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Investigating hydrothermal alteration associated with gold mineralization in Birnin-Gwari through tranformation of aero-radiometric data

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ABSTRACT

Gold mining is a significant driver of wealth, serving as a reliable store of value against currency decline and a favoured hedge against inflation. Regions with hydrothermal alteration are key indicators of gold mineralization, and certain mapping techniques have proven effective for identifying these zones. However, these techniques have not yet been applied within the Birnin Gwari Schist Belt. This study used these established techniques to examine the spectrometric data over a known gold mine within the belt. The findings reveal that the gold mine area shows moderate potassium levels with low thorium and uranium readings, indicating hydrothermal alteration. Additionally, a region northwest of the mine may have undergone a similar alteration, suggesting a potential gold mine (PGM). The ternary map indicates the location of both the gold mine and PGM have high potassium concentrations. Both sites also record high potassium deviation (Kd) values, consistent with potassic alteration. The computed parameter value for the gold mine and PGM suggests their rock formations have undergone moderate alteration.

Keywords: Hydrothermal alteration, Gold mining, Potassium deviation, F parameter.

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1. INTRODUCTION

The pivotal role played by gold in stabilizing currencies and managing economic certainty remains undisputed. It is a safe-haven asset during financial crises, preserving wealth and its market dynamics influence investment strategies [1]. In Nigeria, gold occurs in placer deposits, i.e., a collection of valuable minerals that have been concentrated by gravity and erosion and are often found in riverbeds, alluvial fans and beaches. Gold in the western half of Nigeria are in primary veins with supracrustal zones, schist belts [2].

The primary mineralization of gold is associated with veins, stringers, lenses, and reefs of rocks with mineralogical composition ranging from quartz to quartzo-feldspathic, and to quartzo-tourmalinitic minerals [3]. Schist belt veins are fractures in the schist that can host gold and other mineral deposits. About 12 notable schist belts are identified in western Nigeria; Zuru, Anka, Maru, Wonaka, Kazure, Karaukarau, Kushaka, Zungeru-Birnin Gwari, Iseyin-Oyan, Ife-Ilesha, Igarra and Egbe-Isanlu [3–5], not all the schist belts host gold mineralization in Nigeria. Kushaka, Zuru, Egbe-Isanlu, Ilesha, and Birnin Gwari schist belts are notable for gold mineralization [3]. The setting and geochemical character of the gold mineralization at Tsohon Birnin Gwari are

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similar to what have been reported from the Brinin Yauri area (Zuru schist belt) of northwestern Nigeria and many areas of Archaean and younger mesothermal gold mineralization in the world [2].

Zungeru-Minna-Brinin Gwari has been considered an important schist belt due to the presence of gold deposits, thus, attracting the attention of several researchers on gold exploration [2, 6, 7], [8]. The main characteristics of the gold mineralization around Dikko, part of the Birnin Gwari schist belt, appear to indicate hydrothermal mineralization in connection with shear zones [7]. The associated quartz veins are generally concordant with the main N-S regional structural trend. Abdullahi *et al.* [6] attributed elevated resistivity in the gold deposit at Bogai town in Birnin Gwari to silicification and related a high-resistivity anomaly at a depth greater than five meters (5 m) with well-defined patterns observed in the 3D resistivity model to the mineralization of gold-bearing quartz veins, trending in the NW and NE direction. However, mapping potassic alteration within the Brinin-Gwari schist belt is necessary as Potassium concentration is often present alongside sulphide which is one of the scrubber elements of gold in the sericite zone [9]. An alteration zone could be delineated by K or eTh/K as an anomaly indicator, and the vein bodies could also be delineated using low K or eTh as an anomaly indicator [10].

This research focused on identifying location with potentials for gold mineralization through the transformation of radioelements. Some techniques, (K/eTh, Kd and ternary images) were used in highlighting Potassic alterations related to gold mineralization within the Brinin Gwari schist belt and their impacts on known mining site was observed and then utilized to identify possible gold mines in the study area. Thus, making the techniques veritable tools in the precise target of gold deposits in other areas.

1.1. GEOLOGY OF THE STUDY AREA

The Birnin-Gwari gold deposit is located in the north-western axis of Kaduna state bounded by the geological coordinates, latitude 10.667˚N and longitude 6.533˚E. The geological setting of Birnin-Gwari is characterized by two geological terrains, the basement complex and the schist belts. The basement complex is overburdened by gently immersed cretaceous sediments of the lullemmeden basin in the northwest while the schist belts are sectioned into two main categories. The Kusshaka Schist Belt (Figure 1), which extends across the Birnin-Gwari basin, consists of coarse- to fine-grained igneous rocks, predominantly phyllites and iron formations [2].

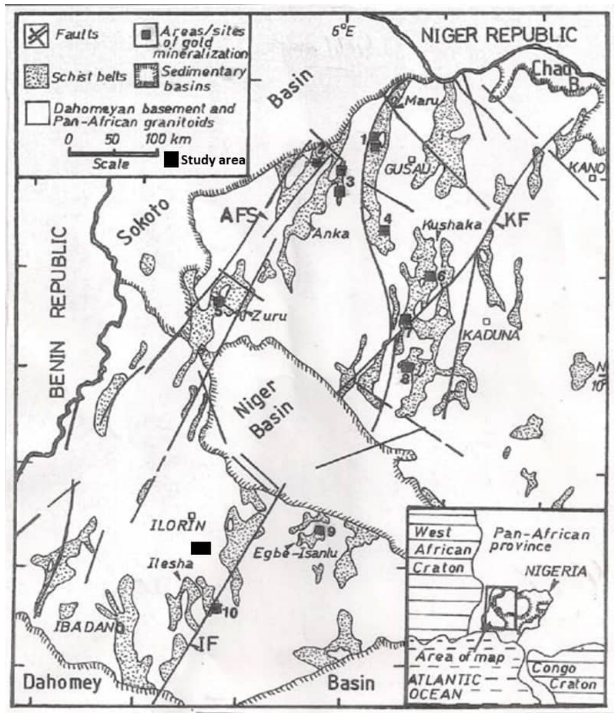

Figure 1. Geology map of Birnin Gwari.

2. MATERIAL AND METHOD

2.1. MATERIALS USED FOR THIS STUDY

The primary materials used for this study are aero-radiometric data (between sheets 121, 122, 142, and 143), and Oasis Montaj^{TM} software. The Data was obtained from Nigerian Geological Survey Agency (NGSA).

2.2. DATA ACQUISITION

The data were acquired by attaching a spectrometer to an aircraft or, less frequently, helicopters. Fixed-wing aircraft fly in a grid-like pattern at a predetermined altitude, velocity, and line spacing to acquire airborne radiometric data. To achieve the required resolution, the survey area must be significantly bigger than the target area and the line spacing must be thick enough [11]. Gamma energy is measured by onboard sodium iodide scintillation counters, and GPS position data is stored in the digital data stream. Depending on the speed of the aeroplane, channels for the overall gamma count, U, Th, and K are individually accumulated, often at one-second intervals that equate to 30 to 60 meters across the ground. Maps displaying the total count and specific radioisotope concentrations (equivalents for U and Th) are produced after the data are corrected for flight height, air temperature, humidity, cosmic noise, Compton scattering, and radon effects.

The airborne radiometric data used in this study (longitude 6.25°E – 6.75°E, and latitude 10.40°N – 10.90°N). The airborne radiometric dataset obtained from NGSA was part of the airborne survey carried out between 2005 and 2009 by Fugro on behalf of NGSA. The data were acquired and obtained at an altitude of 100 m along with a flight line spacing of 500 m oriented in NW-SE and a tie line spacing of 2000 m. The maps are on a scale of 1:100,000 and half-degree sheets [11].

2.3. METHOD

A thorough understanding of the effects of silicification, potassium–alteration (K-alteration), weathering processes and local lithological variations is required to evaluate the mineralization potential associated with the radioelement anomalies in regards to hydrothermal alteration [12]. Thus, it is essential to isolate areas of Potassium enrichment caused by hydrothermal alteration from other processes; weathering, leaching and weathering activities, to identify hydrothermally altered areas. To achieve this,

i. Ratios of radioelements: Areas enriched in Potassium are combined in ratios with equivalent Thorium and Uranium concentrations (eTh and eU). The abundance ratios (K/eTh and K/eU) are often more diagnostic of changes in rock types and mineralogical changes caused by hydrothermal alteration [13].

ii. Ternary map: It facilitates various displays of different radioelements' data which are correlative in the same area: The ternary map is often used to get an indication of radioactivity distributions and, consequently, enables narrowing down favorable target areas for hydrothermal alteration associated with orogenic gold mineralization. This was facilitated by the combination of concentrations of K, eTh, and eU.

iii. F-parameter: To evaluate the possibility of the gamma ray spectrometric method characterization of areas of change linked with hydrothermal occurrences in the study area, the F-parameter was used. Due to two substantial correlations between the richness of K and the eTh/K ratio and the richness of eU and the eTh/K ratio, the F-parameter is particularly crucial in hydrothermal alteration mapping, equation (1) [14]:

$$F = \frac{K \times eU}{eTh}. \tag{1}$$

As a reflection of the Th/U ratio and the concentration of potassium, the F-parameter is a crucial marker of hydrothermal alteration in rocks [15]. This is particularly important in distinguishing hydrothermally altered areas by eliminating processes other than hydrothermal alteration by the ratio combinations of K, eTh and eU. Hence, high anomaly is regarded as hydrothermally altered areas [16].

iv. Potassium deviation (Kd): It was proposed by Ref. [17] and has been found appropriate in delineating hydrothermal alteration haloes related to orogenic gold mineralization prompting its application in the study area. Based on the method proposed by Refs. [17, 18], the nominal K value (Kn) in relation to the equivalent Thorium (eTh) concentration was extracted from equation (2) [14]:

$$Kn = \left(\frac{K_{map\ average}}{Th_{map\ average}}\right) Th_{map}. \tag{2}$$

Deviation from the nominal K values (Kd) were thought to signify potassium enrichment levels as they were obtained through hydrothermal alteration processes as obtained in equation (3) [14]:

$$Kd = \left(\frac{K - Kn}{Kn}\right). \tag{3}$$

Note: High K/eTh, high F–parameter and high Kd values are indicative of hydrothermally altered zones accentuated by Potassium enrichment.

3. RESULT AND DISCUSSION

High Potassium anomaly over felsic rocks and intrusives such as granitoids are attributable mainly to high K–feldspar content. Thus, Potassium radiation is mainly due to K-feldspar, especially microcline and orthoclase or micas such as muscovite and biotite, which are common in granites and are relatively low in basalts and andesites. Hydrothermal alteration is associated with high heat content, which in turn is associated with felsic rocks and granitoids, proxies to heat source [9]. Therefore, regions exhibiting high potassium concentrations near granitoids – such as por-

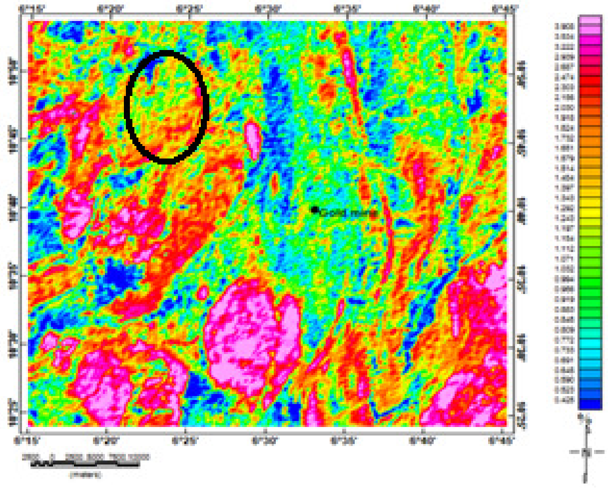

Figure 2. K concentration map of the study area.

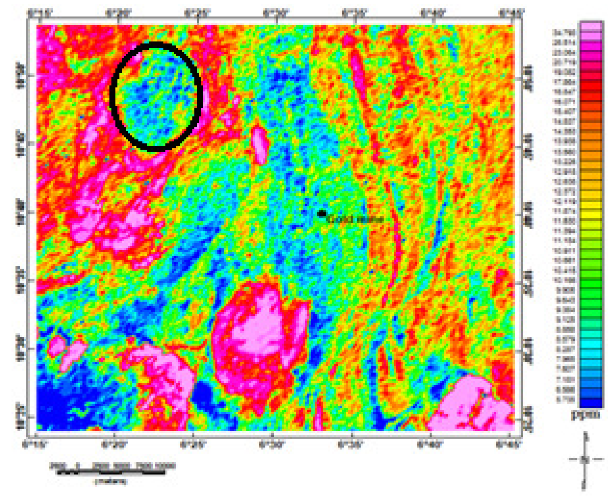

Figure 3. Th concentration map of the study area.

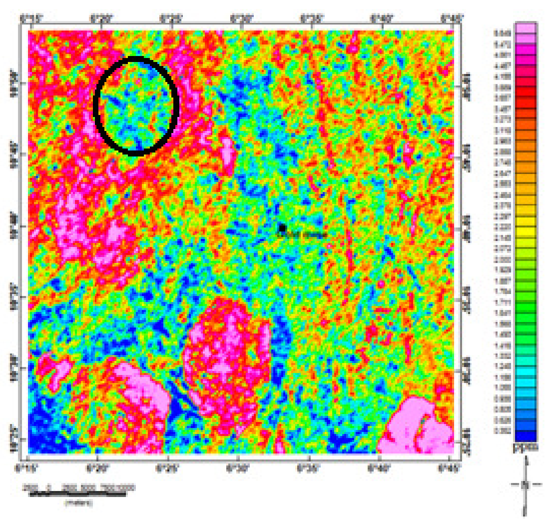

Figure 4. U concentration of the study area.

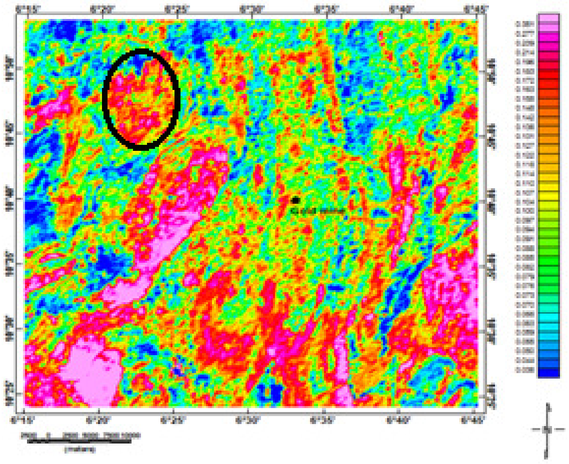

Figure 5. K/Th map of the study area.

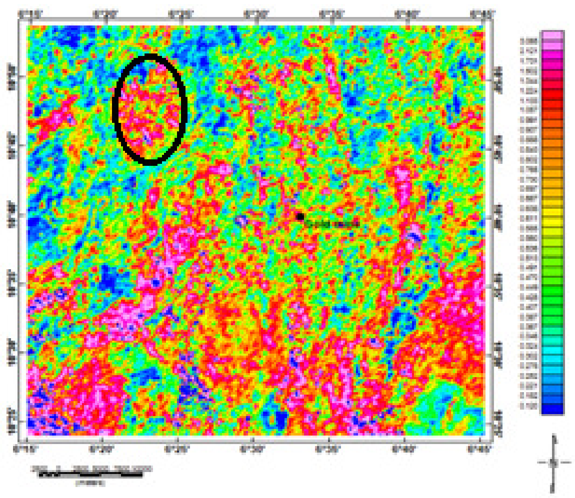

Figure 6. K/U map of the study area.

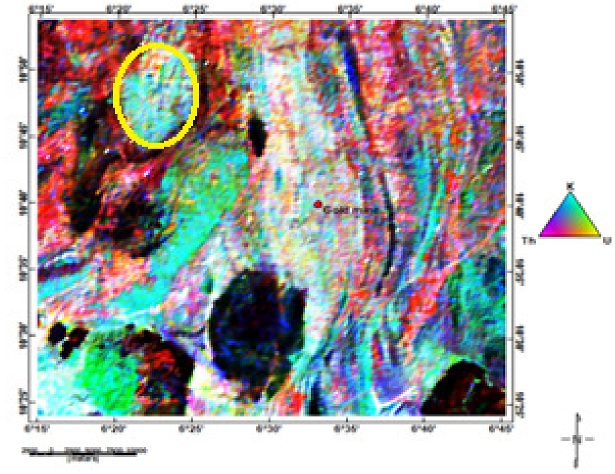

Figure 7. Ternary map of the study area.

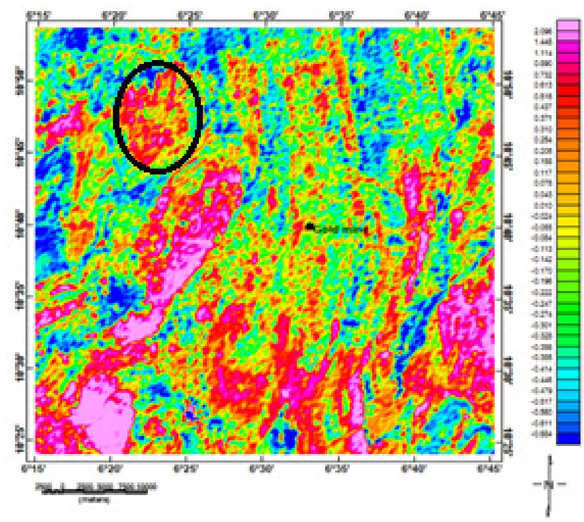

Figure 8. Kd map of the study area.

phyritic granite, granite gneiss, and migmatite gneiss – are potential hydrothermally altered zones [2, 19]. Moreover, regions of high concentration of Potassium counts are indicative of the migration of Potassium since Potassium is more geochemically active than other radioelements. As such, areas of potassic alteration leading to orogenic gold formation are suspected in regions where there are very high and high counts of Potassium concentrations [9].

The Potassium distribution of this study area vary from 0.425% to 3.908% (Figure 2), as compared to that of Ife-Ilesha schist belt which vary from 0.152 to 3.562 %, reflects heterogeneity in the lithological distribution and variation in the response to geological processes in this study area. The mine site exhibits a high potassium concentration (1.343%). Similar potassium concentrations are found in the region delineated by a circle, NW of the mine site, suggesting potassic alteration that may be linked to gold mineralization. A NE trending linear structure was observed around the mine site, which is consistent with the imprints of the pan-African orogeny [20, 21].

Thorium depletion is associated with hydrothermally altered areas [9]. It is noteworthy that Thorium is commonly considered very immobile [18], thus the areas with low eTh concentration suggest that it was mobilized in hydrothermally altered systems since Thorium depletion is associated with hydrothermally alteration [9]. The distribution of thorium and uranium vary from 5.735 to 34.793 ppm and from 0.352 to 6.649 ppm respectively. The concentration of thorium and uranium around the mining site and the circled region is low, see Figures 3 and 4, respectively.

To isolate regions that have undergone hydrothermal alteration, high anomalies from the ratio maps of potassium with thorium and potassium with uranium are thus, useful in delineating hydrothermally altered zones [9, 12, 15, 22]. The ratio maps, Figures 5 and 6, revealed the mining site and circled region (a possible hydrothermally altered zone which could be associated with gold mineraliztion) are characterized by high anomalies.

Traditionally, ternary map of the radioelements (K, eU and eTh) channels (Figure 7) provides supplementary information as compared to individual channel maps [23]. Dark coloration on the map is indicative of zones where there is high concentration of K, eTh and eU. The enrichment of eTh, eU and the impoverishment of K in those areas does not reveal the effect of hydrother-

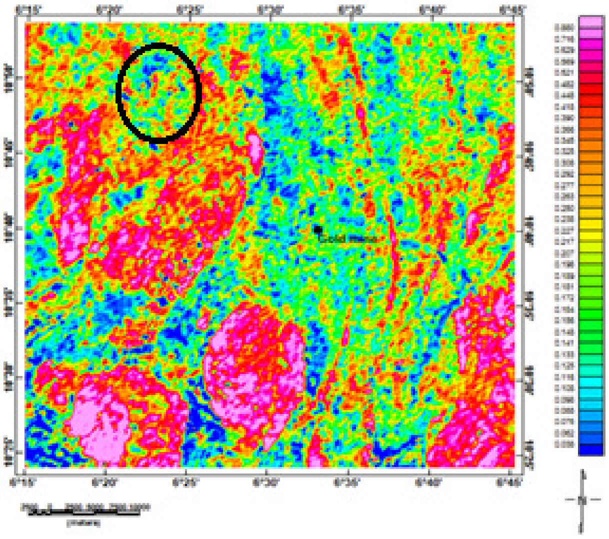

Figure 9. F-parameter map of the study area.

mal alteration process. Similarly, regions with light colouration as a result of low concentration of K, eTh and eU does not represent alteration [9]. However, locations with dominance of K concentration, such as the mining site and the circled region (Figure 7), are indicative of hydrothermal alterations.

Saunders *et al.* [17] proposed the Kd (potassium anomalies) map which provides variable distribution of potassium to isolate hydrothermally altered areas represented by anomalously high Kd values [16]. The ability of the Kd map to delineate probable hydrothermally altered areas is due to the ratio combination of K and eU, making it a veritable means of identifying hydrothermally altered areas. Figures 8 shows that the mining site and the circled region are characterized by high Kd values which is an indication of hydrothermal alteration in the region, agreeing with results of Figures 2 – 7. Similar finding was reported around known hydrothermally altered regions in Ife-Ilesha Schist Belt [9].

The F–parameter map of the study area shows anomaly values ranging from -1.064 to 2.096. However, highly altered rocks are always indicated with F–parameter values in the range of 2 – 5 and sometimes reaching 10, while moderate to intermediate altered rocks have anomaly values in the range of 0.5 and 2 [12]. Hence, the mining site and the circled region are observed to be of moderate/intermediate altered rocks (Figure 9).

4. CONCLUSION

The primary focus of this was to identify location with potentials for gold mineralization through the transformation of radioelements. The adopted techniques in this research was known to be very effective in mapping alteration zones around the Ife-Ilesha schist belt. The results indicated that the gold mine area has moderate potassium levels with low thorium and uranium readings, indicating hydrothermal alteration. Additionally, a region northwest of the mine may have undergone a similar alteration, suggesting a potential gold mine (PGM). The ternary map indicates the location of both the gold mine and PGM have high potassium concentrations. The mining site within Birnin Gwari schist belt has undergone hydrothermal alteration and also the rocks around the site experienced moderate alteration. Additionally, a potential gold-bearing site was identified using these techniques, highlighting their value for future explorations.

DATA AVAILABILITY

The Data is available on the website of Nigeria Geologic Survey Agency (NGSA). https://ngsa.gov.ng.

References

[1] D. R. McKay & D. A. Peters, "The midas touch: gold and its role in the global economy", Plastic Surgery **25** (2017) 61. https://doi.org/10.1177/2292550317696049.

[2] I. Garba, "Geochemical characteristics of the gold mineralization near Tsohon Birnin Gwari, Northwestern Nigeria", Geochemistry **62** (2002) 60. https://doi.org/10.1078/0009-2819-00008.

[3] I. A. Kankara & M. R. Darma, "A review of gold metallurgeny (metallogeny) in Nigeria", International Journal of research in chemical, metallurgical and civil Eng. **3** (2016) 293. https://doi.org/10.15242/IJRCMCE.

[4] U. A. Danbatta, Y. I. Abubakar & A. A. Ibrahim, "Geochemistry of gold deposits in Anka schist belt, Northwestern, Nigeria", Nigerian Journal of Chemical Research **13** (2008) 19. https://ajol.info/index.php/njcr/issue/view/8792.

[5] N. B. Salawu, J. O. Fatoba, L. S. Adebiyi, M. M. Orosun & S. S. Dada, "New insights on the Ife-Ilesha schist belt using integrated satellite, aeromagnetic and radiometric data", Sci Rep **11** (2021) 15314. https://doi.org/10.1038/s41598-021-94813-1.

[6] N. Khalid Abdullahi, M. Sani Ahmad & A. Abubakar, "Application of electrical resistivity tomography technique for delineation of gold mineralization in Bugai town, Birnin Gwari, Kaduna, North Western Nigeria", Environmental and Earth Sciences Research Journal **5** (2018) 29. https://doi.org/10.18280/eesrj.050105.

[7] A. A. Mohammed, A. U. Mohammed, O. Abdulganiu & D. A. Sadiq, "Geology of the structurally controlled quartz vein gold mineralization in the Dikko area, part of Zungeru—Minna—Birnin Gwari schist belt, NW Nigeria", Journal of Geoscience and Environment Protection **09** (2021) 180. https://doi.org/10.4236/gep.2021.97012.

[8] O. O. Alabi & Y. E. Gbadamosi, "Investigating the potentials of sluice box angle of tilt on the beneficiation of Birnin-Gwari gold deposit", FUOYE Journal of Engineering and Technology **6** (2021) 2. https://doi.org/10.46792/fuoyejet.v6i2.620.

[9] A. A. Akinlalu, "Radiometric Mapping for The Identification of Hydrothermally Altered Zones Related to Gold Mineralization in Ife–Ilesa Schist Belt, Southwestern Nigeria", *Indonesian Journal of Earth Sciences* **3** (2023) A519. https://doi.org/10.52562/injoes.2023.519.

[10] H. Syaeful, "Radiometric signatures of gold mineralization zone in Pongkor, West Java, Indonesia: a baseline for radiometric mapping application on low-sulfidation epithermal deposit", *Resources*, **13**(2023) 2. https://doi.org/10.3390/resources13010002.

[11] Y. A. Bello, M. B. Yakubu & M. A. Bilal, "Delineating potential hydrocarbon targets through aero-radiometric techniques", PHYSICS Access **4** (2024) 116. https://doi.org/10.47514/phyaccess.2024.4.2.014.

[12] S. H. Abd El Nabi, "Role of γ-ray spectrometry in detecting potassic alteration associated with Um Ba'anib granitic gneiss and metasediments, G. Meatiq area, Central Eastern Desert, Egypt", Arabian Journal of Geosciences **6** (2013) 1249. https://doi.org/10.1007/s12517-011-0378-4.

[13] G. Erdi-Krausz, M. Matolin, B. Minty, J. P. Nicolet, W. S. Reford & E. M. Schetselaar, "Guidelines for radioelement mapping using gamma ray spectrometry data", International Atomic Energy Agency (IAEA), 2003. [Online]. https://www.iaea.org/.

[14] T. F. P. de Quadros, J. C. Koppe, A. J. Strieder & J. F. C. L. Costa, "Gamma-ray data processing and integration for lode-Au deposits exploration", Natural Resources Research **12** (2003) 57. https://doi.org/10.1023/A:1022608505873.

[15] N. Maden & E. Akaryalı, "Gamma ray spectrometry for recognition of hydrothermal alteration zones related to a low sulfidation epithermal gold mineralization (eastern Pontides, NE Türkiye)", J Appl Geophy **122** (2015) 74. https://doi.org/10.1016/j.jappgeo.2015.09.003.

[16] M. Eleraki, B. Ghieth, N. Abd-El Rahman & S. Zamzam, "Hydrothermal zones detection using airborne magnetic and gamma ray spectrometric data of mafic/ultramafic rocks at Gabal El-Rubshi area, Central Eastern Desert

(CED), Egypt'', Advances in Natural and Applied Sciences **11** (2017) 182. https://www.aensiweb.com/ANAS.

[17] D. F. Saunders, S. A. Terry & C. K. Thompson, ''Test of national uranium resource evaluation gamma-ray spectral data in petroleum reconnaissance'', Geophysics **52** (1987) 1547. https://doi.org/10.1190/1.1442271.

[18] A. M. Silva, A. C. B. Pires, A. Mccafferty, R. A. V. de Moraes & H. Xia, ''Application of airborne geophysical data to mineral exploration in the uneven exposed terrains of the Rio Das Velhas greenstone belt'', Brazilian Journal of Geology **33** (2003) 17. https://ppegeo.igc.usp.br/portal/wp-content/uploads/tainacan-items/15906/45048/9837-11496-1-SM.pdf.

[19] S. O. Sanusi & J. O. Amigun, ''Structural and hydrothermal alteration mapping related to orogenic gold mineralization in part of Kushaka schist belt, North-central Nigeria, using airborne magnetic and gamma-ray spectrometry data'', SN Appl Sci **2** (2020) 1591. https://doi.org/10.1007/s42452-020-03435-1.

[20] A. A. Akinlalu, A. O. Adelusi, G. M. Olayanju, K. A. N. Adiat, G. O. Omosuyi, A. Y. B. Anifowose & B. E. Akeredolu, ''Aeromagnetic mapping of basement structures and mineralisation characterisation of Ilesa Schist Belt, Southwestern Nigeria'', Journal of African Earth Sciences **138** (2018) 383. https://doi.org/10.1016/j.jafrearsci.2017.11.033.

[21] A. A. Akinlalu, G. M. Olayanju, K. A. N. Adiat & G. O. Omosuyi, ''Mineralisation potential assessment using analytical hierarchy process (AHP) modeling technique: a case study of Ilesha schist belt, southwestern Nigeria'', Results in Geophysical Sciences **7** (2021) 100026. https://doi.org/10.1016/j.ringps.2021.100026.

[22] S. O. Elkhateeb & M. A. G. Abdellatif, ''Delineation potential gold mineralization zones in a part of Central Eastern Desert, Egypt using airborne magnetic and radiometric data'', NRIAG Journal of Astronomy and Geophysics **7** (2018) 361. https://doi.org/10.1016/j.nrjag.2018.05.010.

[23] M. L. Airo, ''Aeromagnetic and aeroradiometric response to hydrothermal alteration'', Surv Geophys **23** (2002) 273. https://doi.org/10.1023/A:1015556614694.