/or analyzed during the current study are available on purchase from https://ngsa.gov.ng/airborne-magnetic-data-download/.

References

[1] M. A. S. Youssef & S. T. Elkhodary, "Utilization of airborne gamma ray spectrometric data for geological mapping, radioactive mineral exploration and environmental monitoring of southeastern Aswan city, South Eastern Desert, Egypt", Geophysical Journal International **195** (2013) 1689. https://doi.org/10.1093/gji/ggt375.

[2] V. Paoletti & Pinto, "A. Insights into the Structure and Surface Geology of Isla Socorro, Mexico, from Airborne Magnetic and Gamma-Ray Surveys", Surv Geophys **37** (2016) 601. https://doi.org/10.1007/s10712-015-9352-0.

[3] E. Elawadi, A. Ammar & A. Elsirafy, "Mapping surface geology using airborne gamma-ray spectrometric survey data-A case study", Proceedings of the 7th SEGJ International Symposium, Japan, 2004, pp. 11–17. https://www.researchgate.net/publication/259822736.

[4] G. M. Saleh, A. M Afify, B. M. Emad, M. I. Dawoud, H. A Shahin & F. M. Khaleal, "Mineralogical and geochemical characterization of radioactive minerals and rare earth elements in granitic pegmatites at G. El Fereyid, South Eastern Desert, Egypt", Journal of African Earth Sciences **160** (2019) 103651. https://doi.org/10.1016/j.jafrearsci.2019.103651.

[5] R. B. K. Shives, B. W. Charbonneau & K. L. Ford, "The detection of potassic alteration by gamma-ray spectrometry—Recognition of alteration related to mineralization Detecting Ore Using GRS and K Alteration, Geophysics **65** (2000) 2001. https://doi.org/10.1190/1.1444884.

[6] A. R. Faruwa, W. Qian, A. T. Agbele, A. B. Babinisi & B. A. Yekeen, "Airborne radiometric mapping for natural radiation assessment over Okitipupa southeast belt of the bituminous sand field of Nigeria", Radiation Protection Dosimetry **192** (2020) 97. https://doi.org/10.1093/rpd/ncaa188.

[7] M. A. Adabanija, O. N. Anie & M. A. Oladunjoye, "Radioactivity and gamma ray spectrometry of basement rocks in Okene area, southwestern Nigeria", NRIAG Journal of Astronomy and Geophysics **9** (2020) 71. https://doi.org/10.1080/20909977.2020.1711695.

[8] R. A. Y. El Qassas, M. Salaheldin, S. M. A. Assran, T. Abdel Fattah & M. A. Rashed, "Airborne gamma-ray spectrometric data interpretation on Wadi Queih and Wadi Safaga area, Central Eastern Desert, Egypt", NRIAG Journal of Astronomy and Geophysics **9** (2020) 155. https://doi.org/10.1080/20909977.2020.1728893.

[9] T. O. Lawal, "Integrated aeromagnetic and aeroradiometric data for delineating lithologies, structures, and hydrothermal alteration zones in part of southwestern Nigeria", Arabian Journal of Geosciences **13** (2020) 775. https://doi.org/10.1007/s12517-020-05743-7.

[10] A. S. Akingboye, A. C. Ogunyele, A. T. Jimoh, O. B. Adaramoye, A. O. Adeola & T. Ajayi, "Radioactivity, radiogenic heat production and environmental radiation risk of the Basement Complex rocks of Akungba-Akoko, southwestern Nigeria: insights from in situ gamma-ray spectrometry", Environmental Earth Sciences **80** (2021) 228. https://doi.org/10.1007/s12665-021-09516-7.

[11] W. O. Raji & R. B. Bale, "The geology and geophysical studies of a gravel deposit in university of Ilorin, Southwestern Nigeria", Continental journal of earth Sciences **3** (2008) 40. https://www.researchgate.net/publication/315112835.

[12] A. S. Aromoye, S. A. Alimi, O. S. Bello, W. O. Raji, L. O. Olawale & D. S. Bonde, "2-D Electrical resistivity tomography for groundwater potential in basement terrain of a part of Ilorin Sheet 223 NW Nigeria", Audi J Eng Technology **4** (2019) 357. http://scholarsmepub.com/sjet/.

[13] O. B. Balogun, "Tectonic and structural analysis of the Migmatite–Gneiss–Quartzite complex of Ilorin area from aeromagnetic data", NRIAG Journal of Astronomy and Geophysics **8** (2019) 22. 10.1080/20909977.2019.1615795.

[14] N. G. Obaje, "Geology and Mineral Resources of Nigeria", Springer, Berlin, Germany, 2009, pp 1–9. https://doi.org/10.1007/978-3-540-92685-6.

[15] O. S. Ogungbemi, J. O. Amigun, G. M. Olayanju & G. O. Badmus, "Airborne and ground geophysical evaluation of potential mineralized zone in parts of Ilesha schist belt, southwestern Nigeria", Interpretation **9** (2021) SH75. https://doi.org/10.1190/INT-2021-0012.1.

[16] O. T. Olurin, "Interpretation of high resolution airborne magnetic data (HRAMD) of Ilesha and its environs, Southwest Nigeria, using Euler deconvolution method", Materials and Geoenvironment **64** (2017) 227. https://doi.org/10.1515/rmzmag-2017-0013

[17] Nigeria Geological Survey Agency, "Airborne Magnetic Data", 2024. [Online]. https://ngsa.gov.ng/airborne-magnetic-data/.

[18] W. O. Raji & O. K. Ibrahim, "Geophysical investigation for Basement Rock Structures around a proposed Dam site", Adamawa State University Journal of Scientific Research **5** (2017) 38. https://www.researchgate.net/profile/Toyin-Ibrahim-Alli.