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RESEARCH ARTICLE

PETROGRAPHY AND GEOCHEMISTRY OF METASEDIMENTS FROM BUGAJI, PART OF MALUMFASHI SHEET 79 NE, KANO STATE, NORTHWESTERN NIGERIA

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ABSTRACT

This research is aimed at determining the protolith of metasediments that underpin the geology of Bugaji region of Kano State. The study area was mapped systematically and the lithologies encountered include phyllite, undifferentiated schist, quartzo-feldspathic schist, and gneiss. Samples taken from several outcrops were subjected to mineralogical and geochemical analyses using X-ray diffraction and X-ray Fluorescence (XRF), respectively. The metasedimentary rocks have evidently undergone significant deformation textures (foliation, lineation, and fractures), and metamorphism, indicating the area is situated in a tectonically active zone. Quartz, feldspar, mica, and a number of accessory minerals make up majority of the metasediments, while the geochemical data show enrichment of aluminum, silica, and iron. The geochemical indicators support the idea that the rocks developed on a continental margin. The mineralogy and geochemistry indicate the rocks likely came from a source region with a predominance of granitic rocks.

KEYWORDS

Quartzo-feldspathic schist; phyllite; metasediments, Protolith; Petrographic analysis, gneiss; Schist belt; metamorphism.

1. INTRODUCTION

During metamorphism, the original sedimentary rocks undergo a physical and chemical change, which can result in the formation of new minerals and the recrystallization of existing ones. The degree and duration of heat and pressure that the rocks experience can vary, leading to the formation of different types of metamorphic rocks, such as slate, schist, and gneiss. The geological history of metasediments can provide valuable insights into the history of the region in which they formed. The orientation of the metamorphic foliation, or the alignment of minerals in the rock, can provide clues about the direction and intensity of the pressure that the rocks experienced.

Nigeria has a complex geology that includes a wide variety of metamorphic rocks, including metasediments. The study of metasediments in Nigeria has focused on several regions, including the basement complex and the Pan-African mobile belt. The Schist Belts comprise low grade, metasediment-dominated belts trending N–S which are best developed in the western half of Nigeria. These belts are considered to be Upper Proterozoic supracrustal rocks which have been infolded into the migmatite-gneiss-quartzite complex. The lithological variations of the schist belts include coarse to fine grained clastics, pelitic schists, phyllites, banded iron formation, carbonate rocks (marbles/dolomitic marbles) and mafic metavolcanics (amphibolites). Some may include fragments of ocean floor material from small back-arc basins. The schists are considered as either stemming from metamorphic changes of several basins of deposition or relicts of a single supracrustal cover (Oyawoye,1972; Grant, 1972/1978).

For investigated the metasediments in the northwestern part of Nigeria, which includes parts of Kano state (Idris and Lawal, 2016). The study combined field observations, petrographic analysis, and geochemical analysis to identify the mineralogy, texture, and chemical composition of the metasediments. The study found that the metasediments in this region were derived from a variety of different sedimentary rocks, including sandstones, shales, and limestones, and that they had undergone varying degrees of metamorphism, ranging from low-grade to high-grade. The researchers also identified several deformation events that had affected the metasediments, including folding, faulting, and shearing. Additionally according to the study found out that the metasediments in this region had undergone hydrothermal alteration, which had resulted in the formation of mineral veins, such as quartz and calcite veins (Idris and Lawal, 2016). The researchers suggested that the hydrothermal alteration may have been caused by fluid flow associated with nearby igneous intrusions. The proto- investigation of metasediments in northeastern Nigeria, including Kano state, is important for understanding the geological history of the region, particularly the types of sedimentary rocks that were present and the tectonic processes that were involved. The study also highlights the potential for mineral exploration in the region, particularly with regards to mineral veins associated with hydrothermal alteration.

Despite existing research, there remains limited information on the petrology of metasediments in the Gwarzo area of Kano, specifically Bugaji. Moreover, geochronology, metamorphic cycles, and the history of different rock types in this region are yet to be established. To address these knowledge gaps, it is crucial to determine the protolith of metasediments, which remains unaccomplished. Besides, only a few studies have tried to characterize the petrology in terms of the actual mineralogy and geochemical composition to fully differentiate between the metasediments (Ajibade 1982, 1987; Idris and Lawal, 2016). This research is aimed at determining the protolith of metasediments that underpin the Geology of Bugaji region of Kano using geochemical techniques. This way, we can be able to fully understand the petrology of the metasediments of Gwarzo area for proper integration with the known Schist belts of Nigeria. Studying the geochemistry and mineralogy of metasediments can help us understand the tectonic and thermal history of

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the region, including the movement of tectonic plates and the formation of mountain ranges. It can also provide insights into the formation and distribution of mineral resources, such as gold, copper, and zinc, which are often associated with metamorphic rocks. The aim of the study is to determine the protoliths of the metasediments based on geochemical data. This paper also investigates the textural variations in the metamorphic rocks using thin-section petrography, and identifies the micro-domains in the metamorphic rocks.

2. GEOLOGY OF KANO

The basement complex made up approximately 97% of Kano state, while the sedimentary basin cover just 3% located in the northern part of the state, mostly around Dambatta and Makoda local government areas (KNARDA, 1986). These sediments were believed to be the extension of Gundumi formation of Sokoto/Illummeden Basin. The boundary between the basement complex and sedimentary basin is generally well defined, although in few areas there is transition zone in which the sediments are swallow for quite some distance dipping down gently. In the basement complex, the rock type encountered were predominantly granite, with migmatite gneisses, schist and minor occurrence of quartzite, volcanic basalt and rhyolite.

The study of the tectonic history of Kano State has revealed the presence of several tectonic events that have shaped the region over time. One of the key tectonic events that have shaped the region is the Pan-African orogeny, which is believed to have occurred approximately 550 million years ago (Dada et al., 2006). The Pan-African orogeny is characterized by the formation of large mountain ranges, the creation of new crustal plates, and the collision of existing plates (Burke and Dewey, 1972). Another significant tectonic event that has shaped the region is the opening of the Atlantic Ocean, which is believed to have occurred approximately 200 million years ago (Dada et al., 2006). The opening of the Atlantic Ocean is characterized by the separation of the African and South American continents, which resulted in the formation of a new oceanic plate (Burke and Dewey, 1972). In addition to these tectonic events, the study of the tectonic history of Kano State has also revealed the presence of several volcanic events, which are believed to have occurred as a result of tectonic movements and deformation. The volcanic events in the region are characterized by the presence of volcanic rocks, such as basalt and rhyolite, which provide important information about the timing and intensity of the volcanic events.

The structural geology of the region has revealed the presence of several geological features, such as folds and faults. The tectonic history of Kano State has revealed the presence of several key tectonic events, such as the Pan-African orogeny and the opening of the Atlantic Ocean, which have shaped the region over time. The structural features of the rocks in the region, such as fold axes, lineations, and faults, provide important information about the deformation processes that have shaped the region over time. The several fold axes are believed to have formed as a result of tectonic movements and deformation (Danbatta, 2003/2008). The fold axes in the region are characterized by steeply dipping limbs and gently dipping hinges, which suggest that the folds were formed during regional compression (Danbatta, 2008). Faults are also a significant feature of the structural geology of Kano State, which have provided important information about the timing, magnitude and direction of tectonic movements.

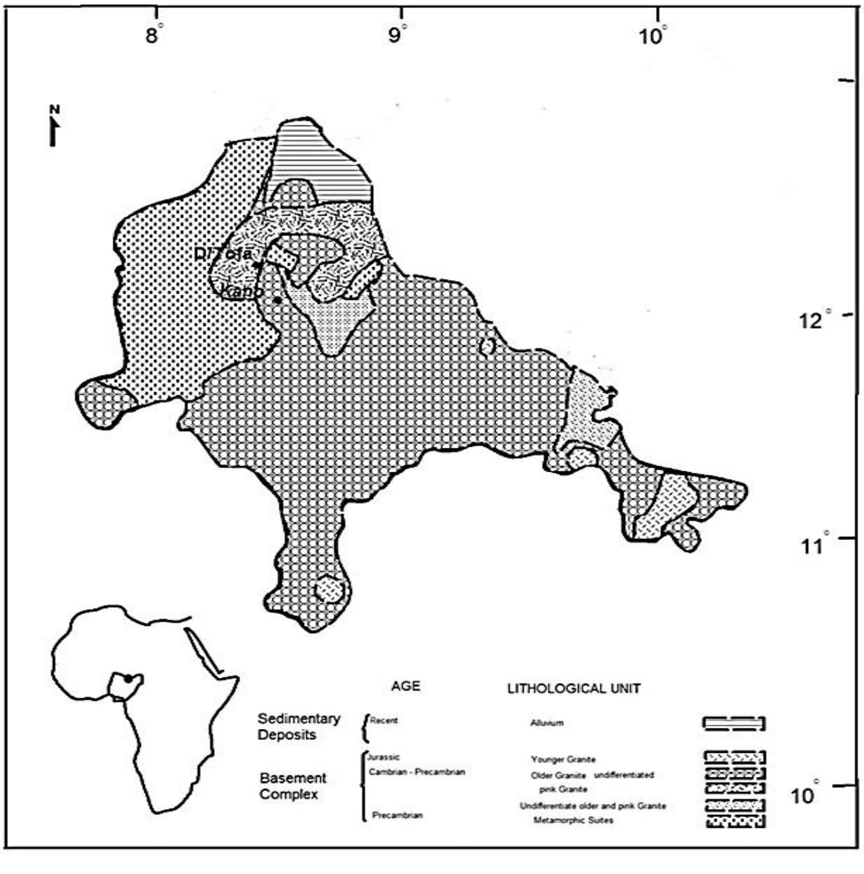

Figure 1: Geological map of Kano state

The rock type in Kano State can be classified into three main groups: granites, gneisses, and schists. Granites are the most abundant and are characterized by their light-colored, coarse-grained texture. Gneisses are metamorphic rocks that have been subjected to high pressure and temperature, resulting in a layered, banded appearance. Schists are also metamorphic rocks, but have a more finely-grained texture and are often composed of minerals such as mica and chlorite. The distribution of these rock types varies across the state, with granites being most abundant in the northern and eastern regions, and gneisses and schists being more prevalent in the western and southern regions (Obaje, 2009; Tijani, 2023).

The mineral content of the rock formations in Kano State is also of great significance, as it provides insight into the geological evolution of the region. The mineralogy of the rocks in the region is characterized by a diverse range of minerals, including silica, aluminum, biotite, quartz, feldspar, and others (KNARDA, 1986). For example, granites in the region are rich in silica and aluminum and are believed to have formed from the partial melting of ancient crustal rocks (Kitha et al., 2022). Gneisses and schists, on the other hand, are composed of minerals such as biotite, quartz, feldspar, and other minerals that formed as a result of metamorphic processes. The presence of these minerals in gneisses and schists suggests that they have been subjected to high pressures and temperatures over time. In addition to their mineral content, the rock formations in Kano State also provide important information about the region's tectonic history. For example, the presence of high-pressure metamorphic rocks such as gneisses and schists suggest that the region has been subjected to tectonic forces and high temperatures over time.

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3. MATERIALS AND METHODS

This involved detailed geological mapping using all the necessary field equipment. Description of all rock samples encountered was done on the field by hand observation of texture, color, mineralogy and structures based on which the rocks were named. It also involved the differentiation of geological structures as well as rock types and outcrops of the area. Samples were collected at different locations of certain distances, and were labeled to avoid mix up and are afterwards used to produce the geological map of the area as noted on the topographic map.

Thin sections of the rocks were prepared and analyzed under a microscope to study their mineralogy and texture. The optical properties of the rock were analyzed under both Plane Polarized Light (PPL) and Cross Polarized light (XPL). X-ray Florescence (XRF) was used for chemical composition determination. The analysis begins with creating an application calibration and validating the calibration before measurement of prepared samples. Manufacturer set standards were adhered to, so as to ensure accuracy of results. The samples were first grounded into a homogenous powder approximately 100-200 mesh, and then about 5g of each samples were weighed into 32 mm sample cups with a polypropylene X-ray film of 4 μm thickness and were hydraulically pressed. Sample heights were measured in millimetres and sample cups were capped. The EDXRF analysis was performed using a Rigaku NEX DE EDXRF spectrometer equipped with a fifteen-place sample changer with spin function using slow and steady spinning mode. The XRF data was analyzed using GeoChemical Data (GCD) ToolKIT (freeware version). This is based on the use of variation diagrams to analyze the rock compositional data.

4. RESULTS AND DESCRIPTION

4.1 Field Mapping and Outcrop Description

Figure 2: An overview of the sampled weathered outcrop

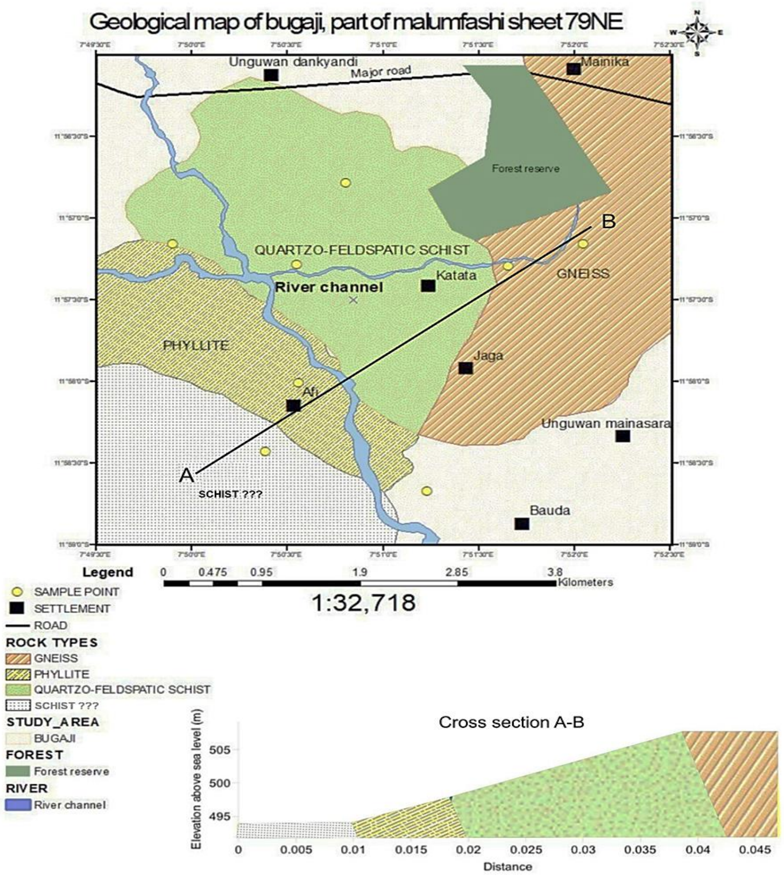

Figure 3: Geological map of the study area (part of Malumfashi sheet, 79 NE), showing the distribution and cross section of the identified lithological units

The mapped area of Bugaji consists mainly of metasediments as the main rock types with varying mineralogical compositions and different textures and structures. However, most of the outcrops are evidently affected by weathering as shown in Fig. 2. Based on visual observations of rock texture and mineralogy, 4 key rock units were identified, which include, phyllite, quartzo-feldspathic schist, gneiss and a highly weathered schist (identified based on its retained relic of schistosity). These lithological units displayed fractures, faults, anticlinal folds, joints, veins and pegmatic structures, with high degree of weathering. These rocks are well exposed along stream beds, river channels and excavation sites.

Based on data gathered on the outcrop orientation (strike and dip), height, and traversing the distribution of the rock units, a geological map was developed, as shown in Fig. 3. The gneiss rock unit is found in the North-eastern part of the mapped area, Traversing westward showed the presence of the quartzo-feldspathic schist. This schist covers the north and central part of the mapped area. The phyllite units can be seen in the south western part of Bugaji, while the highly weathered schist is found in the southern corner of the mapped area. A cross section was drawn across the study area, from north east to south west. The cross section clearly shows a sequence of low grade metamorphism (phyllite) to high grade metamorphism (gneiss) in the direction of East to West.

4.2 Identified Rock Units

The major rock types identified in the study area include phyllite, quartzo-feldspathic schist and gneiss. Coarse and fine textured variations of the quartzo-feldspathic schist were also observed. The rock types are analyzed and discussed in the subsections below

4.2.1 Phyllite

As shown in Fig. 4A, the phyllite rock is a gray/blackish/dark greeenish foliated rock, glossy or reflective sheen/larger minerals are indicative of mica or chlorite, which differentiates it from slate. Phyllite is a low-grade metamorphic rock. The light colored laminations show the parallel arrangement or alignment of the mica grains, which gives the rock its fissile nature, i.e. ability to be easily split into sheets or slabs (Fig. 4B). The phyllite is denoted by clay to mica transformation. The dark grey illites show prominent linear fabrics.

Figure 4: Photograph Of Phyllite Showing (A) Laminations, And (B) Alternating Dark Bands

The phyllite is formed from the mild alteration of slate or mudstone by heat and direct pressure from regional metamorphism. They are usually indicative of convergent plate boundaries involving continental lithosphere. The initially random semi-random oriented clay minerals are then aligned in parallel, and the clay minerals are transformed by heat and chemical activity into chlorite or mica. Figure. 5A presents the top-view of the phyllite interbedded with the light-colored mineral grains, i.e. more coarser or larger mica and chlorite grains. The alternating bands are of similar width. As observed in Fig. 5B, the light-colored band appears larger than the phyllite layer, suggesting a higher heat transformation phase. Fig. 5C shows a sharp contact differentiating the phyllite from the quartzo-feldspathic schist, indicating a complete metamorphic transformation. Along the contact zone, the schist show rough foliation identified by elongated quartz and feldspar grains. The transformation of the phyllite into the quartzo-feldspathic schist indicates increase in heat and chemical activity.

Figure 5: Photograph showing (A) alternating phyllitic and light colored layer, and (B) phyllite interbedded with light colored band, (C) sharp contact between quartzo-feldspathic schist and phyllite

4.2.2 Quartzo-Feldspathic Schist

This flesh-colored rock unit shows a layered, strongly foliated rock (Fig. 6), indicating the abundance of quartz and feldspar. The colour and mineralogy of the schist suggest the protoliths are typically granites, rhyolites, or arkosic arenites. The quartzo-feldspathic schist consists of coarse and fine grained (Fig. 6A & B), suggesting different phases of metamorphism. The coarse quartzo-feldspathic schist (Fig. 6A) displays a porphryblastic texture with clear schistocity. This low lying rock unit extends over the central part of the study area. In some outcrops, these rocks appear to be fractured and cut by quartz veins, resulting in their silicification, which could be responsible for their salient hardness.

Figure 6: Field photograph showing (A) coarse grained quartzo-feldspathic schist, and (B) fine grained quartzo-feldspathic schist

4.2.3 Gneiss

Gneiss is a banded, foliated metamorphic rock, showing more developed differentiation of the psammitic (light) and pellitic (dark) or mafic bands (Fig. 7A). The rock is medium to coarse grained. The gneiss is identified by the much coarser texture (coarser than schist) and prominent. Unlike in schist, the bands in gneiss are discontinuous and wane off after some indefinite scale. As observed (Fig. 7B), the schistose foliation is poorly developed, possibly due to the relatively lower mica in the rock. This also accounts for the compactness and increased hardness of the rock as compared to the phyllite and schist rock units. However, the outcrop show intense weathering effects, as indicated by the brittleness and bleached rock color. This similarly low lying rock unit is present in the eastern part of the study area.

Figure 7: Field photograph showing (A) fractured gneiss (B) distinct alternating gneissose banding of light and dark colored minerals

4.3 Thin Section Petrography

The optical properties and the mineral composition of the phyllite under both plane polarized light (PPL) and cross polarized light (XPL) conditions were analyzed. The crossed polars image reveals that there are several minerals present: quartz in grey and whites and micas in higher order colors. The alignment of the micas is clearly apparent. The undulose extinction and elongate sub grains in quartz can be attributed to dislocation formation and migration. The thin section shows that the grey phyllites exhibit a lepidoblastic texture where approximately 90% consists of fine grained crystals. This further supported by the recrystallized quartz with irregular (sutured) boundaries, formed by grain boundary migration. Quartz is identifiable from its low relief under PPL (Fig. 8A), and distinct sub-hedral structure under PPL. The quartz is mostly equigranular, fine-grained andaligned. Muscovite is also recognized under crossed polars based on its columnar shape and pleochroic color. Fig. 8B shows the sinusoidal alignment of the matrix material to form a crenulation structure. The formed crenulation obviously compact and re-align the quartz grains to create a close parallel arrangement, which accounts for the fissility of the phyllite. Therefore, the rock is definitively phyllite and shows both foliation and crenulation.

The fine and coarse quartzo-feldspathic schist were studied under both PPL and XPL conditions. As shown in Fig. 8(C&D), the schist is composed of fine to medium sized quartz grains, as well as both biotite and muscovite mica, chlorite, sericite, plagioclase and opaques. Plate 6A&B shows the presence of clinopyroxene as identified by its colorless property under PPL and pale brown color under XPL, medium to high relief, and parallel to [110] cleavage that intersects at 90°. The presence of pyroxene indicates the instability of the sheet silicates, and the metamorphic progression of the schist into a higher grade. Fig. 8D shows that the euhedral muscovite mica and chlorite are scattered in the quartz groundmass. The granoblastic quartz crystals showed undulatory extinction and contained micro-cracks. As observed, the quartz grains are aligned in a preferred direction, parallel to the micas and chlorite microcrystals.

The thin section of the gneiss rock, a high grade metamorphic rock, shows the presence of clinopyroxene, which is evident by the dark color in XPL, high relief, and almost perfect cleavage (Fig. 8H). These pyroxeneminerals tend to form elongated crystalsand become segregated in distinct bands through the rock, to produce thegneissic banding.The grains show a preferred orientation with their longdirections perpendicular to the maximum differential stress. The dark colourminerals re-align the interlocked/sutured quartz grains to create a foliation or band.Hence, it appears the foliation is wrapped around a porphyroblast.

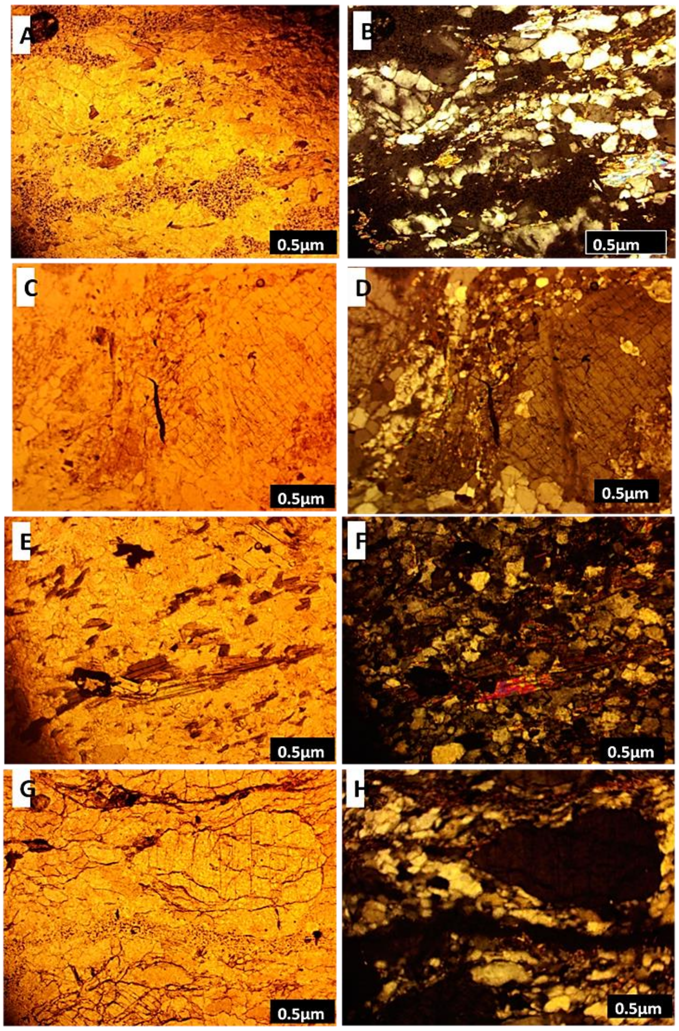

Figure 8: Thin section photomicrographs of phyllite under (A) PPL and (B) XPL, Coarse quartzo-feldspathic schist under (C) PPL and (D) XPL, fine-grained quartzo-feldspathic schist under (E) PPL and (F) XPL and gneiss under (G) PPL and (H) XPL

4.4 Structures

A fold was sited at a weathered gneiss outcrop in Bugaji area (Fig. 9), which appears to be affected by weathering on the surface, but the direction of overturning was apparent. The type of fold was an anticlinal fold with four limbs, as shown in Fig. 9. During our mapping of Bugaji metasediment area, we also observed few fractures (Fig. 10A) accompanied with series of joints. Quartz and quartzite veins were also observed within the quartzo-feldspathic schist (Fig. 10B), indicating the infilling of fractures by the silica rich magma. No concordant structural features were observed in the quartz, suggesting the veins were probably formed after metamorphic changes.

Figure 9: Photograph of the anticlinal fold in the Gneiss

Figure 10: Field photographs of fractured schist, and (B) quartz and quartzite vein within the quartzo-feldspathic schist

4.5 Geochemistry

4.5.1 Major Oxide Geochemistry

Table 1 presents the major oxide composition of the rock samples, while Table 2 presents the trace elemental composition. Utilizing discriminating plots based on the major element composition of the metamorphosed sedimentary rocks, an initial geochemical approach was made to investigate the nature of the source area and the tectonic context of the depositional basin. SiO_2 (64 wt.%) and Al_2O_3 (15 wt.%) plot (Fig. 11)grouped the phyllites, fine quatzo-feldspathic Schist of the study area into metapelites (MPEL) and the quartzo-feldsphatic schists and gneiss into metapsammites (MPSA) group.

Table 1: Major oxide composition of the metasediments

Oxide composition (%)	Pelitic Phyllite	Coarse Quartzo Feldspathic Schist	Fine Quartzo-Feldspathic Schist	Gneiss	Veins	Fine Quartzo-Feldspathic Schist
Al_2O_3	25.981	15.805	19.330	15.160	1.550	22.255
SiO_2	57.357	69.475	60.929	66.443	96.838	65.824
P2O5	0.393	0.381	0.473	0.465	0.323	0.343
SO_3	0.069	ND	0.0560	0.055	ND	ND
K_2O	4.418	4.598	4.003	5.870	0.300	5.896
CaO	2.010	1.500	1.914	1.492	0.136	0.870
TiO_2	0.712	0.352	0.585	0.574	172.9	0.152
MnO	0.050	0.027	0.030	0.082	ND	0.027
Na_2O	ND	2.236	2.974	1.229	ND	2.922
MgO	1.701	0.420	0.964	0.629	ND	ND
Fe_2O_3	4.956	2.580	3.397	4.547	0.299	1.481
L.O.I	2.100	2.400	4.000	3.200	0.400	2.000

Table 2: Trace element composition of the rock samples

Oxide composition (%)	Pelitic Phyllite	Coarse Quartzo Feldspathic Schist	Fine Quartzo-Feldspathic Schist	Gneiss	Veins	Fine Quartzo-Feldspathic Schist
Cl (ppm)	ND	ND	ND	ND	140.6	ND
V (ppm)	113.2	19.1	93.1	30.9	18.9	0.0
Cr (ppm)	88.6	164.4	56.7	75.1	277.9	172.8
Ni (ppm)	21.6	29.5	16.6	19.2	55.1	36.8
Cu (ppm)	38.5	55.4	13.3	27.5	ND	ND
Zn (ppm)	64.1	59.7	107.8	66.4	ND	36.4
Ga (ppm)	23.2	28.1	42.5	23.8	ND	39.4
As (ppm)	1.9	0.0	3.4	0.4	ND	0.0
Rb (ppm)	198.8	223.0	188.4	242.1	15.5	288.6
Sr (ppm)	130.8	187.8	957.7	128.4	4.9	272.3
Y (ppm)	46.8	19.7	27.0	50.4	3.1	41.2
Zr (ppm)	317.5	192.1	281.3	394.8	5.3	151.1
Nb (ppm)	14.4	17.4	9.0	10.3	ND	6.2
Sn (ppm)	82.1	84.5	73.3	76.6	59.8	71.7
Ti (ppm)	ND	ND	578.1	ND	ND	0.0
Te (ppm)	ND	50.4	ND	ND	ND	42.6
Pb (ppm)	26.5	41.8	28.4	43.8	ND	70.0
Th (ppm)	13.5	17.5	ND	23.9	8.1	34.4
Nd (ppm)	ND	ND	ND	17.6	ND	42.3
Ba (ppm)	283.6	208.5	578.1	285.9	ND	220.5
Mo (ppm)	ND	ND	ND	ND	6.8	ND

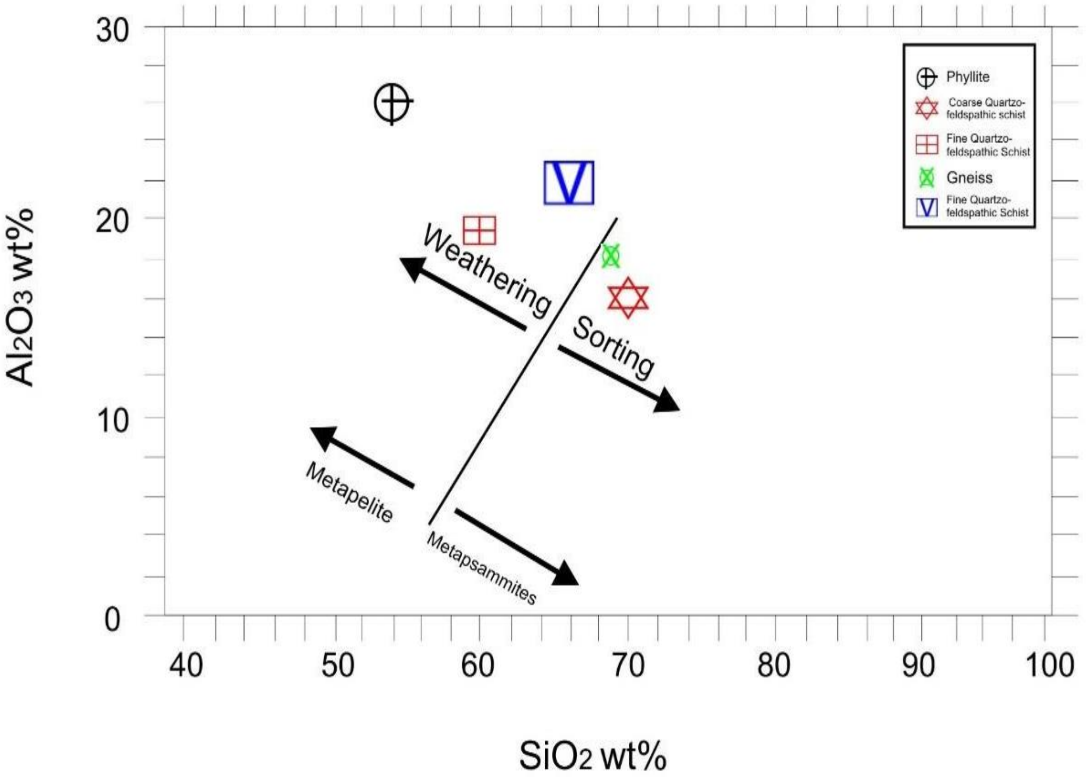

Figure 11: Plot of Al_2O_3 VS SiO_3

From the distribution of samples in the plot, it is obvious that the protolith suffered neither intensive weathering nor sorting. One of the main factors of variability in composition of observed oxides is the granularity of studied samples. The majority of fine-grained samples (FGQFS and Ph) have higher contents of Al_2O_3 and the coarser-grained samples (GN and CG-QFS)) have the higher contents of SiO_2. The higher contents of Al_2O_3 are a result of the relatively higher content of clayey minerals in finer-grained protolith. The absence of organic matter also in Metapellites as well as in Metapsammites indicates the slow transport and burial of the protolith of metamorphosed sedimentary rocks from one source area. We suppose that samples within the immediate boundary dividing MPEL and MPSA have a composition close to that of the parent rocks.

The metamorphosed sedimentary rocks of the first geochemical group (metapellites) formed in geochemical classification plot for sediments (Fig. 12), the relatively homogenous field with position corresponding to Sub-lithic Arenite. Metapsammites have the higher values log SiO_2/Al_2O_3 as Metapellites at comparable values log Fe_2O_3/K_2O (Herron, 1988). The Gneiss have in this geochemical classification plot essentially the same position as Schists. The metamorphosed Sedimentary rocks of metapsammites geochemical group had evidently different protolith.

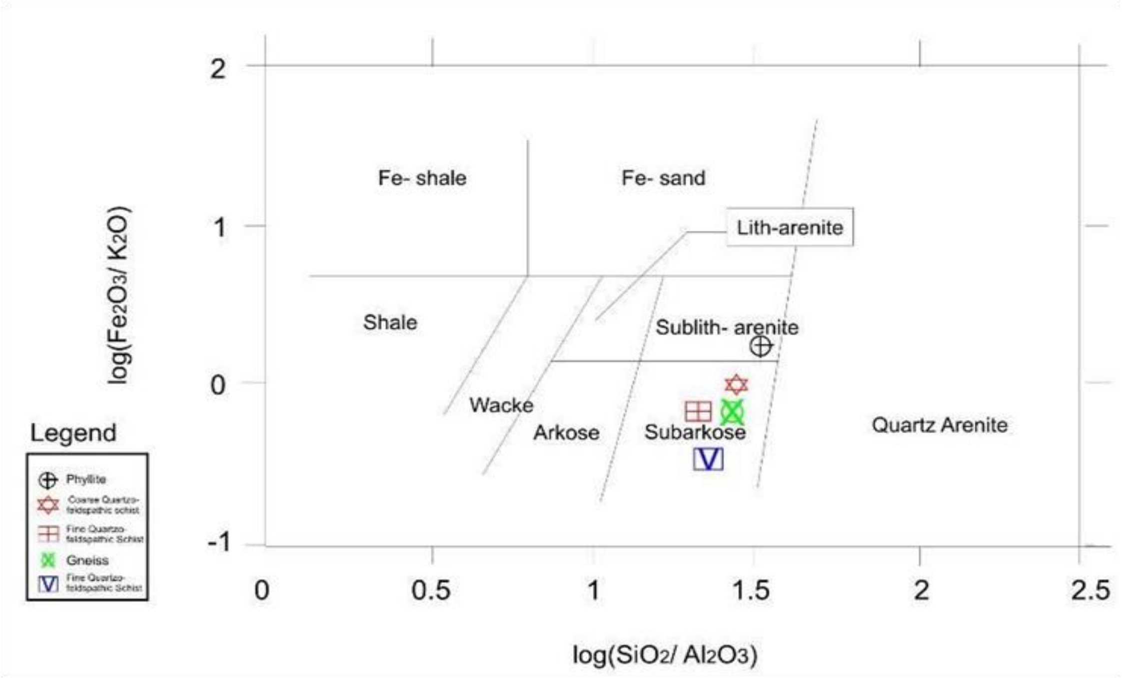

Figure 12: The Major element chemical classification plot of the terrigenous clastic rock types (after Herron, 1988) for metamorphosed sedimentary rocks

4.5.2 Paleoweathering Conditions

Chemical weathering may be imprinted in the sedimentary record which can provide a useful tool for monitoring source-area weathering conditions (McLennan et al. 1993; Garba, 2003). The most widely used chemical index to quantitatively measure the intensity of source-area weathering is the chemical index of alteration (CIA) (Fig. 13). The range of chemical changes caused by the weathering in source area or during transport of sediments into the sedimentary basin is expressed by the paleoweathering index [CIA=100*[Al_2O_3/(Al_2O_3+CaO*+Na_2O+K_2O)] all in molecular proportions and CaO represents the CaO in silicate fraction only.

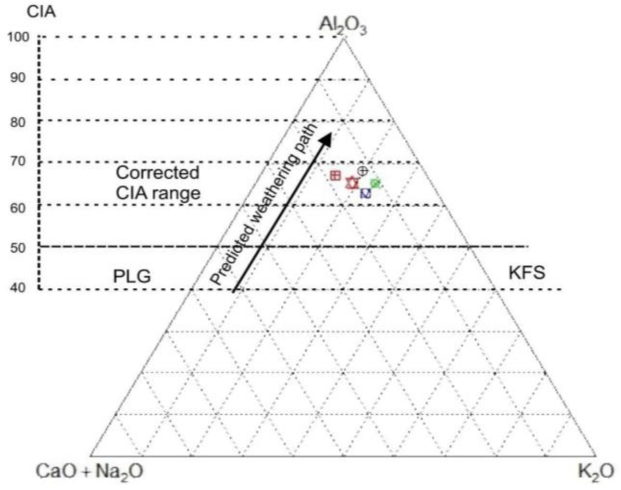

Figure 13: A–CN–K ternary plot for the metamorphosed sedimentary rocks from the Premetasomatized CIA values

The low CIA values (50–60) indicate the absence or poor chemical weathering in the source area. For medium phase of weathering the values CIA 70–75 are characteristic, the higher CIA values demonstrate the intensive chemical weathering. The medium CIA values of metamorphosed sedimentary rocks of the two geochemical groups indicate the presence of chemical weathering in the source area (Fig. 14). The medium CIA values in MPEL relative to MPSA can be explained by the relatively higher clay ratio in finer grained protolith resulting from depositional sorting. The A–CN–K triangular plot can also be used to constrain initial compositions of source rocks. Because weathering trends are parallel to the A–CN line, it is possible to use the trends of the sedimentary rocks to project backwards to the feldspar join, indicating the inferred source composition.

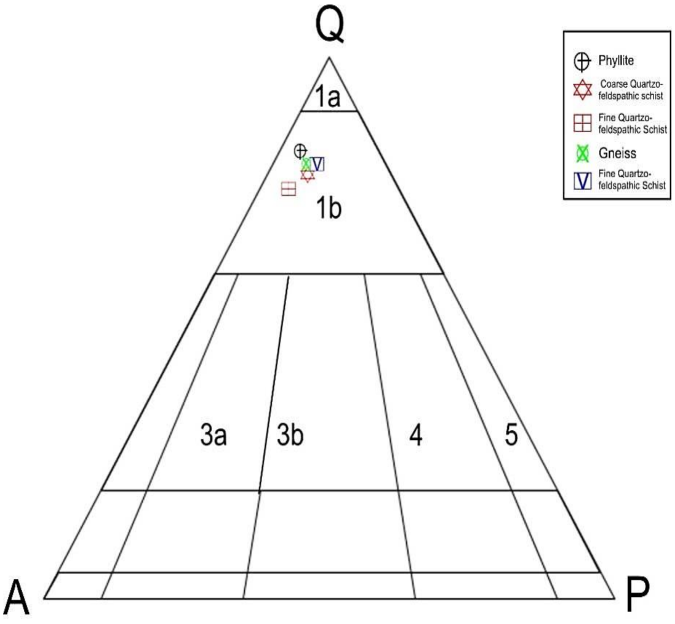

Figure 14: The metamorphosed sedimentary rocks from Bugaji in the QAP mesonormative classification plot for plutonic rocks. 1a - quartzolite, 1b – quartz-rich granitoids, 3a - syeno-granite, 3b - monzo-granite, 4 - granodiorite, 5 – tonalite.

From the intersection point of the trend formed by samples of this group with the line between Plg and K-feldspar it can be supposed that composition of rocks in the source area was similar to Quartz-rich granitoids (Fig. 14). The corrected values of CIA (pre-metasomatic) have ranged from 55-70 and from calculated values they more distinctly differ only by insignificant number of samples. The MPSA lies close to supposed weathering trend and their computed and corrected CIA values are nearly identical. It indicates the minimum influence of MPSA by K-metasomatism. This fact confirms the assumption that chemical composition of MPSA closely corresponds with the composition of parental rocks. Gneisses have a range of CIA values, as well as a range of corrected CIA values, similar to phyllites. This indicates the influence of metamorphism and metasomatism on distribution of discussed chemical elements is insignificant. The plagioclase index of alteration (PIA) describes the varying amount of plagioclase alteration in sediments as a result of weathering. Feldspars that have not been altered or have only been mildly altered often have low PIA values, while those that have undergone extensive chemical weathering have high PIA values.

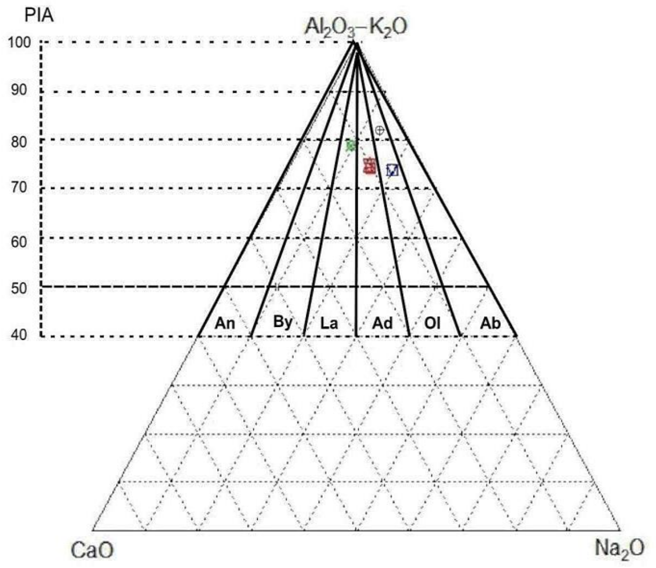

Figure 15: (A–K)–C–N ternary plot for the studied rocks. Compositions: Ab = albite, Ol = oligoclase, Ad = andesine, La = labradorite, By = bytownite, An = anorthite

High PIA values (75-85) from the metamorphosed sedimentary rocks of the first geochemical group indicate the presence of feldspar alteration in the protolith (Fig. 15) and the dominance of physical weathering in the source area. The PIA values from this group demonstrate the trend from labradorite to albite (Roser, 1988). This trend is distinct mainly in samples MPSA, having the lowest values of CIA as well as PIA values. This trend can theoretically reflect also the magmatic fractionation of feldspars in former plutonic/volcanic parental rocks. The position of MPEL is in comparison with MPSA, closer to the Al_2O_3-K_2O peak. It is a result of relatively more intensive alteration of plagioclases and confirms the assumption about the relatively higher clay content in MPEL protolith. The PIA values of the metamorphosed sedimentary rocks of the second geochemical group indicate different genesis of the protolith.

4.6 Discussion

The type of exposure in the study area was stream bed and most of the rocks were exposed to chemical weathering. Based on visual observations of rock texture and mineralogy, 4 key rock units were identified, which include, phyllite, quartzo-feldspathic schist, gneiss and a highly weathered schist (identified based on its retained relic of schistosity). These lithological units displayed fractures, faults, anticlinal folds, joints, veins and pegmatic structures, with high degree of weathering. The cross section of the geological map developed for the area clearly showed a sequence of low grade metamorphism (phyllite) to medium grade (schist) to high grade metamorphism (gneiss) in the direction of East to West of Bugaji.

The phyllite rock is a gray/blackish/dark greeenish foliated rock, glossy or reflective sheen/larger minerals are indicative of mica or chlorite, which differentiates it from slate. Thequartzo-feldspathic schist is light reddish to flesh-colored which indicates the abundance of quartz and feldspar. The foliated schist displayed porphryblastic texture with clear schistocity consists of coarse and fine grained, suggesting differential metamorphic changes phases of metamorphism. The gneiss occurred as a banded, foliated rock, with more developed differentiation of the psammitic (light) and pellitic (dark) or mafic bands.

The petrographic analysis showed that the phyllites exhibit a lepidoblastic texture where approximately 90% consists of fine grained crystals. The fine grained, equigranular quartz was identifiable from its low relief and distinct sub-hedral structure under PPL, while Muscovite was identified recognized under crossed polars based on its columnar shape and pleochroic colors. The quartzo-feldspathic schist was studied under both PPL and XPL conditions. The schist showed the presence of quartz, biotite and muscovite mica, chlorite, sericite, plagioclase and opaques. The presence of clinopyroxene indicated the instability of the sheet silicates, and the metamorphic progression of the schist into a higher grade. The pyroxene minerals in gneiss tended to form elongated crystals and become segregated in distinct bands through the rock, to produce the gneissic banding. From the petrographic studies, the micro-metamorphic domains of the phyllite, quartzo-feldspathic schist and gneiss were thus: sinusoidal alignment of the finer matrix material to form a crenulation structure that compresses and re-aligns the quartz grains to create a close parallel arrangement (fissile); alignment of quartz grains in a preferred direction that is parallel to the micas and chlorite microcrystals, and re-alignment of the interlocked/sutured quartz grains by mafic minerals to create a foliation or band (i.e. foliation is wrapped around a porphyroblast).

Geochemical analysis was performed to analyze the nature of the source area and the tectonic context of the depositional basin using discriminating plots based on the major element composition of the metamorphosed sedimentary rocks. Phyllites, fine quartzo-feldspathic schist, and gneiss were categorized into the metapelites and metapsammites groups, respectively, by the plot contents of SiO_2 (64 wt%) and Al_2O_3 (15 wt%). The first geochemical group of the metamorphosed sedimentary rocks (metapellites) formed in the homogeneous field of the sediment classification plot, with the position corresponding to sub-lithic arenite and the second group to Sub-Arkose. Metapsammites have greater $\log SiO_2/Al_2O_3$ values than Metapellites, which have similar $\log Fe_2O_3/K_2O$ values. In this geochemical classification diagram, gneisses essentially occupy the same position as schists. Evidently distinct protoliths were present in the metamorphosed sedimentary rocks of the metapsammites geochemical group.

Furthermore, the sedimentary record contained traces of chemical weathering, which was a useful tool for tracking weathering conditions in the Provenance (Méres, 2005). The chemical index of alteration (CIA) is the chemical index that is most frequently used to quantify the severity of source-area weathering. The paleoweathering index [$CIA=100*[Al_2O_3+CaO^*+Na_2O+K_2O]$] showed the range of chemical changes brought about by weathering in the source area or during the transfer of sediments into the sedimentary basin. QAP Ternary plot were used and it can be assumed that the composition of rocks in the source area was comparable to quartz-rich granitoids, based on the junction point of the trend created by samples of this group with the line between Plg and K-feldspar. The pre-metasomatic CIA values varied from 55 to 70, and their corrected values only differed from calculated values by a negligible number of samples. The computed and adjusted CIA values of the MPSA and alleged weathering trend are substantially comparable. It showed the minimal impact of K-metasomatism on MPSA. This result supported the hypothesis that the MPSA's chemical composition closely resembles that of its parent rocks. Similar to phyllites, gneisses have a range of CIA values as well as a range of corrected CIA values.

5. CONCLUSION AND RECOMMENDATION

This study achieved its clear objectives of developing a geologic map of the study area, identifying the textural variations, and recognizing the micro-domains in the metamorphic rocks. The exhaustive field study provided geological evidence that suggests the Bugaji area has undergone prograde metamorphism due to variation in mineral composition and gradual sequence of low grade metamorphism (phyllite) to medium grade metamorphism (quartzo-feldspathic schist) to high grade metamorphism (gneiss) in the direction of East to West. Using thin section petrography, we were able to determine how the grade of metamorphism shapes the texture of the rock to create distinct micro-domains that are unique to each metamorphic rock type. The presence of high-pressure metamorphic rocks such as gneisses and schists suggest that the region has been subjected to tectonic forces and high temperatures over time. The intricate geochemical examinations and mineralogical evaluation of the metamorphosed sedimentary rocks allowed for the objective derivation of the protoliths and achieving an accurate understanding of the processes that formed the rocks. The geochemical features of metamorphosed sedimentary rocks from the Bugaji region show lithological variations in the protolith composition. The metasediments show similarities in their mineralogy and rocktypes with the Zungeru-BirninGwari Schist Belt. The weak-medium chemical weathering of the source area (low range of CIA and PIA values), accelerated transport (geochemical and mineralogical non-mature weakly sorted protolith) and slow burial (the absence of organic matter) show that protolith of the study area was similar to Subarkose and Sublithic arenites. The geochemistry of parent rocks in the source area resembled Quartz rich-granitoid.The characteristics of the major elements of these samples suggest that the provenance of metasedimentary rocks from Bugaji is dominantly felsic, and that the tectonic setting is an active continental margin and (or) continental island arc.

The study conducted in the Bugaji region of Kano State, Nigeria, has provided valuable insights into its geology and metamorphism. However, further investigation is required to address certain limitations. One crucial aspect is determining the precise age of the metamorphic events, which can be achieved through geochronological studies like zircon U-Pb dating. Including isotopic studies, such as Nd-Sr isotopes, and exploring trace elements and rare earth element analyses can provide information about the region's geological history and tectonic setting.

Detailed structural analysis, incorporating strain analysis and kinematic indicators, can shed light on the tectonic deformation history of the rocks in Bugaji. Expanding the sample size for future studies can better represent the area's geological complexity, while collaboration with other institutions can enrich the study's outcomes. The challenging terrain and limited accessibility of some regions should be considered, and complementary analytical methods can help overcome the impact of weathering on certain analyses. Overall, addressing these areas will contribute to a more comprehensive understanding of the Bugaji region's geological and tectonic history.

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