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Litho-Geochemistry, Petrogenesis and Mineralisation Potential of Amphibolite-Schists Around Gadaeregi Area, North-Central Nigeria

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Abstract
This study investigated the geochemical compositions of Amphibolite-schists around Gadaeregi area of North-Central Nigeria to establish the petrogenetic evolution, geotectonic setting and associated potential mineralization. It was carried out across an area of 134.4km^2 within Bida sheet 184 NE on a scale of 1: 25, 000. The area is bounded by latitudes 9^o 22' 00"N - 9^o 28' 00"N and longitudes 6^o 17' 00"E - 6^o 24' 00"E. Systematic field investigation was carried out which revealed that the area is underlain majorly by migmatite-gneiss, amphibolite-schist and granite. Ten (10) samples of amphibolite-schist were subjected to geochemical analysis with reference to major oxide and trace elements using X-ray fluorescence (XRF). Plotting the geochemical results on typical discrimination diagrams revealed that the amphibolite-schists are of calc-alkaline and tholeiitic affinity. It shows a sedimentary origin, basaltic/andesitic progenitor and mixed (continental and oceanic) tectonic setting. Furthermore, the mineralization potential of the area was noted by comparing the result of trace elements in this study with their respective established crustal abundances, hence, Pb, Ag, Bi, Hg, Re, Pd, Ru and Au showed considerable anomalous concentrations in all/or some of the samples, though Au showed highest anomalies. This agrees with the fact that potential mineralization of Au is generally high within the schist belts of Nigeria. It is highly recommended that high resolution sampling at a larger scale be made to delineate the points with high prospects.
Keywords: Gadaeregi, Amphibolite-Schist, Geochemistry

1. Introduction
Nigerian segments of the Precambrian Trans-Saharan Pan-African orogeny lie within the mobile belt which separated the West African and Congo Cratons. It is related to Aïr, Hoggar, Cameroun and Borborema Pan-African (Brasiliano) regions (Ferre *et al.,* 1998). The total area of Nigeria is occupied in almost same ratios by basement and sedimentary lithologies (Rahaman, 1988). The basement rocks are splited into Basement Complex, Younger Granites and Tertiary-Recent volcanic rocks (Kogbe, 1989). The Nigerian Precambrian Basement Complex constitutes the migmatite gneiss complex, schist belts and Older Granites with the largest area of Basement Complex in north-central Nigeria (Obaje *et al.,* 2006; Obaje 2009, Ajibade *et al.*, 2008). Gold exploration has a long standing history in the Nigerian Basement complex, which included the works of Woakes et al., 1987; Garba, 1988,2000; Ramadan and Fatta, 2010.

Geological and geochemical investigations of rocks in an area play a very vital role in identification of various rock types and their chemical compositions. Based on this, some scholars have published works on geochemical characteristics of gneissic, schistose and granitic rocks of the Nigerian Basement Complex. They utilized the geochemical data in classifying these rocks based on different parameters with variable opinions. Garba 1988 reported that origin of Okolom – Dogonnaji were types that are ascribed to metamorphic processes similar to many other Au occurrences in Nigerian Schist belts. In a similar studies conducted by Garba, 2000 he reported that lithophile elements (K, Rb, Ba and Sr) and stable isotopes of (S, C, O) has further suggested that the origin of the mineralizing fluids in Bin Yau area one of the schist belt of Nigeria were mainly metamorphic in origin.

Adedoyin *et al* (2014) worked on the composition of schists and amphibolites from south-western Nigeria. The schists showed sedimentary origin of arkosic to greywacke parentage while the amphibolites are alkaline island arc theoliites that were probably contaminated by crustal materials. Okunlola and Okoroafor (2009) opined meta-sedimentary and continental post Achaean supracrustal rocks of arkosic progenitors for schists of Okemesi fold belt in south-western Nigeria.

However, not much is known about the amphibolite-schists occurring in the Bida sheet 184 NE of north-central Nigeria of which the study area is a part (Fig. 1). Generally, the amphibolite-schists of the study area were earlier identified by McCurry (1976) and Ajibade *et al.* (2008) on the basis of field mapping and petrography with no geochemistry, and were on regional scales. Precambrian rocks especially the schist belts are noted for hosting metallic and non-metallic mineral deposits of economic value. Thus, the information on geochemical characteristics of rocks will not only be of petrogenetic importance but also contribute to fruitful exploration for minerals (Adedoyin *et al.,* 2014). This work therefore presents the results of geochemical investigation of amphibolite-schists around Gadaeregi in north-central Nigeria; with the aim to determine their geochemical characteristics with emphasis on petrogenesis, geotectonic setting and the mineralisation potential of the area as additional data set to the existing ones in regarding the area.

1.1 Study Area Description

The research area forms part of Bida sheet 184 NE situated around Gadaregi, Kacha Local Government Council, Niger State in north central Nigeria (Fig. 1). It lies between latitudes 9° 22' 00''N and 9° 28' 00''N and longitudes 6° 17' 00''E and 6° 24' 00''E on a scale of 1:25,000. It covers an area extent of 134.4km^2. Furthermore, the area is accessible through the major road that runs from Minna to Bida and through a network of minor roads and footpaths. The railway which cut across the area westward also provides an easy accessibility (Fig.1).

However, the relief of the area is characterised by gentle undulating and lowland topography. The northern half of the area is made up of ta rugged terrain; examples include Gadaeregi and Dogon-ruwa areas. The elevations above sea level in the area vary from 350ft to 600ft (Fig. 1). The area is strongly dissected by two major rivers namely; River Chanchaga flowing southwest and River Dagga (Maar) from the north which drains into River Chanchaga in the southwest in addition to many tributaries exhibiting a dentritic pattern of drainage. Ajibade *et al.* (2008) concluded that these water channels in the area are mostly controlled by lithologic and structural units.

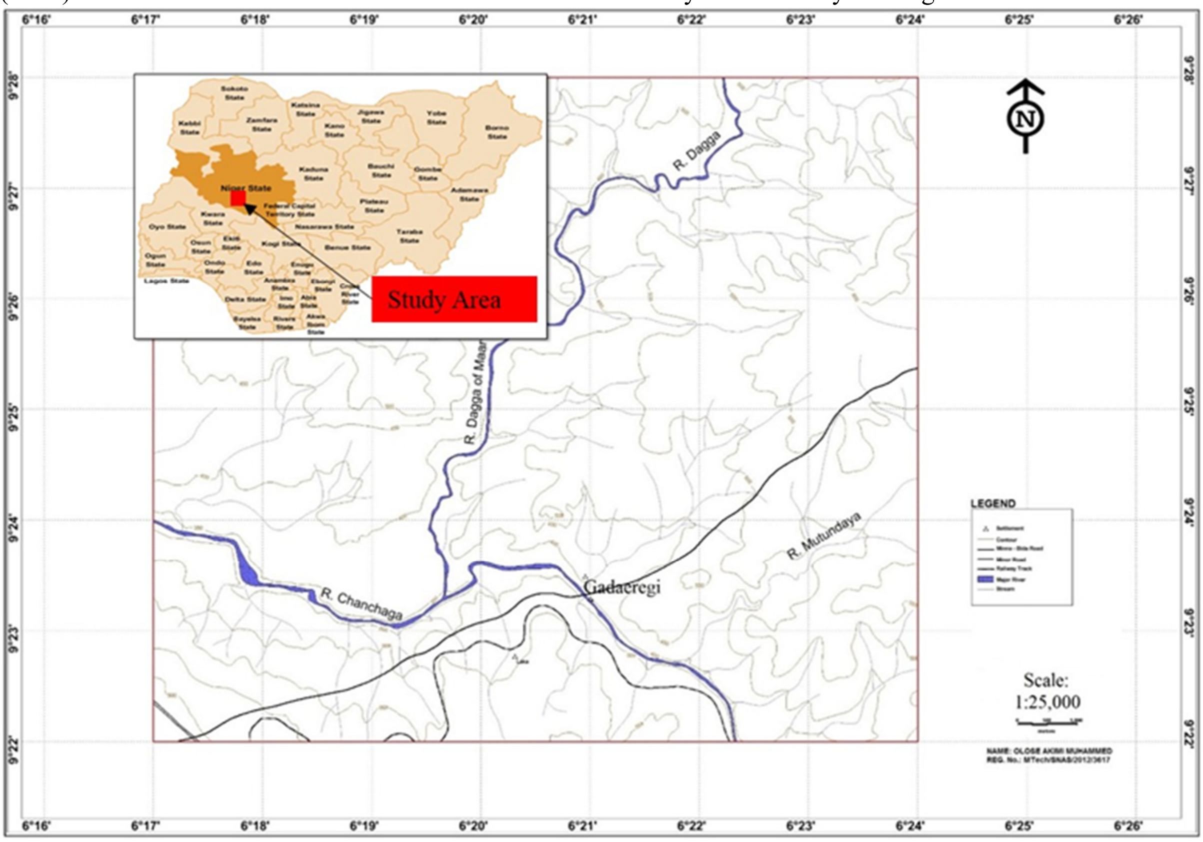

Figure 1: Location Map of the Study Area Gadaeregi Area, North-Central Nigeria

The climate is tropical climate that is attributed to rainy and dry seasons. The rainy season commences with southwest wind as from the month of April to October with apexes in July and August every annum. Sum of yearly precipitation ranges from 1270mm to 1524mm (Ileoje, 1981). The dry season starts from the month of November to March and this is marked by northeast, cold, dry, dust-laden harmattan wind blowing from the Sahara Desert respectively (Iloeje, 1981). The hottest period is usually between the months of February and March every year. The average annual temperature ranges from 28°C to 31°C (Iloeje, 1981).

The vegetation of the area is typically of the Guinea Savannah (Iloeje, 1981). This is characterised by sparse to moderate vegetation. This comprises of shrubs, thorny trees and other trees of moderate heights as well as distinct species of tall and short grasses. Examples include locust beans/mango trees, elephant/carpet grasses among others

The area is made up of few settlements that range from hamlets to villages. The major settlement in the area is Gadaeregi characterised by moderate population of about 4,000. The inhabitants include Gbagyis, Hausas and Nupes who uses the land mainly for agricultural activities. These include cultivation of crops (yams, guinea corn, millet, maize, melon, rice, beans, pepper, ground nut, potatoes and cassava) and rearing of animals (cattle, goats, sheep, rams and poultry) for both commercial and domestic purposes.

2. Methods/Techniques

The methods employed in this research involved desk study of relevant literatures, detailed geological field mapping/rock sampling and laboratory work. The geological mapping exercise was carried out on a scale of 1:25,000 to reveal the various rock types in the area by open traverse. Fresh representative rock samples were carefully collected and labelled with the aid of a sledge hammer and marker pen respectively during this exercise. The rock samples were prepared and analysed at the National Geosciences Research Laboratories (NGRL), Nigerian Geological Survey Agency, Kaduna. The analytical method applied is x-ray fluorescence (XRF) spectrometry. Each of the representative bulk samples from the field was crushed, using agate mortar and pestle. The crushed samples were then sieved by a 100µm mesh sieve. The sieved samples were sub-sampled by an apparatus called 'rifle box' to obtain a quantity of 60g each (homogenisation stage). The samples were then pulverised to fine powder to ensure homogeneity, with 'planetary micro mill pulverisette 7' and the pulverised samples were sieved to pass a 150µm mesh sieve. Five **(**5) grams of the pulverised samples were weighed into a beaker and one (1) gram of starch soluble as binding aid was added to form a mixture. The mixture was thoroughly homogenised and compressed under high pressure (6 "tone") to produce pellets. The pellets were well-labelled and packaged for XRF analysis. The sample pellets were in turn fed into the XRF machine ("Minipal 4" model) for determination of the concentrations of major oxides and trace elements.

3. Results and Discussion

3.1 Geology

Three major lithologic units were identified as a product of the fieldwork. These include migmatite-gneiss, amphibolite-schist and granite. These rock units are well represented in the geological map (Fig. 2) based on inferred lithologic boundaries.

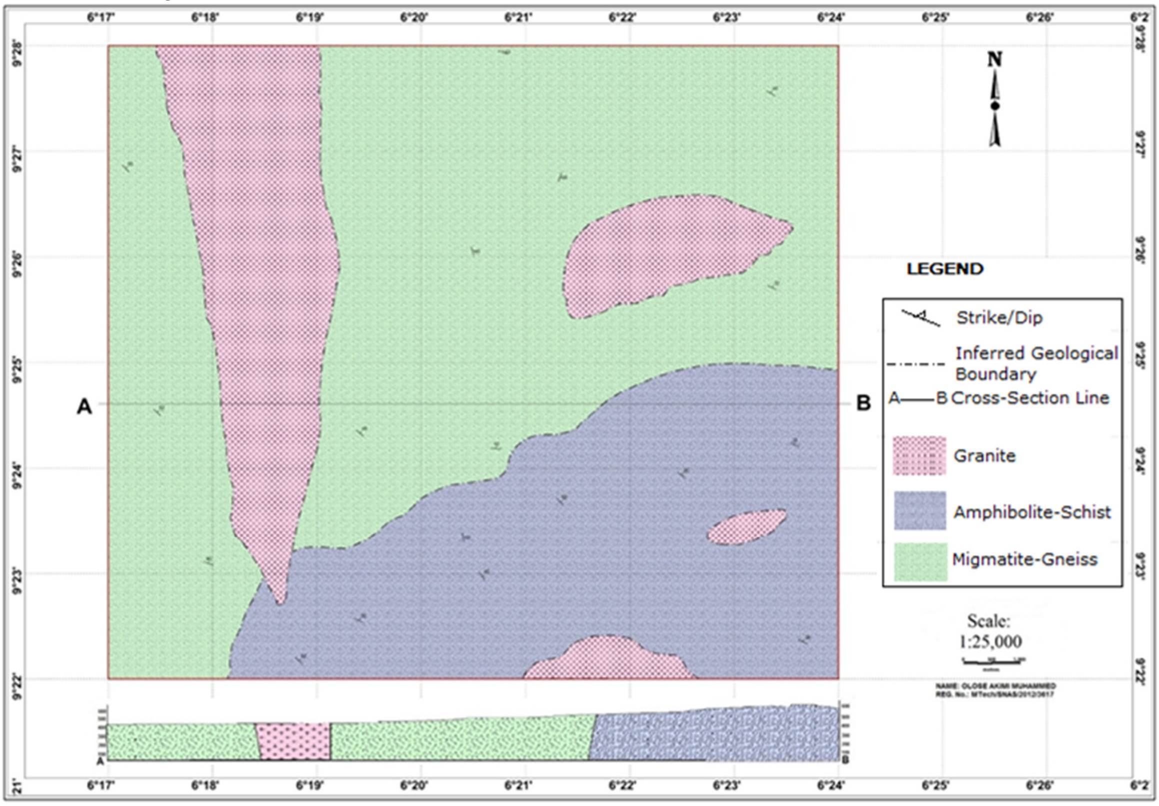

Figure 2: Geological Map of Gadaeregi Area, North-Central Nigeria

3.1.1 Migmatite-Gneiss

The Migmatite-gneiss rocks which are of complex nature covering up to 60% of the study area (Fig. 2). Most of the outcrops occur in the form of low lying boulders and massive outcrops. They are mainly grey to dark-grey in colour and show medium to coarse-grained texture. In hand specimens, the rocks consist of quartz, plagioclase feldspars and muscovite and biotite. The Migmatite-gneiss were characterised by structural elements such as foliations, lineations, joints, faults, folds, and quartz veins (as gash fractures (en-echelons) in various locations.

3.1.2 Amphibolite-Schist

The amphibolite-schists occupy about 25% of the area (Fig. 2). These rocks mainly occur as low lying massive and foliated outcrops. They are mostly exposed along rivers and stream channels. Some of the outcrops have been intensively weathered. All the outcrops are generally green to dark green in colour. They show fine-medium grained texture. In hand specimens, the rocks consist of quartz, hornblende, biotite and muscovite. They were characterised by strong foliations defined by preferred mineral orientation indicating schistosity. The structural features associated with these rocks include simple joints, quartz veins, foliation, and folds mainly. At some locations, the amphibolite-schists are interlayered with minor Quartzite's which stand more resistant to weathering than the schist.

3.1.3 Granite

The granitic rocks occupy about 15% of the area (Fig. 2). The granitic rocks occur in the form of boulders and massive outcrops which intruded the Migmatite-gneiss and the amphibolite-schist (Fig. 2). The outcrops in the area were generally partially weathered. The rocks show medium to coarse-grained texture and do not show any preferred orientation of minerals. In hand specimen, the rocks consist of quartz, orthoclase/plagioclase feldspars, muscovite and biotite. The rocks are generally leucocratic to mesocratic in colour. The structural features on some of the outcrops include joints and quartzofeldspathic veins.

3.2 Geochemistry

3.2.1 Major Oxides (wt%)

The result of major oxides of the analysed samples of amphibolite-schist is presented in Table 1. SiO_2 content is (50.96wt%-61.35wt%; average = 54.69wt%). Al_2O_3 content is (10.5wt%-16.6wt%; average = 13.7wt%). P_2O_5 content is (0.001-0.043wt%; average = 0.02 wt%). The content of Na_2O is (0.04wt%-3.01wt%, average = 1.54wt%). K_2O content (0.075wt%-2.92 wt%; average = 1.33wt%). The concentration of CaO is (3.91wt%-11.6wt%; average = 8.65wt%). MgO concentration is (2.69wt%-12.64wt%; average = 8.66wt%). TiO_2 content is (0.41wt%-3.26wt%; average = 1.56wt%). Fe_2O_3 is moderate to high in concentration (6.2wt%-10.72wt%; average = 9.08wt%). The content of MnO is (0.15wt%-0.52wt%; average = 0.3wt%) and LOI is (0.18wt%-1.02wt.

The geochemical composition of the amphibolite-schist samples is dominated by silica, alumina, lime, magnesia and iron oxide. These indicate their derivation from a basaltic magma in an oxidizing environment (Winter, 2010 and Adedoyin *et al.,* 2014).

From the AFM plot, the amphibolites-schist samples show both calc-alkaline and tholeiitic characteristics (Fig. 3). This point to their intermediate colour defined by the availability of high iron and magnesia contents in the samples. The amphibolite-schists are either of different petrogenetic sources or there have been significant contaminations from continental materials during evolutionary history of the progenitor (Adedoyin *et al.,* 2014).

Table 1: Concentrations of Major Oxides (wt%) for Amphibolite-Schist of Gadaeregi Area, North-Central Nigeria

Sample No	SiO_2	Al_2O_3	P_2O_5	Na_2O	K_2O	CaO	MgO	TiO_2	Fe_2O_3	MnO	LOI	Total
OL1	50.96	14.6	0.02	1.24	0.25	11.35	11.29	1.1	8	0.24	0.18	99.23
OL2	52.72	11.43	0.022	1.32	1.39	10.47	9.45	1.02	10.72	0.18	0.35	99.07
OL3	51.17	15.5	0.02	1.03	0.075	11.01	10.07	1.05	9.72	0.37	0.73	100.75
OL4	61.35	16.6	0.05	2.84	1.62	3.91	2.69	0.87	8.76	0.15	1.02	99.86
OL6	58.2	10.8	0.001	0.04	<0.001	11	8.53	0.41	10	0.39	1.02	100.39
OL7	56.86	10.5	0.02	1	<0.001	11.6	7.1	3.26	8.42	0.34	0.19	99.29
OL10	55.4	14.1	<0.001	1.11	2.92	5.3	7.35	2.29	10.49	0.38	0.59	99.93
OL11	53.64	13.2	0.024	2	1.3	9.06	12.64	1.65	6.2	0.52	0.41	100.64
OL12	52.5	15.11	0.043	2	0.96	8.6	9.31	1.47	9.03	0.17	0.6	99.80
OL13	54.1	15.2	0.011	2.85	2.1	4.21	8.42	2.53	9.44	0.26	0.81	99.93
Average	54.69	13.70	0.02	1.54	1.33	8.65	8.69	1.57	9.08	0.3	0.59	

Table 2: Concentrations of Trace Elements (ppm) for Amphibolite-Schist of Gadaeregi Area, North-Central Nigeria

Sample No	V	Cr	Ni	Co	Rb	Sr	Mo	Cu	Pb	Ag
OL1	0.15	0.021	0.27	<0.001	<0.001	0.2	<0.001	0.019	0.004	0.41
OL2	0.13	0.005	0.098	<0.001	<0.001	0.354	<0.001	0.072	0.005	0.61
OL3	0.144	0.809	<0.001	0.002	<0.001	0.074	0.002	0.003	0.03	2.47
OL4	0.13	0.016	<0.001	<0.001	<0.001	0.062	<0.001	0.018	0.007	0.85
OL6	0.078	0.398	0.11	<0.001	<0.001	0.18	0.19	<0.001	0.013	2.4
OL7	0.18	0.086	0.008	0.001	<0.001	0.241	<0.001	0.089	0.024	2.82
OL10	0.152	0.086	0.056	<0.001	<0.001	<0.001	1.03	0.253	0.001	3.41
OL11	0.19	0.065	0.02	<0.001	0.11	<0.001	<0.001	0.044	0.01	2.59
OL12	0.16	0.41	0.03	0.005	0.001	0.23	0.51	0.16	0.043	0.75
OL13	0.082	0.28	0.12	0.02	0.02	0.07	0.08	0.076	0.02	1.86
C-V	95	70	44	12	98	290	1	24	0.06	0.06

Table 2: (continued)

Sample No	As	Zn	Bi	Au	Hg	Ba	Re	Zr	Pd	Ru
OL1	0.05	0.048	2.1	<0.001	0.071	<0.001	0.07	0.1	0.16	<0.001
OL2	<0.001	0.037	0.1	<0.001	0.3	0.1	0.003	<0.001	<0.001	<0.001
OL3	0.005	0.04	0.4	0.01	0.2	0.28	0.12	0.08	<0.001	0.615
OL4	<0.001	0.04	2.4	<0.001	<0.001	<0.001	0.067	<0.001	<0.001	1.33
OL6	0.002	0.055	1.01	0.4	0.05	0.012	0.001	0.014	<0.001	0.58
OL7	0.005	0.021	0.14	0.082	0.098	<0.001	0.02	0.054	0.34	<0.001
OL10	0.004	0.056	0.78	0.013	0.05	0.31	0.01	0.024	0.032	<0.001
OL11	<0.001	0.083	<0.001	<0.001	0.05	0.31	0.01	0.024	0.032	<0.001
OL12	0.01	0.026	0.63	<0.001	0.08	0.16	0.011	0.048	0.021	0.87
OL13	0.06	0.06	0.12	0.02	0.1	0.25	0.035	0.061	0.015	1.02
C-V	1.7	77	0.082	0.004	0.03	730	0.001	160	0.001	0.001

C-V = Clarke's value (Wedepohl, 1975)

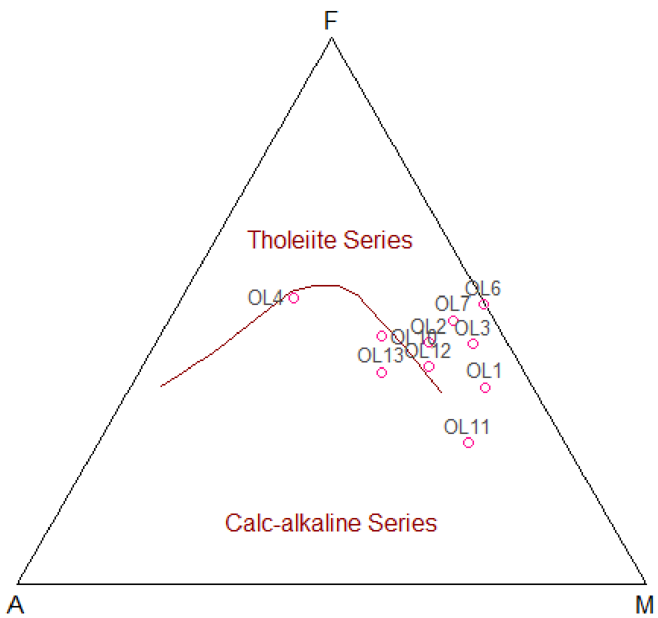

Figure 3: AFM plot of amphibolite-schist

This is followed by a discriminant plot of K_2O/Al_2O_3 vs Na_2O/Al_2O_3 in which the entire samples plot in the field of sedimentary/metasedimentary (Fig. 4). This indicates a sedimentary origin for the amphibolite-schist in the area. This agrees with schists from south-western Nigeria (Adedoyin *et al.,* 2014). The ternary diagram further shows that the amphibolite-schists are from mixed (continental and oceanic) tectonic setting (Fig. 5). This strengthened the possibility of different petrogenetic sources during evolution of the progenitor. It was further deduced that the sediments (now metamorphosed) were derived from greywacke protoliths as shown in the plot of Na_2O vs K_2O (Petijohn, 1975) (Fig. 6).

Amphibolite-schists are known to have basic to ultra-basic protoliths and contamination of the protoliths during or after the emplacement could have altered the original chemistry (Adedoyin *et al.,* 2014). The high probability of such inference can be supported from the TAS plot (Middlemost, 1989) (Fig. 7) which indicates that the rocks are mainly of basaltic-andesitic progenitor.

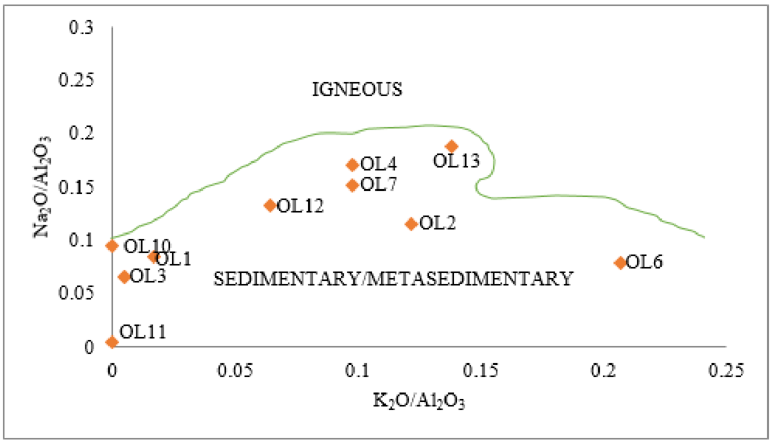

Figure 4: Na_2O/Al_2O_3 versus K_2O/Al_2O_3 plot of the amphibolite-schist

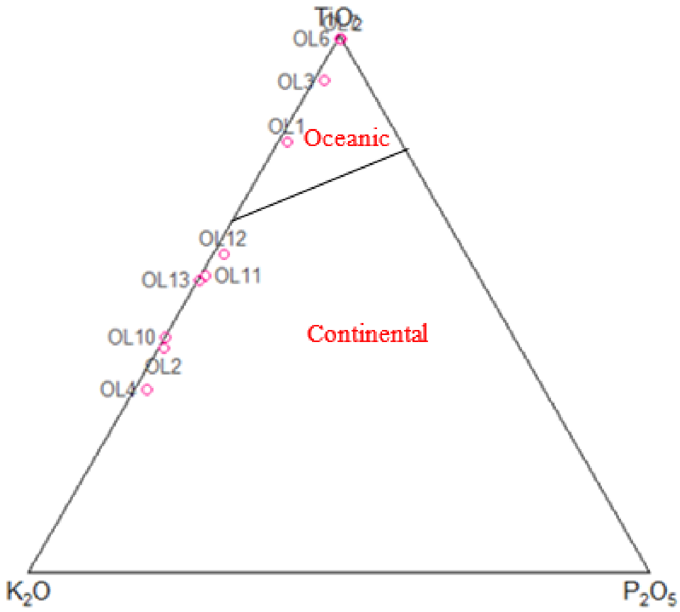

Figure 5: Ternary plot of the amphibolite-schist

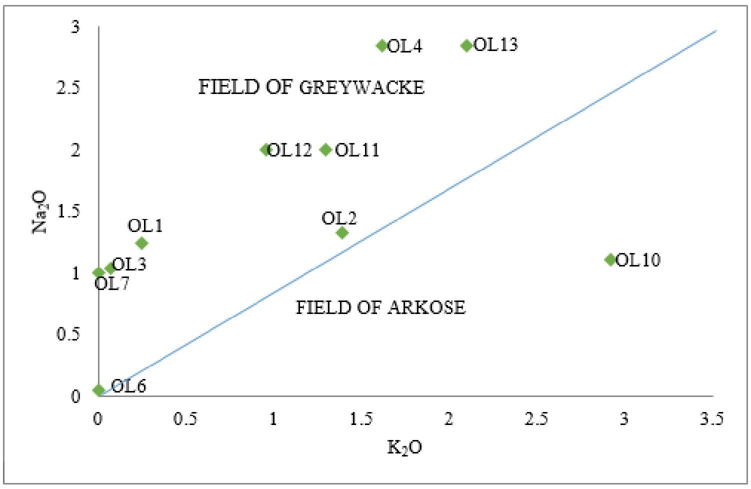

Figure 6: Na_2O versus K_2O plot of the amphibolite-schist

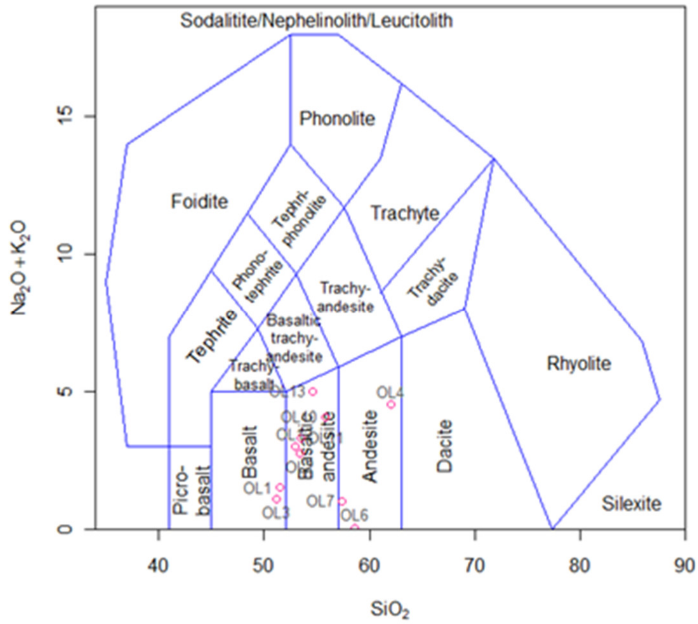

Figure 7: TAS plot of amphibolite-schist

3.2.2 Trace Elements (ppm)

The result of trace elements concentrations is presented in Table 2. This shows an enhancement of Ba over Rb in the amphibolite-schist, which is a signature of K-feldspar-rich protoliths (Adedoyin, *et al.,* 2014). The original sediments would have contained significant amounts of feldspar, clay minerals, carbonates, and organic matter. Availability of Cr and Ni in the rocks indicates presence of some amounts of mafic constituents in the sediments. This is in agreement with the Woakes et al. (1987) where they reported that the type of metallogenic provinces that existed in other Pan African terrains are absent in Nigeria which included the basemetal deposits of associated to plate accretion type.

Among the trace elements analysed only Ag, Bi, Au, Hg, Re, Pd and Ru show considerable anomalous values in all or some samples in comparison with their respective Clarke's values (Table 2). Ag values range from 0.41 to 3.41 ppm among all the samples. This range is comparable with the Clarke's value (0.06 ppm). This is interpreted as indicating potential occurrence of Ag minerals associated with ores of Bi, Co, Ni and Pb in the area (Adepoju and Adekoya, 2011).

Bi values range from 0.1 to 2.4 ppm in all samples except one (OL11). This range is comparable with the Clarke's value (0.082 ppm). This suggests strong affinity with ores of Ag, Co, Ni and Pb in the area.

Au values range from 0.01 to 0.082 ppm in six samples (OL1, OL3, OL6, OL7, OL10, and OL13). This range is on the high side compared with the Clarke's value (0.004 ppm). This indicates Au mineralisation in the amphibolite-schist of the area.

Hg values range from 0.05 to 0.3 ppm in all samples except one (OL4). Compared with the Clarke's value (0.03 ppm) the concentration of Hg is moderate. This might be related to limited or lack of Hg mineralisation which indicates similar trends to the results obtained by Adepoju and Adekoya (2011) and Garba, 2000.

Re values range from 0.001 to 0.12 ppm in all samples. Compared with Clarke's value (0.001 ppm) Re is moderate in concentration. Pd values range from 0.015 to 0.34 ppm in six samples (OL1, OL7, OL10, OL11, OL12 and OL13). A comparison of Pd with its Clarke's value (0.001 ppm) shows that the concentration of Pd is relatively moderate.

The concentration values of Ru in the five samples (OL3, OL4, OL6, OL12 and OL13) range from 0.58 to 1.33 ppm. Its comparison with the Clarke's value (0.001 ppm) shows relatively low concentration of Ru. At this point, it can be said that the amphibolite-schist in the study area is liable to potential mineralisation of Ag, Bi, Au, Hg, Re, Pd and Ru.

Conclusion

The outcome of the geological mapping of the research area revealed three major lithologic units. They include the migmatite-gneiss, amphibolite-schist and granite Geochemical results of the rocks from the area show that the amphibolite-schists in the area are mainly of greywacke para-schists that were probably derived from a somewhat to moderately weathered feldspathic igneous sources. The amphibolite-schists are essentially tholeiites that were probably contaminated by crustal materials.

In terms of potential mineralisation in the study area, some trace elements such as Pb, Ag, Bi, Au, Hg, Re, Pd and Ru show considerable anomalous concentrations in the amphibolite-schists when compared with their respective Clarke's values proposed by Wedepohl (1975). Though mineralisation potential for gold (Au) is higher than other elements due to its high anomalies in some samples. This agrees with the fact that potential mineralisation of Au is generally high within the schist belts of Nigeria.

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