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Influence of regional transcurrent fault systems on mineralization in the Nigerian Pan-African province

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ABSTRACT

Regional fault systems evolve as a result of crustal movements of massive scale trailing for hundreds to thousands of kilometers across land and sea. The impact of these large-scale geologic structures within such provinces has resulted in the development of primary and secondary conduits, serving as pathways for the movement of mineralizing fluids. Such effects lead to ore deposit formations. The Nigerian regional fault systems trending NE-SW include the Anka–Zuru and Kalangai–Zungeru–Ifewara faults which traverse the entire western half of Nigeria, evident within the Neoproterozoic supracrustal low- to medium-grade metasediments. They are marked by a series of discontinuous quartzite ridges, mylonites, sheared, and cataclastic rocks of discrete bodies. Gold and rare-metal mineralization, however, evolved within associated hydrothermal fluids that exploited the conduits and precipitated within and associated subsidiaries. This paper looks at these regional faults as they act as the primary plumbing systems and points of economic mineralization. Concentrated mineralizing fluids enriched by valuable elements, ions, and metals are thus dispersed into various lithological and/or structural units through multiple subsidiary fractures/faults within the basement complex of Nigeria.

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1. Introduction

Nigeria is endowed with a variety of economic mineral deposits that are distributed within the basement complex and rocks of the sedimentary basins. Of these are the structurally controlled gold (Au) and rare-metal mineralization that are majorly confined to the western half of the country. This region also hosts the two conjugate regional fault systems of the Anka–Zuru and the Kalangai–Zungeru–Ifewara that run through the entire length of the western half of the country, terminating into the Atlantic Ocean. These fault systems have been studied in relation to their mineralization and geochronological importance (Fagbohun et al., 2020; Guillot et al., 2018; Obaje, 2009). Several authors are of the opinion that these two major NE-SW fault systems represent crustal sutures where aggregates or fragments of crustal blocks may have been welded together, serving also as zones of weakness and shear movement (Ajibade and Wright, 1989; Burke et al., 1977; Hubbard, 1975; Wright et al., 1985). Evidence for this is the presence of ultramafic and associated rocks identified along major faults (McCurry, 1989; Wright, 1976), and the occurrence of mafic and ultramafic rocks of ocean floors and island arc compositions in association with serpentinites of the Anka–Zuru fault system. Phase gradients acting on both brittle

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and ductile structures enable fluid migration to zones of deposition within the crust. Transient pressure exists between the regional faults that have been reactivated and the subsidiary fractures, whereby migration of hydrothermal fluids is from high to low pressure regimes across the fractures. This consequently led to gold and rare-metal mineralization. This study discerns the origin, formation, evolution, and roles of major fault systems in Au and rare-metal mineralization within the Pan-African province of Nigeria.

2. Evolution of the Nigerian Regional Fault Systems

Prior to the break-up of the Pangaea, leading to the opening of the Atlantic Ocean, collisions between continental crusts gave rise to the Borborema province of Brazil (South America) and Togo–Benin–Nigeria (Dahomeyan) province of West Africa (Almeida et al., 1981; Dada, 2008). Katz (1981) described the NE-SW trending fractures and N-S shear zones to have evolved across the continents from the abovementioned tectonic event, with the Sobral fault of northeastern Brazil considered representing a continuation of the Kandi fault of southwestern Hoggar. These with other geological and geochronological data were used to propose a rigorous Precambrian fit and correlation of the two continents (Arthaud et al., 2008; Caby, 1989). The West African craton collided with and subducted beneath the Congo craton during the Pan-African orogeny of 600 ± 50 Ma, resulting in the evolution of the Togo–Benin–Nigeria shield whereby several crustal blocks, continental fragments, and island arcs were wielded together (Wright et al., 1985).

Further migmatization, granitization, intrusions, regional structures, and several N-S, E-W, and NE-SW trending shear zones evolved across the region (Dada, 2008); however, some of these structures have been masked by subsequent sediment deposition. Ball (1980) stated that a rigid plastic indentation of the West African craton moving eastward toward the Congo Craton gave rise to the N-S shear zones and the conjugate fault systems. He further observed from photo interpretations of the Taureg shield that conjugate strike-slip faults (predominant NE-SW dextral and NW-SE sinistral trending faults) crosscut the whole shield and displace the earlier formed N-S shear zones. In other parts of the shield, younger N-S and NW-SE fractures also cut the shear zones (Caby, 1968; Vitel, 1975). These fault systems exist everywhere in the Pan-African belt as NE-SW transcurrent strike-slip faults (Ferré and Caby, 2006). Most of the hidden fracturations which existed long before sedimentation were identified by a series of emplaced volcanic rocks and dykes (Beuf et al., 1971).

The Nigerian basement is cut by similar conjugate fault systems which crosscut and displace earlier mylonitic shear zones. Two significant dextral strike-slip fault systems are known, mapped in Nigeria trending NE-SW, and extend toward the West African coast near Lagos and Accra. Their intersection with the coastline coincides with the landward projections of Romanché and Chain fracture zones in the Atlantic (Francheteau and Le Pichon, 1972). These are the Anka–Zuru fault system, formed by Atlantic extension of the Romanché fracture zone, and the Ifewara–Zungeru–Kalangai fault system, formed through extension of the chain fracture zone.

2.1. Anka–Zuru fault system

The NE-SW trending Anka–Zuru fault system is made up of two crustal blocks of different contrasting terranes which became welded together during the Pan-African orogeny (Ajibade and Wright, 1989; Wright et al., 1985). The fault system is closely associated with mafic and ultramafic rocks in the Anka and Zuru settlements (Ajibade and Wright, 1989; Gass, 1981; McCurry, 1978; Ogezi, 1977), which suggests a possible crustal suture (major terrain boundary), with characteristics of an island arc but there are somewhat little lithologic contrasts along the southwestern part of the shear zone (Holt et al., 1978; Utke, 1987; Wright and Ogezi, 1977). However, at the southeastern part of the fault are high-grade metasedimentary rocks, quartzites, dioritic rocks of charnokitic affinity that occur, as well as anorthosites and low dip angle supracrustals which have structural features that can be seen from aerial and satellite photographs (Ajibade and Wright, 1989; McCurry, 1978). This fault system cuts across low- to medium-grade Proterozoic metasediments and metavolcanics of the Zuru and Anka Schist Belts (Danbatta, 2003). The fault zones (i.e., Yelwa, Yauri, and Ribah) marked by McCurry (1978) can be correlated with the shear zones at Garin Hawal, Bin Yauri, and Anka, respectively (Ramadan and Fattah, 2010) (Fig. 1).

2.2. Kalangai–Zungeru–Ifewara fault system

The Kalangai–Zungeru–Ifewara dextral transcurrent fault system is one fault system that is covered by Cretaceous sediments in the of the Nupe (Bida) Basin and extends beyond Nigeria further toward the north into Niger Republic (Garba, 2003) (Fig. 2). The NE-SW trending Kalangai fault zone was reported by McCurry (1970) and Akinyede (1981), marked by a series of discontinuous quartzite ridges, mylonites, sheared,

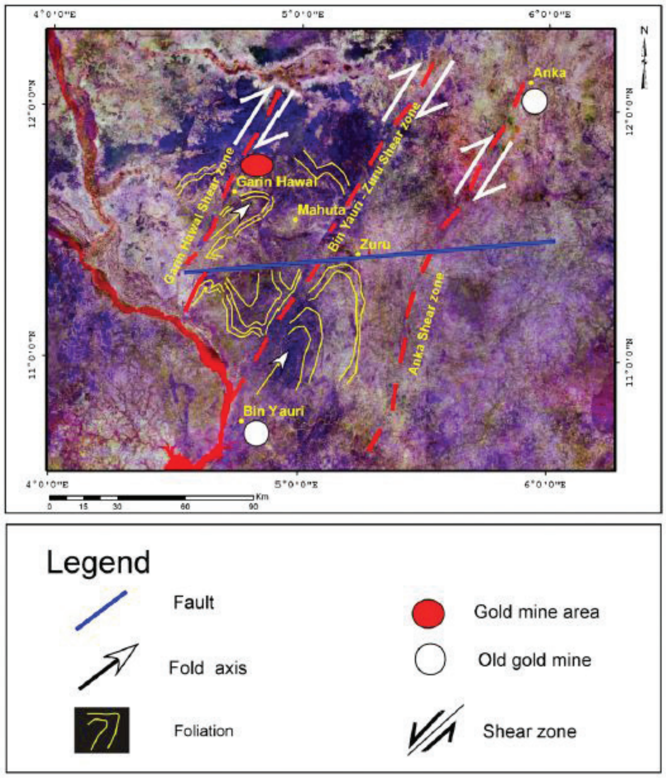

Figure 1. Delineated Garin Hawal, Bin Yauri, and Anka shear zones from a false color composite Landsat image (the blue sub-horizontal line represents the lateral extension of the Anka–Zuru fault system made up of Garin Hawal, Bin Yauri, and Anka shear zones represented by red dotted lines, in Anka and Zuru areas) (Ramadan and Fattah, 2010).

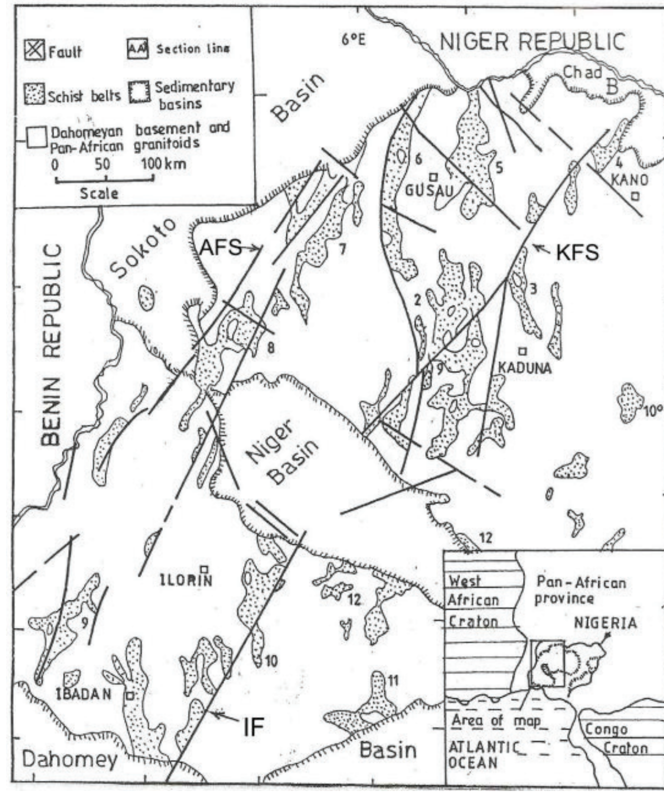

Figure 2. Regional geology and structure of the western half of Nigeria showing the major fault systems. AFS, Anka fault system; KFS, Kalangai fault system; IFS, Ifewara fault system. Modified after Garba (2003).

and cataclastic rocks; all products of shearing are evident throughout the fault zone where they occur as discrete bodies of mylonites (faulted rocks).

Kalangai-Zungeru-Ifewara fault system can be subdivided and described individually into three, namely:

1. The Kalangai fault, as an extensive structural feature, is characterized by fault traces which are marked by minor drag folding and quartz veins, as well as anastomosing foliations in the quartzites (Abdulmalik, 2016). Even though it is poorly exposed, its continuation can be traced by the persistent NE-SW trending quartzite ridges and NE-SW trending courses of River Kaduna. Part of the northern axis of this structure is flanked to the east by highly deformed boulder hills of granitic rocks and scattered metasandstones, and on the west by granitic and gneissic rocks (Abdulmalik, 2016). Subsidiary fractures/faults gave rise to intrusives within the country rocks some of which are quartz–tourmaline pegmatites (Abdulmalik, 2016; Gezawa, 2013). Satellite and aeromagnetic images reveal the trend of the Kalangai fault along with lower order structures which evolved during the late Pan-African tectonism, with a depth of 2–12 km. This indicates the capability of the fault facilitating movement of molten magma and mineralizing fluids (Abubakar, 2017).

2) The Zungeru fault system extends for over 550 km from Ifewara to Zungeru in NNE-SSW direction. It stretches from Ifewara fault system in the southwest, through Okemesi to the south edge of River Niger. A portion of it is covered by Cretaceous sediments of the Nupe (Bida) Basin and reappears extending northward for over 300 km. Satellite imageries have shown that this fault is a dextral strike-slip fault (Ajibade et al., 1979). There are highly folded and foliated rocks which evolved perpendicular to and pre-date the NE-SW fault system. These are the highly sheared Zungeru mylonites which are accompanied with color banding of different compositions (Ajibade et al., 1979). The area is underlain by Ushama, Birnin Gwari, and Kushaka formations and

surrounded by migmatite–gneiss complex in a synclinorium (Ajibade et al., 1979).

3) The NNE-SSW Ifewara megastructure stretches for over 550 km from east of Ijebu Ode, through Ifewara and Okemesi to Zungeru in the northwest of Nigeria. It is covered by sediments of the Nupe Basin and extends northeastward for over 300 km, through Zungeru to Kalangai (Kolawale and Anifowose, 2011). Part of the fault lies within the Okemesi fold belt which represents one of the most distinct manifestations of the late Precambrian deformation in Nigeria (Adepelumi et al., 2008). It cuts across a 3–5 km wide shear zone which is dominated by mylonites and associated with thrust-folded rocks (Affaton et al., 1991). The Ifewara fault system also comprises sinistral strike-slip faults trending NW-SE which were formed during the Pan-African orogeny. Deformation fabrics in the basement complex of southwestern Nigeria are commonly aligned parallel to the direction of the Ifewara fault zone, thus implying that this major fault has a profound and wide influence on the fabric and degree of metamorphism in the area. The Ifewara fault system cuts the Ilesha schist belt into two halves: (i) the western half, which has mylonitic foliations trending NNE-SSW and in which the fault bifurcates into an inverted "V"; and (ii) the eastern half, which has foliations trending NNW-SSE with discontinuous quartzite ridges (Onyedim, 2007).

2.3. Mineralization and impacts of the Nigerian basement complex fault systems

The Nigerian basement complex lies to the east of the West African craton, northwest of the Congo craton and to the south of the Taureg shield. These complexes form part of the Pan-African terrane which is considered as southern prolongation of the Central Hoggar (McCurry, 1976). According to Black et al. (1994), it was formed during the collision of the West African craton, Congo craton, and the East Saharan block. The Nigerian basement complex is divided into three broad lithological groups, namely the Achaean polymetamorphic migmatite–gneiss complex, the Proterozoic low-grade metasediments, and Pan-African syn-late tectonic granitic rocks (Ajibade et al., 1989; Dada, 2008; Woakes et al., 1987), accounting for about 50% of the entire landmass of the country.

The migmatite–gneiss complex is made up of heterogeneous assemblages of rocks which largely include migmatites, ortho- and para-gneiss, amphibolites, and a series of basic to ultrabasic metamorphic rocks (Dada, 2008). The low-grade metasedimentary and metavolcanics rocks are supracrustal assemblages infolded into the migmatite–gneiss complex. They make up the schist belts covering an approximate width of 400 km in the western part of Nigeria. About 12 schist belts have been identified and each is separated from the other by migmatites, gneisses, or granitoids (Fig. 3). The Older Granites or Pan-African granitoids with ages in the range of 450–750 Ma are syn-late tectonic intrusions of biotite and biotite–muscovite granites, gabbros, syenites, charnokites, tonalities, diorites, monzonites, and other similar rocks (Ajibade et al., 1987; Rahaman, 2006). The Older Granites occur intricately in association with both the migmatite–gneiss complex and schist belts where they are tectonically emplaced as intrusions cutting through them.

Fractures serve as plumbing systems and migratory mediums exploited by mineralizing fluids and channeled into subsidiary/conjugate fractures and solidify as pegmatitic veins, sheets, or dykes (Akande et al., 1988; Eisenlohr et al., 1989; El-Nafaty, 1988; Garba, 2000, 2002). They serve as loci of a wide range of economic mineralization associated with convergent terranes or suture zones and as conduits through which fluids/melts flow (Fyfe and Kerrich, 1985; Garba, 2002). Thus, in such settings, mineralization occurs across all lithologies, although some minerals are more concentrated in a particular geologic setting than others, e.g., gold within schist belts (Ajayi, 1982; Garba, 1992a, 1992b, 2000, 2002, 2003; McCurry, 1973, 1978; Ogezi, 1977; Truswell and Cope, 1963; Wright and Ogezi, 1977; Wright, 1976, 1988, 1989).

The occurrences of rare-metal pegmatites have been documented from different parts of Africa (e.g., Rwanda, Egypt, Sudan, South Africa, and Nigeria), with mineralogical indicators and enriched LREE and HREE associated with peraluminous rocks (Anton and Anatoly, 2012; Cerny, 1992; Linen et al., 2012; Matheis, 1987; Morsy and Mohammed, 1990; Morteani et al., 2000). The corresponding structural patterns of the Nigerian and Borborema provinces show a link and control of these fractures to mineralization, from Nigeria to the eastern part of Brazil, respectively (Morteani et al., 2000; Torquoto and Cordani, 1981). Rare-metal pegmatite mineralization was discovered to be concentrated along a well-defined 400-km long pegmatite belt that trends in a NE-SW to ENE-WSW direction oriented N-S from the southwest to north-central Nigeria and at Obudu and Oban massifs in the south, and in the

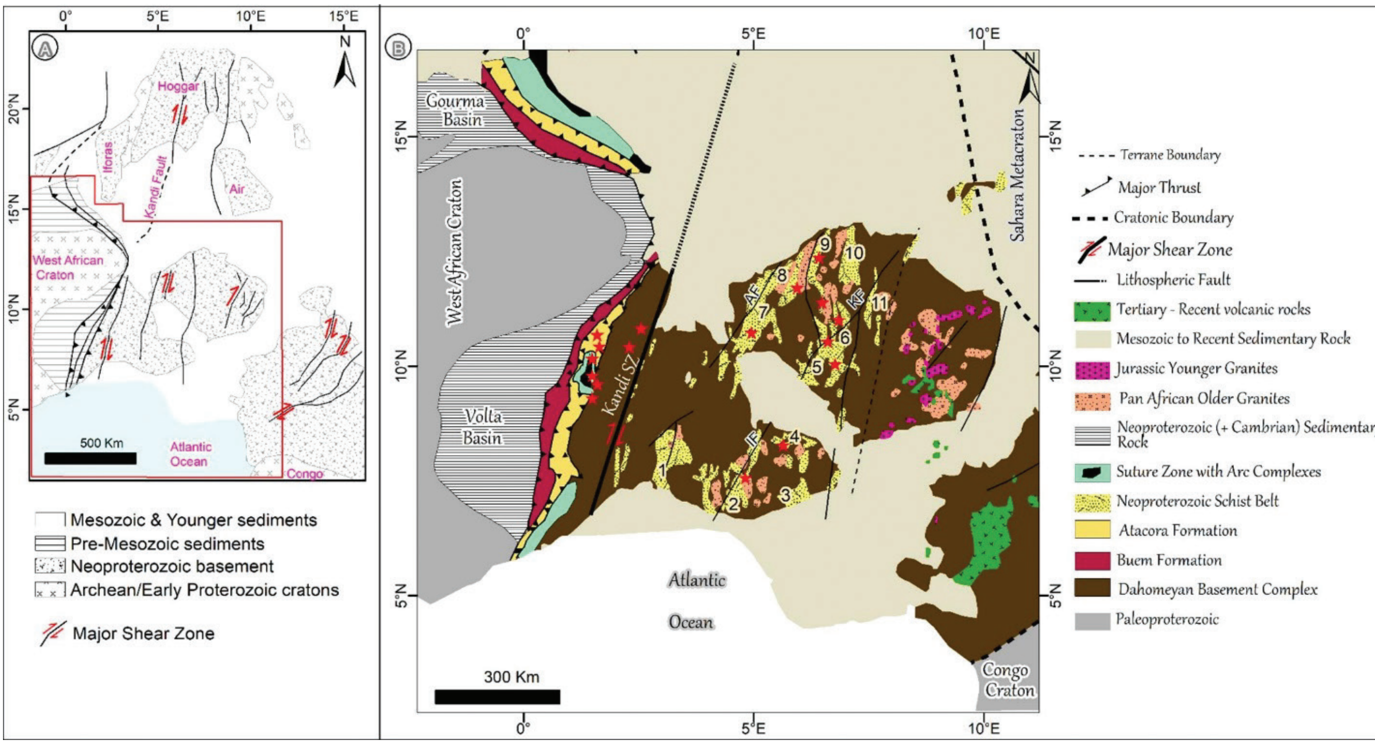

Figure 3. (A) Major lithotectonic units in the trans-Saharan belt and West African craton. Red polygon shows the area covered. (B) Generalized geological map of Dahomeyan shield showing major neoproterozoic schist belts (Fagbohun et al., 2020). 1 = Iseyin-Oyan; 2 = Ilesha; 3 = Igarra; 4 = Egbe Isanlu; 5 = Zungeru–Birnin Gwari; 6 = Kushaka; 7 = Zuru; 8 = Anka; 9 = Maru; 10 = Wonaka; 11 = Karaukarau. IF = Ifewara fault; AF = Anka fault; KF = Kalangai fault.

Kushaka schist belt in northwestern Nigeria (Garba, 2003; Goodenough et al., 2014; Küster, 1990; Matheis, 1987; Olade and Elueze, 1979; Olade, 1976). The mineralized pegmatites were sourced from late stage Pan-African magmatism and emplaced into granitic, gneissic, sedimentary, metavolcanic, and schist belt settings of the Nigerian basement complex, associated with the reactivation of the regional transcurrent fault system (Abubakar, 2014; Ekwueme and Matheis, 1995; Fitches et al., 1985; Garba, 2003; Kinnaird, 1984; Popoff, 1990; Woakes et al., 1987). This mineralization was from Na-rich hydrothermal fluids from the upper mantle which accompanied high-grade metamorphism or partial melting and leaching processes of the basement units or fractionation of late tectonic magmatism as observed from the southwest, north-central, and northwest Nigeria (Akintola and Adekeye, 2008; Garba, 2003; Matheis, 1987; Oshin and Rahaman, 1986). Thus, fractionation of late tectonic melts/hydrothermal fluids leads to the crystallization of peraluminous granites which played a role in large ion lithophile element concentration and rare-metal pegmatite mineralization (Garba, 2002; Küster, 1990; Morsy and Mohammed, 1990). The field occurrences of both gold and rare-metal mineralization lie concordantly along

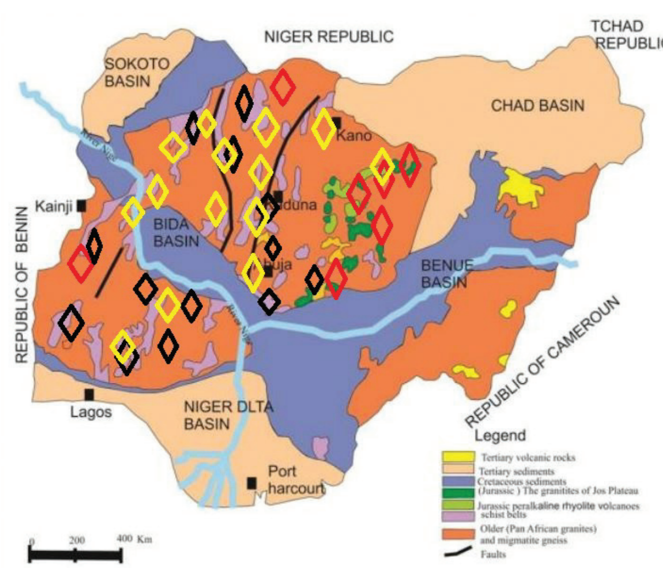

Figure 4. Localization of tin–columbite (Red), coltan (black), and gold (yellow) mineralization coinciding with the regional transcurrent fault systems of Nigeria (modified after Ahmed et al., 2017).

the Kalangai regional fault system within the basement complex (Fig. 4), as they have been established to be products of its reactivation (Garba, 2002).

3. Conclusion

There is a direct relationship between gold and rare-metal mineralization with the regional transcurrent fault system as both were emplaced during the late stages of the Pan-African event. The gold mineralization in Nigeria is known to occur in primary and secondary forms, with the former hosted by quartzo–feldspathic veins, veinlets, and stringers that are found within the basement rocks. The corresponding NE-SW and NNW-SSE trends of these mineralized bodies lead several authors to believe the Anka–Zuru and Kalangai–Zungeru–Ifewara faults were conduits through which the auriferous fluids migrated and deposited within epizonal and meso-zonal regions within the crusts. Although, globally, Archean greenstone belts are known to host large gold deposits, deformation and polymetamorphic episodes like that of the 500 ± 150 Ma Pan-African orogeny can reset, remobilize, enrich, and form new deposits that could be within structures produced during the orogeny or at the waning stages. Thus, the Pan-African provinces in Nigeria, especially the schist belts have auriferous concentrations within the NE-SW and NNW-SSE trending structures. Rare-metal pegmatite mineralization is broadly classified into two: the upper Proterozoic mineralization and Mesozoic mineralization. The movement and fractionation of Na-rich hydrothermal fluids leads to the enrichment and concentration of large ion lithophile elements and rare metals within pegmatites that pervade peraluminous granites, gneisses, and schists. They have been observed to be concentrated along a narrow belt from the southwest to the northcentral region, although recent discoveries reveal their occurrences in the southern and northwestern parts of Nigeria. However, they coincide with the regional fault systems. However, both lack direct relationship with Pan-African granitoids in terms of their source and age differences (Abdulhamid, 2017; Adetunji and Ocan, 2010; Akoh et al., 2015). A significant role was played by continental lineaments in the genesis of rare-metal pegmatites with regard to degree of fractionation of late tectonic melts and the influence of fluid phases along the wall rocks. The mineralization process influences the radioelement contents of rocks which are useful in identifying zones of potential mineralization. Linear aero-radiometric anomalies indicate locations of fault lines which are likely to be mineralized with radioactive elements. More so, the integration of satellite images and geophysical data has so far been highly useful in exposing surface and sub-surface extensions of fractures, as plumbing systems and points of economic mineralization, thus distributing mineralizing fluids into subsidiary fractures.

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