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Non-Invasive Detection of Structural Features and Potential Gold Mineralization Zones in Northwestern Rijau Environ of Zuru Schist Belt, Nigeria

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Abstract*— Non-invasive geophysical methods (aeromagnetic and aeroradiometric methods) have been employed to investigate the subsurface of Northwestern Rijau in the northernwestern part of Nigeria with the aim of addressing the need for a structural map that could guide in-situ gold exploration activities in the area. The aeromagnetic data was processed to enhance the signal-to-noise ratio of the data and subjected to source edge detection techniques for structural interpretation. The aeroradiometric data were used to produce ternary image and potassium-to-thorium ratio map for detection of potential alteration zones associated with gold mineralization. The structural map derived showed predominantly trending NE-SW geological structures and indicates polyphase crustal deformations in the study area. The result also showed high prospectivity zones for gold exploration. These zones are intersected by geological structures, indicating structurally controlled mineralisation and suggesting the likelihood of gold depositions along or near these structural features. Nearly all the known gold occurrence locations in the study area coincides with the interpreted prospective zones, validating the significance of non-invasive geophysical methods in mineral exploration. The geological structures in the identified high prospectivity zones were recommended as targets for in-situ investigations and other gold propecting activities in the study area.

***Keywords*— Solid Earth Physics, Structural Mapping, Mineral Prospecting, Radiometric Method, Magnetic Method**

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I. Introduction

The Nigerian Basement Complex is endowed with many solid mineral resources, most of which are found along schist belts. In the northwestern part of the country, the most significant gold bearing belts are the Zuru, Kushaka, Maru and Anka schist belts [1]. The Zuru Schist Belt (ZSB) is known for its significant occurrence of gold deposits, which are distributed in various localities along the schist belt [2]–[4]. Among these localities is the northwestern part of Rijau and its neighbouring towns (Shanga, Yauri, Zuru and Fakai), where artisanal mining for gold deposits are well established [5]. Despite the richness of the ZSB and its environs in gold deposits and other solid minerals, the ZSB is still understudied among the schist belts in Nigeria [6].

A number of geological, geophysical and geochemical efforts have been made in the literature to study and identify prospective zones for mineral exploration in the ZSB, including the neighbouring towns of Rijau [2], [5]–[9]. In spite of notable artisanal mining operations in the northwestern part of Rijau, the area is significantly understudied compared to its neighbouring Zuru and Yauri provinces due to lack of data-backed reconnaissance prospectivity information that focuses on the area specifically. In response to this gap, this study uniquely focused on the northwestern part of Rijau with the aim of using non-invasive geophysical approach to produce a structural map indicating potential gold mineralization zones that could serve as a reconnaissance guide for in-situ prospecting and other exploration activities. Non-invasive geophysical methods, such as aeromagnetic and aeroradiometric methods, provide information about the subsurface without direct physical contact or disturbance. It is well-suited for reconnaissance purposes, providing information that could help in reducing exploration risks and cost associated with in-situ exploration by narrowing down target zones.

The objectives of this study include delineation of structural features from high resolution aeromagnetic data using well established edge detection techniques, identification of hydrothermal alteration zones from high resolution aeroradiometric data by exploiting the potassic alteration signature (a common indicator of gold mineralization) embedded in the data, and mapping of areas with high potential for gold mineralization in the northwestern part of Rijau. The outcome of this study would contribute to the knowledge of the underlying structural geology of the area and it is expected to guide future in-situ mineral-focused investigations in the area.

II. GEOLOGICAL SETTINGS

Rijau is a basement complex terrane, located along ZSB in the northwestern part of the Nigerian Basement Complex (NBC) (Fig. 1). The ZSB is the largest of the northern schist belts in Nigeria [3]. These schist belts are made up of amphibolites and metasedimentary rocks interpreted as Upper Proterozoic supracrustal rocks that have been tectonically infolded into the migmatite-gneiss-quartzite complex [3]. The northwestern part of Rijau is a westward extension of the ZSB. It is underlain by schists (including quartz, mica and phyllities), quartzite, biotic granites, branded and biotite gneisses, gabbro and migmatite [10]. The geology of the area includes historic imprints of brittle deformations and fluid flow, such as silicified sheared rocks and large quartz veins, which are common indicators of gold mineralization in ZSB and other shear belt regions of the NBC [1], [6], [10], [11].

III. MATERIALS AND METHODS

High resolution aeromagnetic and aeroradiometric geophysical data acquired from the Nigerian Geological Surveys Agency (NGSA) were used for this study. The specifications and other details of the airborne surveys are summarised in Table 1.

The magnetic data was gridded at 100 m spacing using the Minimum Curvature gridding method [12]. In order to enhance magnetic anomaly signature and suppress near-surface noise, the data was upward continued to 40 m. This technique improves signal-to-noise ratio of potential field data by suppressing the short wavelength components associated with near-surface (cultural) features, making anomalies from deeper sources (buried rocks) more ehanced.

Two methods were used to detect the structural features: Euler Deconvolution (ED) methods and Analytic Signal Amplitude (ASA). These methods are well established techniques in potential field studies. They have been widely and successfully used for structural mapping across various geological terranes (e.g. [13]–[18]). The 3D ASA, also known as the total gradient, can be expressed mathematically as [19]:

$$ASA(x,y,z) = \sqrt{\left(\frac{\partial T_{MA}}{\partial x}\right)^2 + \left(\frac{\partial T_{MA}}{\partial y}\right)^2 + \left(\frac{\partial T_{MA}}{\partial z}\right)^2}$$

where T_{MA} is the total magnetic anomaly and (x, y, z) are spatial coordinates. The ASA peaks over magnetic geological structures, which could be contacts, faults, dike and other structural features. The locations of the geological structures were automatically delineated from the peaks of the ASA using the Curvature Analysis algorithm detailed in [20].

The ED technique was applied on the magnetic data to identify the faults and dike-like structures. The locations (x_0, y_0) and depths (z_0) of the geological structures are determined by numerically solving the following Euler equation [14], [21]:

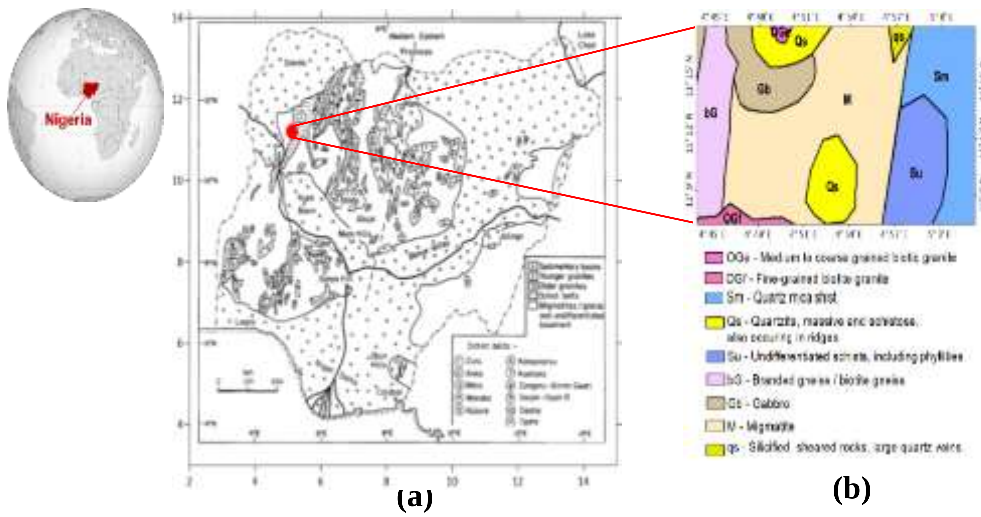

Fig. 1: (a) Simplified Geological Map of Nigeria Showing the Location of the Study Area and Major Schist Belt Localities (After [3], [22]) (b) Geological Map of Northwestern Rijau (Adapted from [10], [15]).

Table 1: Survey Specifications of the Aeromagnetic and Aeroradiometric Data Used

Specification Category	Parameter	Value/Description
Flight Parameters	Line Spacing	0.5 km
	Tie Line Spacing	5 km
	Mean Terrain Clearance (MTC)	0.08 km
	Flight Line Direction	Primarily NW-SE (135 degrees)
	Tie Line Direction	Primarily NE-SW (45 degrees)
Magnetic Survey	Magnetometer Type	Caesium Vapour Magnetometers (e.g., Scintrex CS-3)
	Data Recording Interval	≤ 0.1 seconds (approximately every 7 meters along flight line)
	Magnetic Measurement	Total Magnetic Field Intensity (TMI)
Radiometric Survey	Spectrometer Type	High-sensitivity, multi-channel gamma-ray spectrometer (256 channels)
	Measured Radioelements	Equivalent Thorium, Equivalent Uranium Potassium, Total Count
	Sampling Rate	Typically similar to magnetic data acquisition rate

$$(x - x_0)\frac{\partial T_{MA}}{\partial x} + (y - y_0)\frac{\partial T_{MA}}{\partial y} + (z - z_0)\frac{\partial T_{MA}}{\partial z} = N(T_B - T_{MA})$$

Where T_B is the regional (background) field of T_{MA} and N is the structural index of the geological structures of interest.

The radiometric data used for this study has three components: potassium (K), equivalent uranium (eU) and equivalent thorium (eTh) concentrations. These components were rasterized to produce a ternary image that shows the relative abundance of the radioelements in the area. The ratio of the concentrations of potassium to thorium was computed to highlight the hydrothermal alteration zones in the study area, which are indicative of high potential zones for gold mineralisation in the area [23]–[25].

The results obtained from the analyses of the two datasets (radiometric and magnetic data) were compiled to produce a final map showing the structural features and high prospective areas for gold mineralization in the study area. The known Gold occurrence locations used in this study were digitized from the mineral resources maps of Nigeria [26], [27].

IV. RESULTS AND DISCUSSION

The total magnetic anomaly (TMA) map (Fig. 2a) reveals the local magnetic field variations in the study area. These variations arise mainly from the subsurface rocks having appreciable magnetic susceptibilities. The TMA data was upward continued to enhance the data's signal-to-noise ratio (SNR). The resulting upward continuation map (Fig. 2b) reveals a reduction in the amplitudes of the anomaly (from a range of about -3 – 118 nT to about 2 – 115 nT) and shows smoother magnetic signature, which indicates a possible removal of short wavelength anomalies typically associated with near-surface noise. The low (blue) and high (red-magenta) magnetic anomalies reflect lithological units having high and low magnetic susceptibilities respectively.

The ASA map (Fig. 2c) shows the total gradient of magnetic anomalies whose peaks indicates the locations of the geological boundaries in the study area. The peaks were automatically traced using the curvature analysis algorithm of [20]. The extracted lineaments were overlain on the ASA map as shown in Fig. 2c. These lineaments are traces of undifferentiated structures, which could be lithological contacts, faults, dikes and other structural discontinuities in the northwestern part of Rijau.

The faults and dike-like structures in the study area were identified using 3D ED with the appropriate structural index (N = 1) for these structures [21], [28]–[30][14]. The clustering of Euler solutions indicates the presence of the geological structures [14], [21]. The result obtained (Fig. 2d) revealed the distribution of faults/dikes at different depth layers. The structures at depths ranging from 200 to 400 m have considerable horizontal extents that are capable of focusing hydrothermal activity in the area. These elongated structures likely served as structural channels for gold-bearing fluids and possibly played crucial roles in the distribution of gold deposits in the study area.

The study area's airborne radiometric maps are presented in Fig. 3. These maps show the concentrations of radioelements in the area and are useful for identifying hydrothermal alteration zones. The study area has up to 4.74% potassium concentration, dominantly in the northern and south-western parts. The equivalent thorium and equivalent uranium counts in the study area are up to about 70 and 11 ppm respectively. Fig. 3d shows the relative abundance of the radioelements, with areas richest in potassium, thorium and uranium respectively coloured red, green and blue. The white parts of the map are areas where the three radioelements have

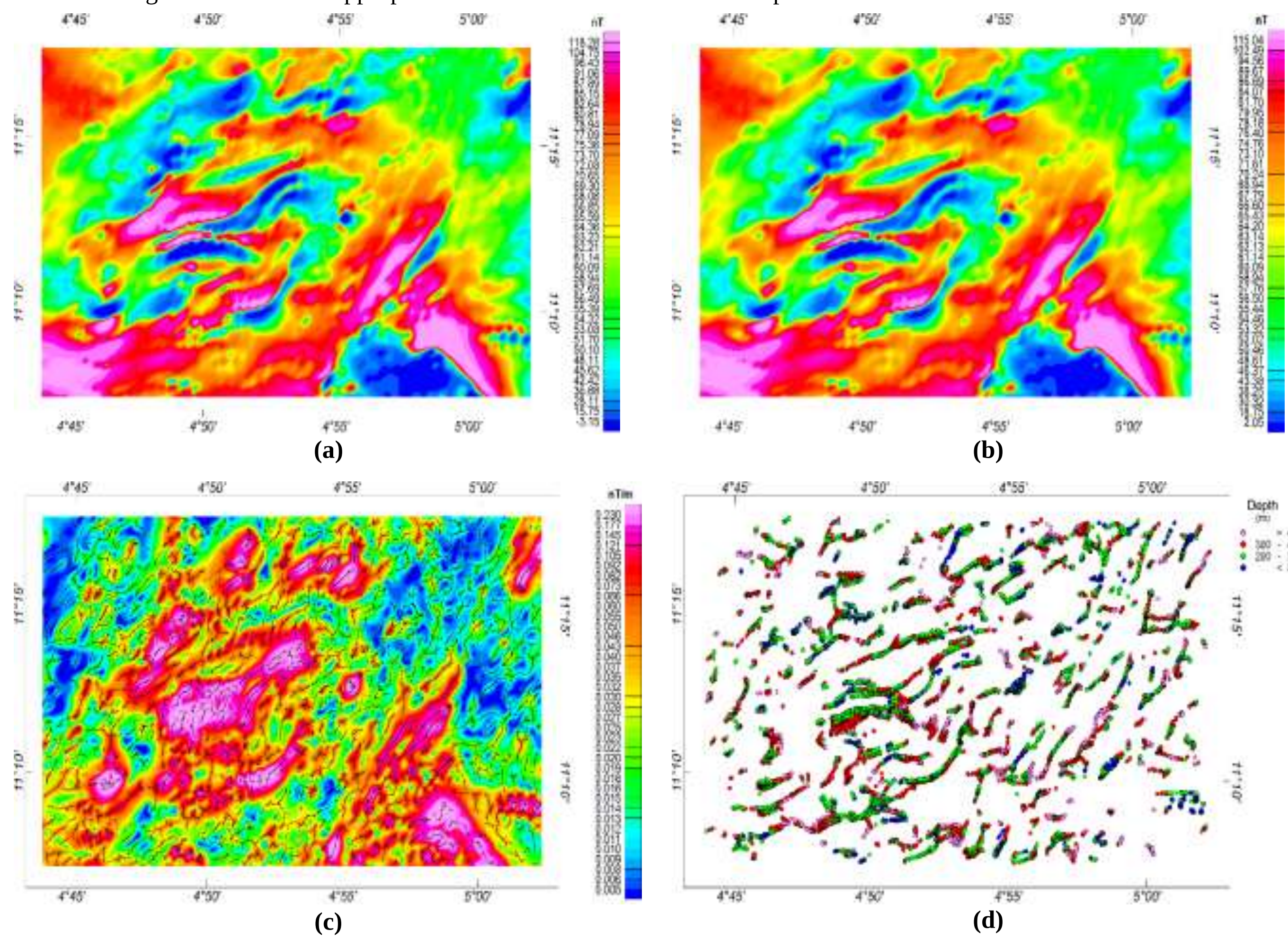

Fig. 2: (a) TMA (b) Upward Continuation (c) ASA and (d) Euler Deconvolution Maps.

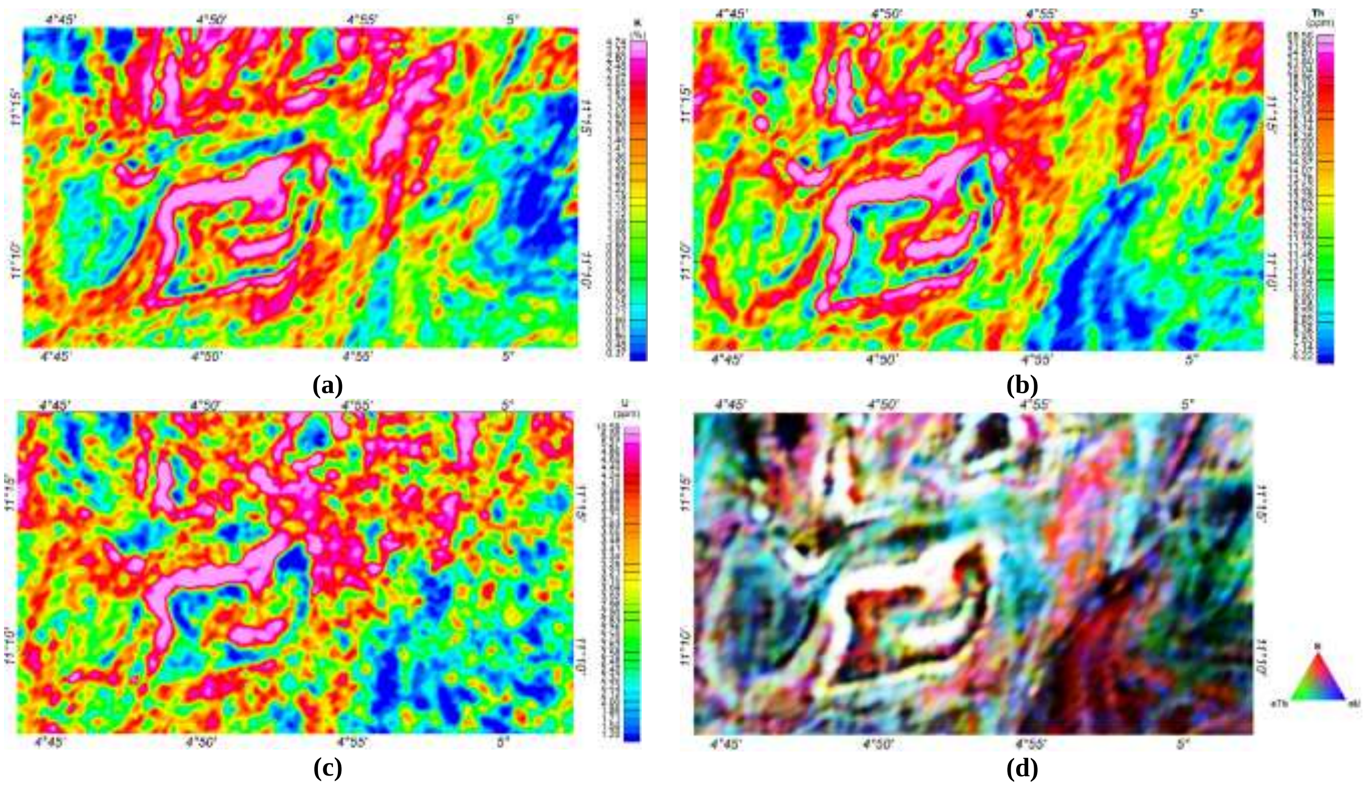

Fig. 3: (a) Potassium (b) Equivalent Thorium (c) Equivalent Uranium and (d) Ternary Image Maps.

high concentrations, while the black parts are areas where the concentrations of the three radioelements are almost equally low. Other colours depict richness of two out of the three radioelements. In order to identify the hydrothermal alteration zones in the area, the ratio of potassium (K) to equivalent thorium (eTh) concentrations was computed and presented in Fig 4. Elevated potassium to equivalent thorium (K/eTh) ratios are pointers to hydrothermally altered zones, which are known to be associated with various ore deposits, including gold [23], [24]. Within the study area, regions showing high K/eTh ratios (red-magenta colour in Fig. 4) are, therefore, interpreted as hydrothermally altered zones with high potential for Gold mineralization.

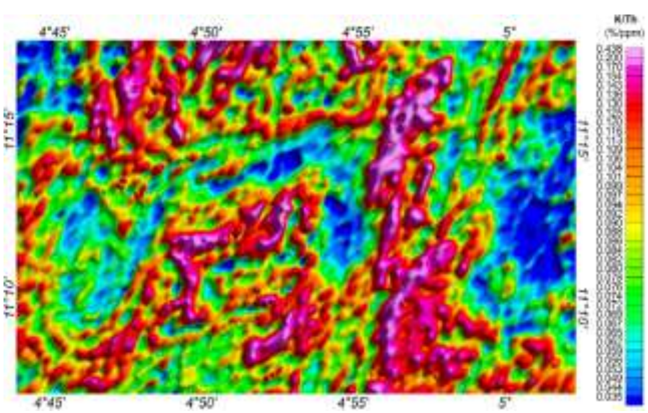

Fig. 4: K/eTh Ratio Map

The results obtained from this study were integrated to produce a structural map (Fig. 5) for the northwestern part of Rijau showing the geological structural features and prospective zones of gold mineralization in the area. As shown by the Rose diagram (Fig. 5), the predominant structural trend in the area is NE-SW. Other significant structural orientations observed include NNE-SSW, ENE-WSW, E-W, and N-S. These structural trends showed that Rijau, and broadly, the Zuru Schist Belt have a polyphase crustal deformation history, reflecting the complexity of the Nigerian basement complex. Most of the identified hydrothermally altered zones, marked as high prospective zones in Fig. 5, are characterized by many geological structures, suggesting that gold mineralisation in the Northwestern Rijau are structurally controlled. Structural controls of gold mineralization along the Zuru schist belt and parts of Northwestern Nigeria have been reported by [2], [24]. The known locations of gold occurrences are indicated on the map by blue rectangles. The structural map (Fig. 5) showed that nearly all the known gold occurrence locations coincide with the marked high prospectivity zones, which validates the interpretive methods employed in this study. The exception near Rafi Na Kacheri, while not directly within a high K/eTh zone, lies along a structural pathway connected to the high prospectivity zone. This suggests that the occurrence of gold in that location might have resulted from secondary deposition mechanisms or remobilisation via fault-controlled fluid flow. The presence of geological structures at the known gold occurrence locations further buttress the possibility of gold deposition on or near structural discontinuities within the study area. Future gold exploration efforts in the Northwestern part of Rijau should prioritize the geological structures within the identified high-prospectivity zones (represented in yellow in Fig. 5).

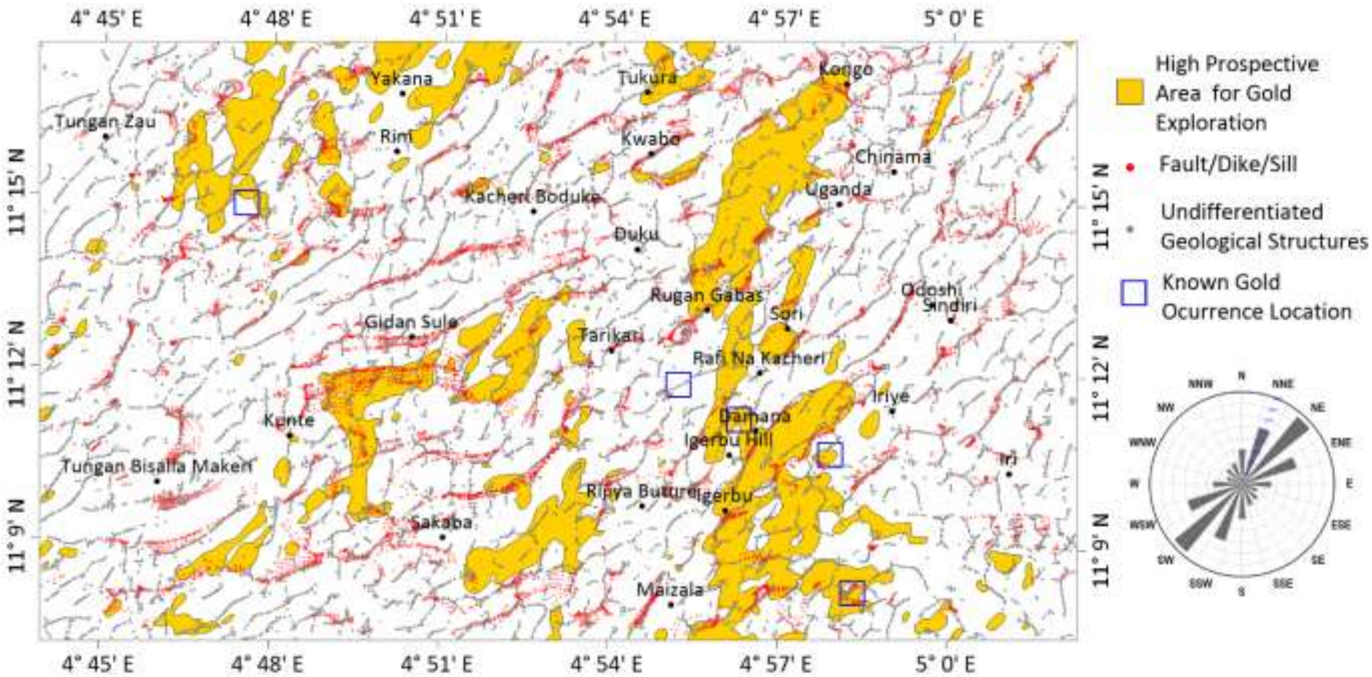

Fig. 5: Structural Map of the Study Area Showing the Geological Structural Features and Potential Gold Mineralisation Zones.

V. CONCLUSION

This study has successfully applied non-invasive geophysical techniques, specifically airborne magnetic and aeroradiometric methods, to detect the geological structures and potential zones of gold mineralization in the Northwestern part of Rijau. The orientations of the geological structures showed predominant NE-SW trend and a polyphase crustal deformation history, typical of a Nigerian basement complex. These structures are spatially associated with potassic alteration zones, which were identified through high K/eTh ratios. Gold mineralization in the study area, according to evidence from this study, is structurally controlled, suggesting gold depositions along or near lithological structural features in the area. Validation of the results obtained in this study with known gold occurrence locations gives positive alignment of the highlighted prospective zones with existing mining sites within the study area, proving the significance of non-invasive geophysical methods in mineral exploration. The structural map presented in this study provides a structural framework for guiding future gold exploration campaigns in the study area. The locations of the geological structures in the identified high prospectivity zones are suggested as exploration targets for in-situ geophysical or geochemical prospecting and other exploration activities in the study area.

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