

Geological, Petrographic, and Geochemical Characterization of the Basement Complex Rocks in Madidi and Its Environs, Gusau Northwestern Nigeria

BELLO ALIYU¹, SAFIRAT HASHIMU², HAFSAT MUHAMMAD³, KHADIJA MUHAMMAD AUWAL⁴

¹State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Chengdu University of Technology, Chengdu, China

²Department of Microbiology, Faculty of Science, Federal University Gusau, Zamfara State, Nigeria

³Department of Geology, Faculty of Science, Federal University Gusau, Nigeria ⁴Department of Geology, Faculty of Science, Bayero University, Kano, Nigeria

Abstract- This study presents the geological, petrographic, and geochemical characterization of Madidi village and its environs, located in Bungudu Local Government Area, Zamfara State, Northwestern Nigeria. The area, covering approximately 30.4 km², forms part of the Precambrian North-Western Nigerian Basement Complex, specifically within the migmatite-gneiss-quartzite complex. Geological mapping at a scale of 1:25,000, supported by field observations, structural measurements, and sample collection, revealed that gneissic rocks dominate the lithology, with subordinate mica schist and minor quartz vein intrusions. The rocks exhibit NE-SW trending foliation and have undergone significant deformation, weathering, and metamorphism. Petrographic analysis under a polarizing microscope showed that gneiss samples are medium- to coarse-grained, phaneritic, and composed predominantly of quartz (~40%), biotite (~35%), plagioclase (~20%), with minor orthoclase, muscovite, and opaque minerals. Foliation and lineation are well-defined. Mica schist displays strong foliation, with muscovite as the dominant mineral (~65%), accompanied by quartz (~25%) and accessory chlorite and opaque phases. Geochemical data indicate high SiO₂ contents (74.42–78.12 wt%) in both rock types, confirming their felsic to intermediate character. Gneiss samples show low Fe₂O₃ and MgO, high K₂O relative to Na₂O, and calc-alkaline affinity, suggesting derivation from a K-feldspar-rich felsic protolith. Mica schist exhibits elevated Al₂O₃, reflecting aluminous clay-rich protolith, and evidence of K-metasomatism during metamorphism. Trace element concentrations, particularly high Ba and Rb, support a supracrustal, pelitic metasedimentary origin with detrital zircon influence. Tectonic discrimination diagrams indicate a calc-alkaline, likely continental arc or syn-collisional setting. The study provides new detailed lithological, structural, and geochemical data that fill gaps in existing regional geological maps and contribute to better understanding of the basement complex evolution in Northwestern Nigeria

Keywords- Geological mapping, Madidi village, Zamfara State, Nigerian Basement Complex, Gneiss.

I. INTRODUCTION

1.1 GENERAL INTRODUCTIONS

The study area (Madidi village and its environs) near Gusau town forms part of the North-Western Nigerian Basement Complex of Precambrian age [1]. Generally, the Basement rocks of Nigeria are distinguished into three lithological units: the migmatite-gneiss-quartzite complex, the schist belts, and the older granites. The study area comprises the area so-called “Migmatite gneiss quartzite complex” in Northwest Nigeria, which produced a variety of gneissic rocks and some micaschist with a dominantly NE-SW trending foliation. Granite rocks occur outside the study area and shortly before and beyond Furfuri village along Bungudu road.

Geological mapping of the study area involved the recognition, identification, and measurement of the different rock types, structures, and their mineral composition. Various mapping techniques were employed during the course of this exercise [2].

The various activities carried out under detailed study include the geological mapping, outcrop logging, taking field measurements, and collection of samples for further analysis. Several outcrops were carefully studied altogether within the study area. Actually, the present field work entails the collection of information

outside a laboratory, library, or workplace setting [21]. Field research in the study area involves a range of well-defined methods: informal interviews, direct observation, participation in the life of the group, collective discussions, analyses of personal documents produced within the group, self-analysis, results from activities undertaken off- or online, and life-histories [22].

1.2 STATEMENT OF PROBLEM

Perhaps due to the complex nature of Nigerian geology, there are some omitted parameters of geologic interest in the geological maps of Nigeria produced by several scholars as well as the Geological Survey Agency of Nigeria [17]. This study, however, aims at bridging such a gap by revealing the local geology of the so-called area in Gusau Local Government Area, Zamfara state. Specifically, this study focuses on the geochemistry and petrography of Madidi village in Gusau Local Government Area, Zamfara State, Nigeria. This study will unveil the petrographic and geo chemical analysis within the study area. However, there are some serious security challenges, such as Fulani Herdsmen and Cattle rustlers, within our study area. During the course of the field mapping exercise, there were so many challenges encountered which caused hindrance to this study, these challenges include: poor road networks, inadequate field mapping equipment, and inadequate vehicles.

II. MATERIALS AND METHODS

2.1 DATA AVAILABILITY

In the process of making a geologic map of the study area, a topographic base map of the area to be mapped was made available. The regional topographic map of the area also produces some required data.

2.2 METHODOLOGY

Geological mapping involves the making of objective geological observations in the field and recording them so that a clear and sound geological map can be produced [16]. The study area covering about 30.4km² was carefully mapped using topographic map for plotting locations of studied outcrops and other features, compass for taking measurements of strike and dip of bedding, foliation, jointing and faulting of

a rock formation and the use of Global Positioning System (GPS) to get accurate location on the map and also, pacing was employed in order to estimate distance (lateral extent of exposure). Different places suitable for the geological study were selected, and their location was determined by the map. Observations related to such structures were taken and copied, such as physical appearances, orientation, and geological structures.

The work was done with the help of the Supervisor as all details were noted in the field note. The different rock types at various locations and their properties were noted down. The specimens were numbered, and the location of the outcrop was marked on the map. Samples of each type of rock were also collected. All the available information, such as the changes in rock type or the structural characteristics of the outcrop seen, was also recorded with the help of photographs and sketches along with text description. Various morphological structures of rivers were also studied there.

2.3 FIELD EQUIPMENT USED FOR MAPPING

Geological mapping of the study area involved the recognition, identification, and measurement of the different rock types, structures, and their mineral composition. Various mapping techniques were employed during the course of this exercise. These included

- Enlarge base map: the use of a topographic map in order to update the new geological map of the study area by inserting different lithologies. The base map used during the exercise has a scale of 1:25,000 produced from an enlargement of 1:50,000 Sheet 54 (Gusau) SE.
- Hammer: A geological Hammer was used to obtain a sample from the field.
- Compass clinometers: A compass clinometer was used to take standard reading such as strikes and dips, on a particular outcrop encountered.
- Hand lens: Used to view and examine the proportion of minerals of the outcrop.
- Global Positioning System (GPS): The GPS was used to locate the actual position on the map as well as to determine the elevation above sea level.

- Camera: used for taking photographs of outcrop occurrences, structures such as fractures, faults, joints, folds, foliation, and intrusion of foreign materials like xenoliths e.t.c.
- Field notebook: use in recording observations, including sketches, measurements (for example, the angle of tilted strata).
- Marker and masking tape: The fresh samples collected from the field were labeled with a marker and masking tape, kept in a sample bag, and transported to the laboratory for further analysis.
- Measuring tape: Measuring tape were use majorly to measure the distance and depths to the water level in hand-dug wells.

2.4 SUMMARIES OF WORKFLOW

The work pattern that most of the activities carried out during this project work is simply illustrated below;

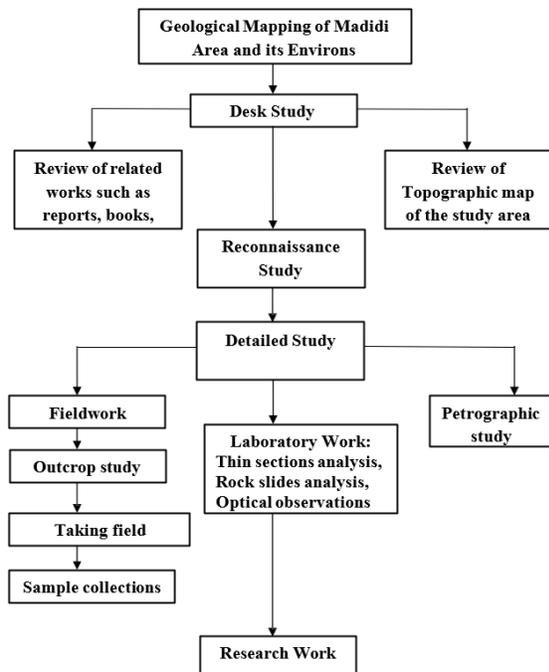


Figure 1: Research Workflow

2.5.1 DESK STUDY

This study involves consultation, examination, and consideration of previous work, literature, and relevant reports, as well as a review of available geological materials through the aid of a topographic map covering the study area. This study, however,

helped in discovering potential areas for a geological mapping exercise.

2.5.2 RECONNAISSANCE STUDY

Reconnaissance study was made to find out as much as possible about the geology of the study area as quickly as possible. This study, however, was carried out to gather information basically based on the human activities as well as the possible mineral occurrences within the study area. Reconnaissance survey also helped in checking the security conditions of the study area.

2.5.3 DETAILED STUDY

A detailed study was made on the study area using a map of 1:25,000 to investigate certain geologic features to make a reliable discovery. The various activities carried out under detailed study include geological mapping, outcrop logging, taking field measurements, pre-mining studies, and the collection of samples for further analysis. Several outcrops were carefully studied altogether within the study area. Actually, the present field work entails the collection of information outside a laboratory, library, or workplace setting. Field research in the study area involves a range of well- defined methods: informal interviews, direct observation, participation in the life of the group, collective discussions, analyses of personal documents produced within the group, self-analysis, results from activities undertaken off- or online, and life-histories.

2.5.4 LABORATORY WORK

In order to make an inference on the petrographic characteristics of the rock samples collected from the study area, the samples were sent to the laboratory for analysis. The results of the laboratory are then examined, and a conclusion on the exact percentage of mineral constituents of the samples can be inferred.

2.5.5 REPORT WRITING

All the findings from the field and laboratory analysis are needed. The completion of any period of geological mapping is usually followed by the production of a geological report to explain the geology of the region investigated. In the end, the data obtained from the field were thoroughly analyzed through observations and explanations. The analyzed data from the laboratory, observations made from the

field, digitization of maps using software, and reviews of existing literature were all assembled to produce a detailed and sound geological report to be documented in a proper geological report writing format.

III. RESULTS AND DISCUSSION

3.1 RESULTS OF GEOLOGICAL FIELD MAPPING

Different rock types were encountered in the study area, ranging from gneiss rocks to mica schist. Among these, however, gneiss rocks dominate the study area, which has been characterized as one of the areas in northern Nigeria. There is an intrusion of quartz veins. Different geologic structures, ranging from primary structures to secondary structures, were also encountered on the exposed outcrops in the study area. The study area has been characterized by a series of small and large outcrop exposures with numerous boulders along these outcrops. The exposed outcrops have been subjected to weathering, deformation, and metamorphism, which result in various geological structures, disintegration of rocks, and the existing metamorphic rocks.

These rocks are systematically examined and described in three fundamental ways. These include;

- Field description, which involves in situ description of the exposed outcrops in the study area. However, it is from this study that different shapes of outcrop exposures and structural features were examined.
- Megascopic description, which involves the description of rock samples obtained from the field using a hand lens and unaided eye to determine the volume percentages of major rock-forming minerals.
- Petrographic description, which involves the description and classification of rocks based on the optical properties exhibited by different minerals under a polarizing microscope.

From the figure below, it is precisely that gneiss rocks are the major lithology that dominates the study area despite minor occurrences of some metamorphosed rocks such as schists. They range widely in age and

composition (mineralogical and chemical composition).

3.1.1 Geologic Map of Madidi and its Environs

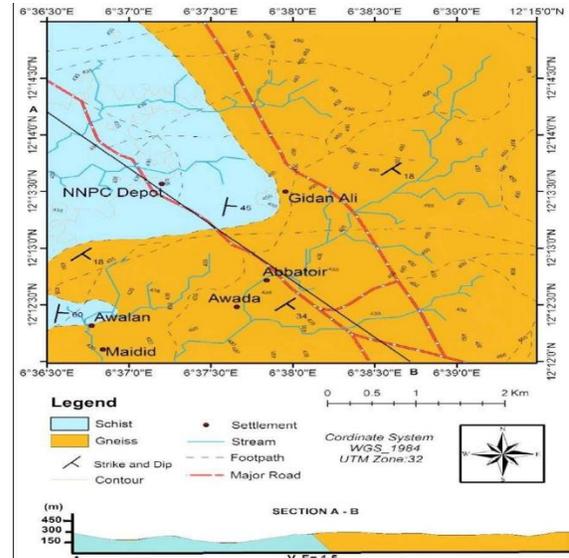


Figure 2: Geologic Map of Madidi and its Environs

3.1.2 STRUCTURAL FEATURES

Many geologic structures were encountered and examined in the study area, which is considered to have been formed as a result of different processes that affected the rocks. The rocks in the study area have a geological history that has resulted in the formation of variable structural elements, based on the difference in the genetic properties of the various rocks, and due to the different stress and strain conditions that prevailed during tectonic events. These structures, however, are classified into two based on their mode of emplacement and time of formation, these include;

- Syn-tectonic structures, or more commonly referred to as primary structures, which are the structures that develop during the emplacement of the rock, and
- Post-tectonic structures, or more commonly referred to as secondary structures, develop after the emplacement of the rock.

3.1.3 FOLIATION

A foliation is a set of new planar surfaces produced in a rock as a result of deformation [3]. Foliation is a general term covering several different kinds of structure produced in different ways. 'Slaty cleavage',

'schistosity', and 'gneissose' are all examples of foliations. Many rocks in the study area exhibit several generations of foliation. Earlier foliations are deformed and cut by later foliations, enabling the structural history of the rocks to be established [19]. The bedding is usually the first recognizable planar surface. The foliated rock encountered in the study area is shown in the photograph below.



Figure 3: Photograph showing a fracture in massive medium-coarse-grained granite gneiss

3.2.1 FRACTURES

A fracture is the commonest type of geological structure, and may be seen in any rock exposure [4]. Fractures are cracks across which the cohesion of the material is lost, and may be regarded as planes or surfaces of discontinuity. In practice, the great majority of fractures show negligible displacement and are classified as joints [5]. Fractures are important in a number of ways. Their presence significantly affects the strength of a rock, and they must be carefully studied in civil engineering operations such as those involved in the construction of tunnels and dams. They are also important sites of mineralization, since dilational fractures developed under extension are normally occupied by vein material such as quartz or calcite deposited from aqueous solution in the space created as the fracture opens. Such veins are a valuable source of ore minerals. Many rocks with fractures have been encountered in the study area as shown below.



Figure 4: Photograph showing fracture on massive medium-coarse-grained granite gneiss outcrop with the coordinates: 12012'49" N006036'16E"

3.2.2 FAULT

A fault may thus be defined as a planar fracture across which the rock has been displaced in a direction that is generally parallel to the fracture plane [6]. Where the fault plane is non-vertical, the block above the fault is referred to as the hanging wall and the block below the fault as the footwall. When a rock mass is subjected to rapid stress, permanent ruptures and cracks are developed [20]. Faults may have displacements of a few cm up to many tens of km. On the field, these structures are recognized by the displacement of matching structures on either side of the plane of displacement (Fault plane) [7]. During the mapping exercise, faults were encountered in several outcrops in the study area as shown in the plate below.



Figure 5 Photograph showing sinistral strike-slip fault on medium-coarse-grained granite at Madidi village with the coordinates:12012'39" N 006036'43E"

3.2.3 JOINT

The fracture where there is no displacement, or when the displacement is too small to be easily visible, the fracture is termed a joint [8]. The distinction between the two is somewhat artificial and depends on the scale of observation; however, in practice, the great majority of fractures show negligible displacement and are classified as joints. Joints may occur in sets of parallel, regularly spaced fractures, and several sets may occur in the same rock, giving a conspicuous blocky appearance to the outcrop [9]. More commonly, however, joints are much less regular and systematic. The granite and gneiss exposures in the study area are characterized by several joints; the majority of the joints identified were striking in N-S and NNE-SSW directions.

Different categories of joints were encountered in the study area during the mapping exercise, as shown in the plate below.



Figure 6: Photograph showing joint system on low-lying medium-coarse-grained granite with the coordinates: 12012'48" N 006042'15E"

3.2.4 VEIN

A vein in geology can be defined as a fissure or fracture containing minerals [10]. The veins observed in the study area include quartz veins, defining the history of the last stage of magma crystallization (pneumatolithic stage). The veins occur in various sizes (width), which depends on the intensity of the stress that acted on the fractures and on the exposures in the rock.

3.2.5 QUARTZ VEIN

Quartz veins are widely distributed in the study area. They occur mostly in the granites. As the name implies, quartz veins contain a single (monomineralic) mineral, quartz. The quartz occurs along fractures or cracks in the granite exposures. The quartz veins are well visible, occurring on the exposures, and are highly resistant to weathering activities [11]. They are small, varying in thickness from a few millimetres to some centimetres in width, but can go to a distance of kilometres in length. The average width of the quartz vein observed is 2.1cm (plate below).



Figure 7: Photograph showing quartz vein on low-lying medium-coarse-grain granite gneiss at 12012'51" N 006036'47E

3.3 RESULTS OF PETROGRAPHICAL ANALYSIS

Petrography is the science of describing and classifying rocks [12]. It relies heavily on observations made with the petrographic microscope, even though observations on the outcrop and with the hand lens are also important. A petrographic description of the rock first involves identification of the minerals, and where possible, determination of their compositions [13]. Textural relations between grains are noted, for these not only help in the classification but also provide evidence of the processes active during the formation of rock. The rock is then classified based on volume percentages of the various rock-forming minerals [14].

3.3.1 FIELD DESCRIPTION

The gneiss rocks and mica schist in the study area occur in different forms, including low-lying, whaleback, inselberg, and in ridges form [15]. Most of the exposed outcrops have experienced a series of deformation, weathering, and metamorphism. Some have reduced to boulders due to weathering, and some

have shattered as a result of deformation and tectonism. They vary greatly in texture from medium to coarse-grained, indicating that they were formed at different depths of burial. They also exhibit different colours due to the fact that they contain various rock-forming minerals ranging from felsic minerals such as orthoclase feldspar (K-feldspar) and quartz, as well as ferromagnesian minerals such as biotite, hornblende, etc. The rock contains numerous geologic structures, ranging from fractures, faults, joints, etc.

3.3.2 HAND SPECIMEN DESCRIPTION

The fresh sample of gneiss rocks obtained from the study area shows a grey to white color with small traces of black to dark brown coloration and is phaneritic in texture. The megascopic observation made indicates that the rock sample is composed of minerals including quartz, feldspar, and biotite. Visual identification of the minerals observed in the sample shows that quartz and feldspar are the major minerals that make up the rock and constitute about 80% of the total volume of the rock, whereas mica minerals account for only 20% of the rock.



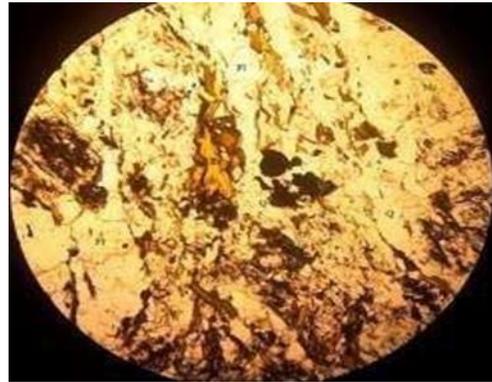
Figure 8: photograph of medium-coarse-grained gneisses in Gusau 12012'37" N006036'56"

3.3.3 PETROGRAPHIC DESCRIPTION

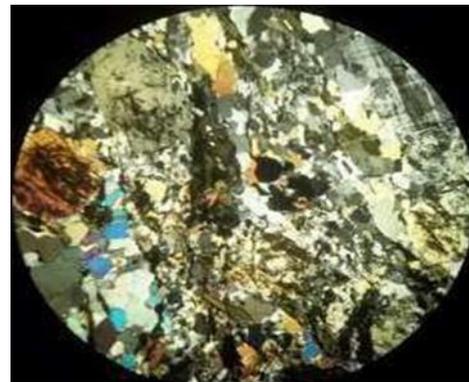
Petrographic analysis indicates that the rock is medium-grained in texture, with individual mineral grains being well-developed, with quartz as the most abundant mineral (about 40%).

Gneiss

In thin petrographic analysis, the sample shows both foliation and lineation of the component minerals. The rock is generally medium-grained with quartz as the most abundant mineral (about 40%). The quartz is subhedral and colourless with the characteristic wavy extinction. Biotite crystals are brown in colour with distinct one-directional cleavage. The biotite constitutes about 35% of the rock. Plagioclase feldspars constitute about 20% of the rock. Other minerals include orthoclase feldspars and muscovite in minor quantities.



A



B

Figure 9: Micrograph of granite gneiss in A PPL and B XPL.

Foliation is defined by the subparallel arrangements of Bt – biotite, lineation defined by the feldspars: Pl – plagioclase and Mc – microcline. Other minerals are Qz – quartz and iron oxide as opaque.

Micas Schist:

Some of these schists are found as silicified rocks, highly indurated and massive. In the hand specimen, the mica schist appears flattened with tiny platy minerals aligned (which are fissile) and trending in the same direction, giving the rock foliation lineament. It readily splits into thin sheets along the cleavage plane. The rock is highly foliated due to the presence of mica minerals and comprises predominantly of muscovite (65%), quartz (25%), with other accessory minerals. In PPL, equigranular colourless quartz with low relief and weak birefringence was observed. It also shows wavy phyllitic texture, moderate relief, and strong pleochroism from light to dark brown. In XPL, it displays straight extinction parallel to the cleavage planes. Mineralogically, the phyllite is composed mainly of mica (muscovite), quartz, and chlorite.

Major minerals in this rock are muscovite and quartz, while the minor ones are the opaque minerals. There is an enormous amount of these white micas (muscovite), constituting about 65% of this rock. It has an interference colour ranging from green to pink; a perfect cleavage and a high birefringence.

Quartz in this rock is anhedral in shape, fine to medium-grained, and occurs as phenocrysts. These crystals are colourless and have a low relief.

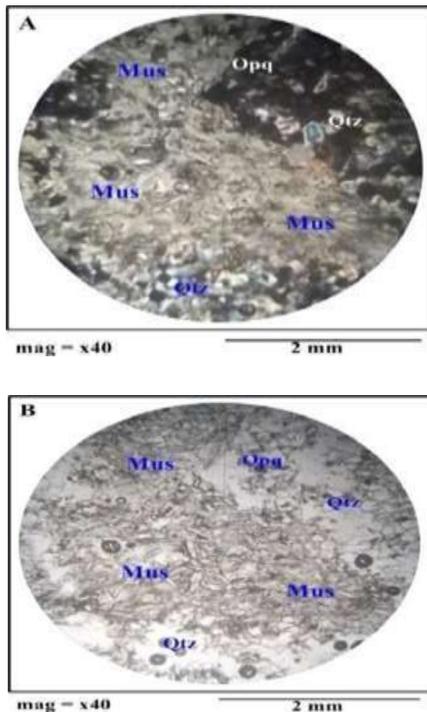


FIGURE 10: Photomicrograph of mica schist/Phyllite. (A) View in XPL. (B) View in PPL. Qtz=quartz, Mus=muscovite, Bio=biotite, Opq=opaque mineral

3.4 GEOCHEMICAL RESULT INTERPRETATION

The results from geochemical analysis are presented in Tables 1 and 2. (The data generated is used for the calculations of the average major and trace elemental composition. The data was interpreted using a geochemical data tool kit (GCD Toolkit 3.0). Major elements are reported in weight percent (wt%), while Trace elements are reported in parts per million (ppm).

Table 1: Major Elements Composition of the Rock Samples in the study Area

	Gneiss 1	Gneiss 2	Schist 1
SiO ₂	78.12	77.42	74.42
Al ₂ O ₃	12.37	14.13	11.29
Fe ₂ O ₃	1.38	1.44	5.46
MgO	1.9	0.98	1.09
CaO	0.79	1.02	0.07
MnO	0.03	0.08	0.11
Na ₂ O	0.12	0.06	0.24
K ₂ O	4.35	4.04	3.03
TiO ₂	0.63	0.29	0.6
P ₂ O ₅	0.12	0.11	0.08
Total	99.81	99.65	96.41

Table 2: Trace Elements Composition of the Rock Samples in the Study Area

Element (PPM)	Gneiss 2	Mica Schist 1	Mica Schist 2
Ba	170	609	367
Co	8.3	20	4.2
Cs	0.5	10.2	7.5
Cu	15	54.4	11.7
Ga	8	16.9	19.3
Ni	20	49.2	121.2

Rb	5.2	176.6	198.8
Sc	2.8		
Sr	12.9	25.1	25.3
Th	5.1	7.8	18.2
U	1	2.6	1.7
V	76	103	18
Y	14	28.7	46.4
Zn	18	88	2
Zr	27	158	268.5
La	11.1	34.7	36.4
Ce	16	93.9	89.9
Nd	8	30.5	45.9
Sm	1.6	6.01	9.85
Eu	0.5	1.31	1.37
Tb	0.5	0.87	1.45
Yb	1.5	2.96	5.52

3.3.4 INTERPRETATION OF GEOCHEMICAL DATA

Symbols & colours by Petrology

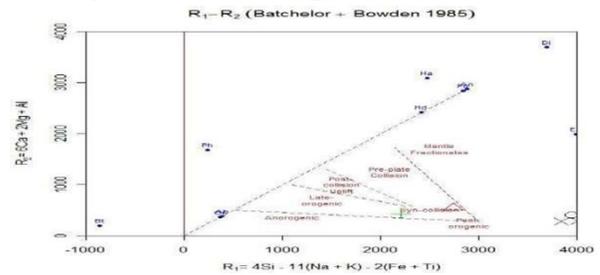


Figure 11: Plot showing the tectonic setting of the granites gneiss after (Batchelor + Bowden, 1985)

Granite tectonic discrimination – Frost et al. (2001)

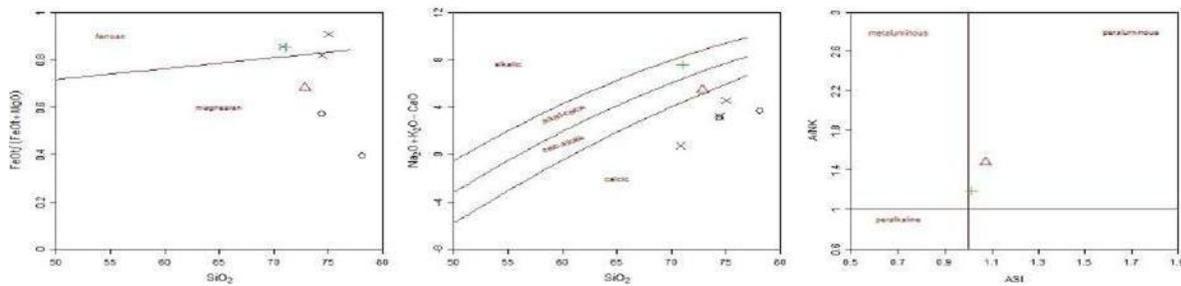


Figure 12: Tectonic discrimination plots showing the different composition of the rocks within study area (Frost et al.,2001)

Granite tectonic discrimination – Maniar and Piccoli (1989)

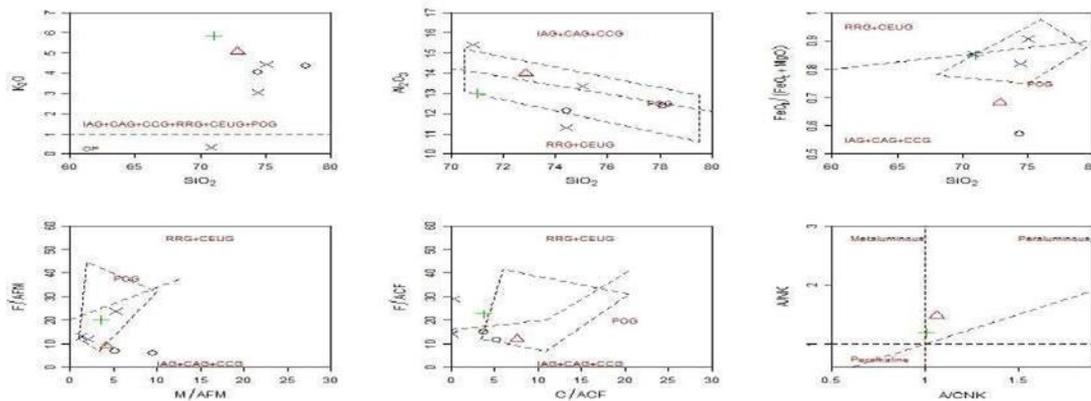


Figure 13: Tectonic discrimination diagrams showing the various tectonic environments of the rocks within study area (Maniar and Piccoli, 1989)

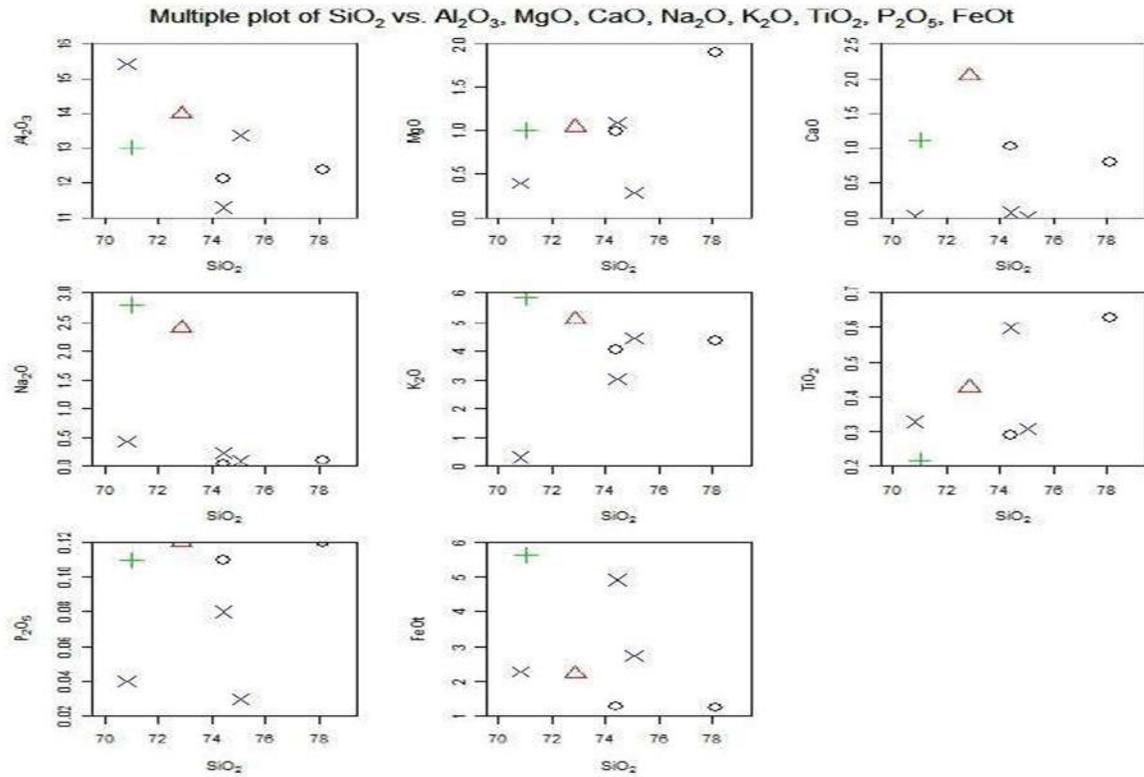


Figure 14: Harker Variation diagram of SiO₂, against Al₂O₃, MgO, CaO, Na₂O, K₂O, TiO₂, P₂O₅, Fe₂O₃

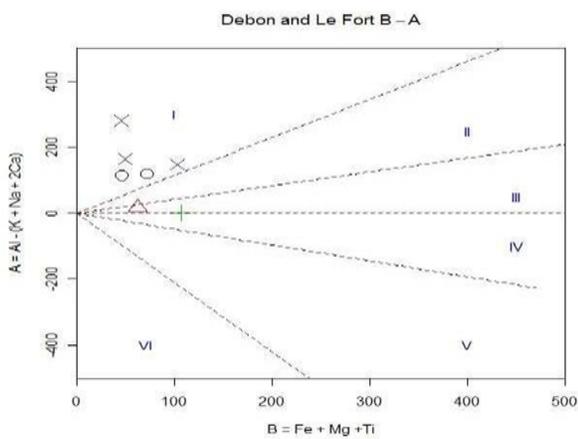


Figure 15: Plot of Debon and Le fort. B – A

AFM plot (Irvine and Baragar 1971)

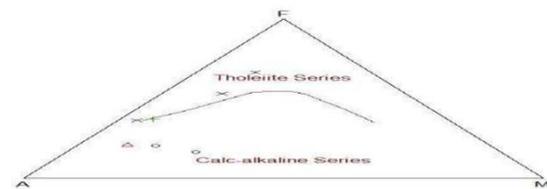


Figure 16: AFM plot showing the series of the rocks within study area. After (Irvine and Baragar, 1971)

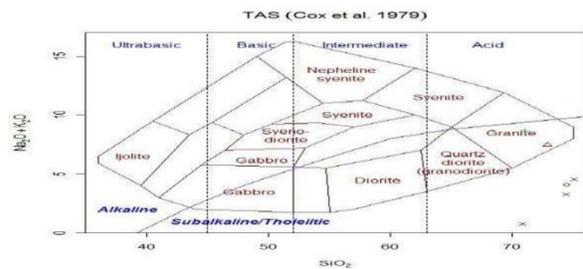


Figure 17: Plot of Na₂O versus SiO₂ (indicating acidic nature of granite I & II)

Major Element Analysis of Gneiss

The major elements of the sample gneiss (1 and 2) exhibit high SiO₂ of 78.12 wt% and 77.42 wt% respectively. The two sample also show low concentration of Fe₂O₃ and MgO (1.38 wt% and 1.448 wt%) and (1.9 wt% and 0.98 wt%) respectively. These suggest that they were derived from a felsic source. This was confirmed by the petrogenetic plot of (Cox et al, 1979, Figure 11), the lesser ratio of Na₂O to K₂O in both samples reflects an abundance of K – feldspar rock forming silicate that is orthoclase and biotite.

The alumina (Al₂O₃) contents of the sample gneiss (1 & 2) are 12.37 wt% and 12.13 wt% respectively, thereby suggesting a calc-alkaline affinity. This was confirmed by the petrogenetic plot (Figure 10) of Irvine and Baraga (1971). This could also be due to then low Fe – Mg bearing silicate minerals.

Trace Elements Analysis of Gneiss

The trace elements of the sample gneiss (1 & 2) show a high concentration of Ba, which is an indication of K–feldspar–rich protolith. Ni and Co are relatively enriched in both samples.

Major Element Analysis of Mica Schist

The mica schist in the study area shows a high content of SiO₂ (77.42 wt% and 74.42 wt%), respectively, and high Al₂O₃ content of 11.29 wt%, 13.36 wt%, and 15.41 wt%, respectively. The K₂O content is in excess when compared to Na₂O. The high Al₂O₃ enrichment in the mica schist reflects the control of their composition by aluminum clay minerals. The ratio of K₂O/ Na₂O probably reflects secondary addition of potassium (K – metasomatism) during metamorphism. The MgO content is in excess compared to the CaO content in the range of (0.01 – 1.09 wt %). Since MgO content is in excess of CaO content.

It is perhaps indicating the almost carbonate–free nature of the protolith. The low CaO content results from the decomposition of plagioclase in the source materials during weathering.

Trace Element of Mica Schist

The mica schist specifically has high Ba concentration ranging from 367 to 948 ppm, Rb from 260.2 to 198.8 ppm. This concentration is typical of the supracrustal

rocks. Zircon (Zr) concentration is a reflection of the presence of detrital zircon (Zr) in the rock. Sr content ranges between 11.6 and 34.4 ppm. While Co concentration ranges between 3.6 to 19.0ppm. The chemical concentration of Rb is similar to their deviation from shales or metapelites, which is a reflection of their origin. Rb/Sr ratio is > 0.4%, which is typical of pelitic metasediments. High Ba indicate K – feldspar rich source rock.

IV. CONCLUSION

The area of study is part of sheet 54 (Gusau) S.E, bounded by latitude 12o12'30"N to 12o14'30" N and longitude 006o36'30.00" E to 006o39'0.00" E. It covers a total area of about 30.4 km² in Bungudu Local Government Area of Zamfara State. It was geologically mapped on a scale of 1:25:000. Madidi and its environs, Bungudu Local Government Area, Zamfara State. which is predominantly underlain by gneiss rocks and some mica schist.

Various types of geological field equipment were used to carry out effective mapping in the study area. Different geologic structures, ranging from faults, fractures, joints, etc., were also encountered and studied in the exposed outcrops within the study area. Petrographical study of two rock samples obtained from the study area reveals that the area is dominated by gneiss rocks and some mica schist.

ACKNOWLEDGEMENT

Special thanks are due to the management and staff of the Geological Survey of Nigeria (GSN) for granting access to relevant regional geological maps and literature that formed the foundation of this study.

I am grateful to my field assistants and colleagues who braved the challenging terrain, security concerns, and logistical difficulties during the geological mapping exercise in Madidi village and its environs. Their companionship, dedication, and assistance were invaluable.

I also acknowledge the technical staff of the Petrography and Geochemistry Laboratories, University of Abuja, for their professionalism and assistance during thin-section preparation,

microscopic analysis, and geochemical sample processing.

REFERENCES

- [1] Tijani, M. N. (2023). Geology of Nigeria. In Landscapes and landforms of Nigeria (pp. 3-32). Cham: Springer Nature Switzerland.
- [2] Rajan Girija, R., & Mayappan, S. (2019). Mapping of mineral resources and lithological units: A review of remote sensing techniques. *International Journal of Image and Data Fusion*, 10(2), 79-106.
- [3] Williams, P. F. (1977). Foliation: a review and discussion. *Tectonophysics*, 39(1-3), 305-328.
- [4] Laubach, S. E., Lander, R. H., Criscenti, L. J., Anovitz, L. M., Urai, J. L., Pollyea, R. M., ... & Pyrak-Nolte, L. (2019). The role of chemistry in fracture pattern development and opportunities to advance interpretations of geological materials. *Reviews of Geophysics*, 57(3), 1065-1111.
- [5] Meinberg, E. G., Agel, J., Roberts, C. S., Karam, M. D., & Kellam, J. F. (2018). Fracture and dislocation classification compendium—2018. *Journal of orthopaedic trauma*, 32, S1-S10.
- [6] Segall, P., & Pollard, D. D. (1980). Mechanics of discontinuous faults. *Journal of Geophysical Research: Solid Earth*, 85(B8), 4337-4350.
- [7] Nicol, A., Watterson, J., Walsh, J. J., & Childs, C. (1996). The shapes, major axis orientations and displacement patterns of fault surfaces. *Journal of Structural Geology*, 18(2-3), 235-248.
- [8] Burwell, H. N., & Charnley, A. D. (1965). The treatment of displaced fractures at the ankle by rigid internal fixation and early joint movement. *The Journal of Bone & Joint Surgery British Volume*, 47(4), 634-660.
- [9] Bhattacharya, A. R. (2022). Joints and Fractures. In *Structural Geology* (pp. 245-269). Cham: Springer International Publishing.
- [10] Jébrak, M. (1997). Hydrothermal breccias in vein-type ore deposits: a review of mechanisms, morphology and size distribution. *Ore geology reviews*, 12(3), 111-134.
- [11] Dott, Jr, R. H. (2003). The importance of eolian abrasion in supermature quartz sandstones and the paradox of weathering on vegetation-free landscapes. *The Journal of Geology*, 111(4), 387-405.
- [12] Folk, R. L. (1959). Practical petrographic classification of limestones. *AAPG bulletin*, 43(1), 1-38.
- [13] Mason, R., & Mason, R. (1990). *Petrology of the metamorphic rocks* (p. 230). London: Unwin Hyman.
- [14] Deer, W. A., Deer, W. A., Howie, R. A., & Zussman, J. (1982, December). *Rock-forming minerals: orthosilicates*, volume 1A. Geological Society of London.
- [15] Upadhyay, R. K. (2025). Rocks and their formation. In *Geology and Mineral Resources* (pp. 351-421). Singapore: Springer Nature Singapore.
- [16] Barnes, J. W., & Lisle, R. J. (2013). *Basic geological mapping*. John Wiley & Sons.
- [17] Whiteman, A. J. (2012). *Nigeria: Its Petroleum Geology, Resources and Potential: Volume 1* (Vol. 1). Springer Science & Business Media.
- [18] Bell, T. H. (1986). Foliation development and refraction in metamorphic rocks: reactivation of earlier foliations and decrenulation due to shifting patterns of deformation partitioning. *Journal of Metamorphic Geology*, 4(4), 421-444.
- [19] Tucker, M. E. (2011). *Sedimentary rocks in the field: a practical guide*. John Wiley & Sons.
- [20] Bhattacharya, A. R. (2022). Faults. In *Structural Geology* (pp. 155-191). Cham: Springer International Publishing.
- [21] Barton, N., & Shen, B. (2017, June). Extension failure mechanisms explain failure initiation in deep tunnels and critical heights of cliff faces and near-vertical mountain walls. In *ARMA US Rock Mechanics/Geomechanics Symposium* (pp. ARMA-2017). ARMA.
- [22] Pettijohn, F. J., Potter, P. E., & Siever, R. (1987). *Sedimentary structures and bedding*. In *Sand and Sandstone* (pp. 97-135). New York, NY: Springer New York.