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GEOCHEMICAL ANALYSIS OF ROCKS AND STREAM SEDIMENTS IN RAGGA PART OF KURRA SHEET 189 SW NORTH CENTRAL NIGERIA

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ABSTRACT: *Geochemical analysis of rocks and sediments from streams in Ragga part of Kurra sheet 189 SW north central Nigeria was carried out to infer the mineral potential of the area. Kurra area was underlined by Precambrian Basement Complex rocks, which among others, include the medium grained banded gneiss and were intruded by pegmatite and quartzo-feldspathic veins that occurred as discordant low lying dykes. The gneisses contained quartz, plagioclase feldspar, biotite and muscovite. The basalts were mainly plagioclase, olivine, phenocryst of magnetite, quartz and ground mass of clinopyroxene in nature. The amphibolite contained plagioclase feldspar, hornblende, quartz, biotite and pyroxene. The pegmatite mostly trends in the NE-SW, and was generally made up of quartz, plagioclase, biotite and muscovite. Most of the pegmatite and medium grained leucocratic gneiss samples fall within the calc-alkali field, whereas the basalt and medium grained melanocratic gneiss samples plotted in the alkali-calcic field. The plot of Na_2O/Al_2O_3 against K_2O/Al_2O_3 indicated that the pegmatites were of igneous ancestry and were within the syn-collisional granite field and were ≥ 30 km depth fields. The concentrations of Au, Ag, Pb, Zr, Sn and Ba in sediments were higher in the NW part of Angwan Maiganga than around Ragga Makaranta. Sn was dominant in the sediments along the streams in the NW part Angwan Maiganga, while Ag was higher around Ragga Makaranta. The transportation of metalliferous ore-forming fluids from the rocks by the river to the sediment might be responsible for the observed higher concentrations of the minerals in the sediments.*

KEYWORDS: Geology, petrology, rock, streams sediments, ternary

INTRODUCTION

The structural and tectonic framework of the Nigerian Basement Complex has been documented by several researchers (Annor and Freeth, 1985; Kuster, 1990; Annor *et al.*, 1990; Olasehinde *et al.*, 1990) to consist of northeast – southwesterly and northwest – south easterly lineaments that are superimposed over a prevailing north-southerly pattern (Olasehinde *et al.*, 1990), and northwest–southeasterly and northeast – southwesterly pair superimposed on a north - south set of joints (Annor *et al.*, 1990). Jacobson and Webb (1946) and Wright (1970) were among the first researchers to document on the pegmatites of Wamba area in Nasarawa State, North Central Nigeria. The contrasting styles of pegmatite of this area with respect to Sn-Nb-Ta-Zn mineralization were also reported (Kinniard, 1984).

Matheis and Kuster (1989) documented on the geochemical exploration guides for rare metal pegmatites with case of Ijero, Wamba, and Jemma in the Central Nigeria. Pollard (1989) documented on the geochemistry of the granites associated with tantalum and niobium mineralization with examples of the Ring-complexes of Northern Nigeria. Tantalum, niobium and other metals occurred with tin and have been produced as by-products. It is estimated that more than 95 % of the over 650,000 tonnes of cassiterite (tin) produced has been from alluvial deposits derived from the Mesozoic Younger Granites (Okunlola &Ocan, 2009). The remaining 5 % of the tin has been derived from pegmatites which form a well-defined ENE-WSW trending zone from the central Jos Plateau to the Ife-Ilesha area (Okunlola & Ocan, 2009).

Kuster (1990) observed that the Late Pan African tectonic granites at Wamba (about 100 km northeast of Nasarawa) are all sub-alkaline, peraluminous, and highly siliceous rocks with their peraluminosity more pronounced with increasing differentiation; and also envisaged that the major elements (Si, Al, K, and Na) show only slight variations; with only Na being enhanced toward the end of granite evolution. Prior to evolution from the biotite granites through biotite-muscovite granites, muscovite granites to the apo-granites, there was a pronounced enrichment of Rb, Li, Cs, Sn, Nb, Mn, and P, whereas B was only slightly enhanced. Strong depletion was evident for Ba, Sr, Zr, Y, La, and Ce together with Ti, Mg, Ca, and Fe. These results support the observation that the rare-metals are related to highly differentiated granitic magmas and represent strongly fractionated residual melts rich in silica, alumina, alkali elements, water and other volatiles, lithophile elements and rare metals (Cerny, 1991; London, 1990). The distribution of As, Rb, Ag, Au, Ba, Pb and Cu values appears in streams around Ragga and Environs trending the N-S direction parallel to the prevailing strike directions in the area being NE-SW and ENE-WSW strikes (Jatau *et al.*, 2012, 2013). The structural characterization of the study area is dorminated by foliation(NE-SW, N-S), fractures and faults NE-SW), Lineation (NW-SE), joints folds and minor faults (N-W, NNE-SSW) that showed cataclasis (Jatau *et al*., 2016) The correlation of the topographic map and the maps that showed the relative distribution of the trace elements in the rock samples as well as the stream sediments revealed that areas with low elevation generally have high concentration of the rare metals, while areas of high elevation tend to have relatively low concentration of the rare elements (Jatau *et al.*, 2018).
The main aim of this research work is to carry out a comparative rock and streams sediments analysis of part of Kurra sheet 189SW, distinguish the different rock types, recognize their petrographic characteristics, study the structural trends of the mineral lineament in the area and infer the economic potential of the minerals of the study area and environs. The scope of this research work involved comparative investigations of rocks and streams sediment using a topographical map Kurra sheet 189SW as the base map; covering an area of 52 km^2 with geology features.

MATERIALS AND METHODS

Study Area

The study area lies between longitudes 8°30'00''E and 8°35'00''E and between latitudes 9°00'00'' N and 9°03'16.22''N (Fig. 1). The area covers part of Kurra Sheet 189SW, in the North-Central part of Nigeria. The area is accessible through five minor roads, namely; Abu – Ragga Gari road, Ragga–Barimaw road, Ragga Hamya-Mota –UngwanMaiganga road and Ragga–Ragga Makarata.The study area is marked by two distinct climatic conditions which are the annual wet and dry season. The climatic condition of the area is characterised by rainy season (April to October) and dry season (November to March) with annual rainfall and temperature varying between 1300 mm – 1500 mm and 28 ℃ – 36 ℃, respectively (Adefolalu, 2002). The area lies within the Savannah grassland region of central (Middle belt) Nigeria. The predominant vegetation of the area is undulating grassland. The topography of Nigeria is generally influenced by planar and linear structures resulting from ductile and brittle deformational events (Onugba and Eduvie, 2003). The structures generally have N – S, NE – SW, NW – SE and sometimes E – W trends (Oluyide, 1988; Olasehinde and Awojobi, 2004). The study area is generally flat and undulating in some places mostly where ridges outcrop with altitude of about1100m – 1650m above the sea level.

The geology of the study area is underlain by the Nigerian Basement Complex. These Basement Complex rocks were emplaced during the Pan African Orogeny before the Jurassic Younger Granites intruded through peripheral ring structures (Aga *et al*., 2012).Geochemical evidence indicates that the Basement Complex of Nigeria is polycyclic in nature and has been reactivated during the Liberian (2,700±200Ma), Eburnean (2000±170 Ma), Pan-African (600±150Ma) orogenesis (McCurry and Wright, 1977; Ogezi, 1977; Annor and Freeth, 1985; Rahaman, 1988; Ajibade *et al*., 1981; Dada, 2006; Ibrahim, 2008).Oluyide (1988) reported that within the Basement Complex, tectonic deformation has completely obliterated primary structures, except in a few places where they survived deformation.

Mapping

Systematic mapping of the area was carried out on the exposed outcrops (gneisses, amphibolite, pegmatite, and basalt) using the base map extracted from the topographic map of Kurra (part of Sheet 189 S.W) published on a scale of 1: 50,000. Sampling was done randomly using geological hammer for rock samples and hand auger for stream sediments collection.

Sediment Sampling

Twenty-five (25) stream sediments were collected along river channels at 500m interval and four (4) control sediment samples were picked randomly within the study area. The samples were collected in the sample bags and were well-labelled using a permanent marker. The coordinates and elevations of sampling locations were recorded with a global positioning system (Garmin eTrex-10). Where necessary, strike and dip were measured for the host rock with the aid of compass clinometer and recorded in the field notebook. Thereafter, the observed outcrops were described and identified in order to determine their textural and structural characteristics, as well as their mode of occurredrence. Textural characteristics of the rocks were elucidated using magnifying hand lens. Photographs of the outcrops were also taken using a digital camera. On the whole, seventeen (17) representative rock samples (Table 1) and twenty-nine (29) stream/control sediments (Table 2) were prepared and sent to National Geosciences Research Laboratory (NGRL), Kaduna, for thin sections preparation and X-ray florescence analysis. Oasis Montaj (Geosoft) software was used to digitize the location map.

Table 1: Representative samples identification, location and descriptions

S/N	Sample No	Longitude	Latitude	Nature of sample	Description
1.	L1	8°31'22.0"E	9°01'27.2"N	Rock	Medium Grained Melanocratic Gneiss
2.	L3	8°30'57.2"E	9°01'42.4"N	Rock	Medium Grained Melanocratic Gneiss
3.	L13	8°30'43.4"E	9°02'48.2"N	Rock	Pegmatite
4.	L29	8°32'06.0"E	9°03'14.2"N	Rock	Medium Grained Leucocratic Gneiss
5.	L31A	8°31'58.8"E	9°02'34"N	Rock	Medium Grained Leucocratic Gneiss
6.	L35A	8°32'21.3"E	9°02'34.3"N	Rock	Pegmatite
7.	L35B	8°32'21.3"E	9°02'34.3"N	Rock	Amphibolite
8.	L40	8°32'46.6"E	9°02'25.2"N	Rock	Medium Grained Banded Gneiss
9.	L44	8°32'18.8"E	9°02'19.2"N	Rock	Medium Grained Banded Gneiss
10.	L67	8°33'48.1"E	9°01'13.8"N	Rock	Amphibolite
11.	L79	8°35'00"E	9°03'00.2"N	Rock	Pegmatite
12.	L87	8°31'12.1"E	9°00'19.4"N	Rock	Pegmatite
13.	L88	8°31'07.9"E	9°00'10.0"N	Rock	Basalt
14.	L95	8°30'07.2"E	9°00'30.9"N	Rock	Basalt
15.	L101	8°31'54.2"E	9°01'34.1"N	Rock	Basalt
16.	L102	8°31'45.6"E	9°00'13.6"N	Rock	Amphibolite
17.	L31B	8°31'58.8"E	9 02' 34" N	Rock	Medium Grained Banded Gneiss

Sample Preparation and Quantification

The laboratory work was concerned with the preparation of thin sections for petrographic study and geochemical analysis. Thin sections of the seventeen (17) representative rock samples were prepared and analysed for petrographic studies. Quantitative geochemical analysis using X-ray fluorescence (XRF) was carried out on seventeen (17) rock samples, twenty-five (25) stream sediments and four (4) control sediments. Thin sections were prepared at the National Geosciences Research Laboratory (NGRL), Kaduna. Petrographic studies were conducted under plane and cross-polarized light on the prepared thin sections. Photographs and photomicrographs of interest were taken under the optical microscope. A representative fraction (fresher portion) of the seventeen (17) rock samples were chopped out, crushed and ground in an agate mortar that was cleaned with ethanol to pass through the 150µ mesh. This was done in order to ensure homogeneity of the samples. The powdered samples were well packaged and labeled for XRF analysis. The major oxides were quantified using Kapton as the primary filter, air as the carrier medium and at 14 kV current flow for 10 sec. However, for trace element measurement, the primary filter used was silver (Ag) and also air as a carrier medium, with a current flow of 30 kV for 100 sec.

Ternary image was plotted for the rock samples and stream sediments using the three grid channels from Oasis Montaj, which includes; the gold (Au), tin (Sn) and tantalum (Ta). Three

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apexes were used to depict compositions of gold (yellow), tin (blue) and tantalum (red). This allows comparison between gold (Au), tin (Sn) and tantalum (Ta) at once, every position or point on the ternary plot represents a different composition of the three elements.

Table 2: Locations and depths of the streams and control sediment samples

S/N	Sample No	Longitude	Latitude	Nature of sample	Depth of sampling (cm)
1	ST1	8°34'1.6"E	9°03'03.9"N	Stream sediment	30
2	ST2	8°34'4.2"E	9°02'55.4"N	Stream sediment	30
3	ST3	8°34'0.5"E	9°02'39.2"N	Stream sediment	10
4	ST4	8°33'58.3"E	9°02'36.9"N	Stream sediment	30
5	ST5	8°33'59.0"E	9°02'24.7"N	Stream sediment	30
6	ST6	8°33'52.4"E	9°01'27.2"N	Stream sediment	30
7	ST7	8°33'51.2"E	9°01'58.5"N	Stream sediment	35
8	ST8	8°33'40.6"E	9°01'49.0"N	Stream sediment	50
9	ST9	8°33'40.0"E	9°01'37.8"N	Stream sediment	10
10	ST10	8°33'45.0"E	9°01'25.9"N	Stream sediment	20
11	ST11	8°33'48.1"E	9°01'13.8"N	Stream sediment	30
12	ST12	8°33'54.6"E	9°01'01.5"N	Stream sediment	30
13	ST13	8°33'51.8"E	9°00'54.0"N	Stream sediment	30
14	ST14	8°33'58.2"E	9°00'52.5"N	Stream sediment	20
15	ST15	8°33'57.6"E	9°00'35.0"N	Stream sediment	30
16	ST16	8°31'34.8"E	9°00'34.8"N	Stream sediment	30
17	ST17	8°30'31.6"E	9°00'08.7"N	Stream sediment	30
18	ST18	8°30'8.6"E	9°01'13.9"N	Stream sediment	30
19	ST19	8°31'54.2"E	9°01'34.1"N	Stream sediment	30
20	ST20	8°31'45.6"E	9°01'29.1"N	Stream sediment	30
21	ST21	8°31'43.6"E	9°01'16.8"N	Stream sediment	30
22	ST22	8°31'43.6"E	9°01'08.5"N	Stream sediment	20
23	ST23	8°31'40.9"E	9°01'01.0"N	Stream sediment	40
24	ST24	8°31'31.1"E	9°00'55.2"N	Stream sediment	30
25	ST25	8°31'31.0"E	9°00'41.0"N	Stream sediment	30
26	CT1	8°31'32.3"E	9°00'41.6"N	Control sediment	30
27	CT2	8°31'8.8"E	9°00'0.7"N	Control sediment	60
28	CT3	8°31'25.6"E	9°00'0.4"N	Control sediment	50
29	CT4	8°31'41.4"E	9°00'2.8"N	Control sediment	50

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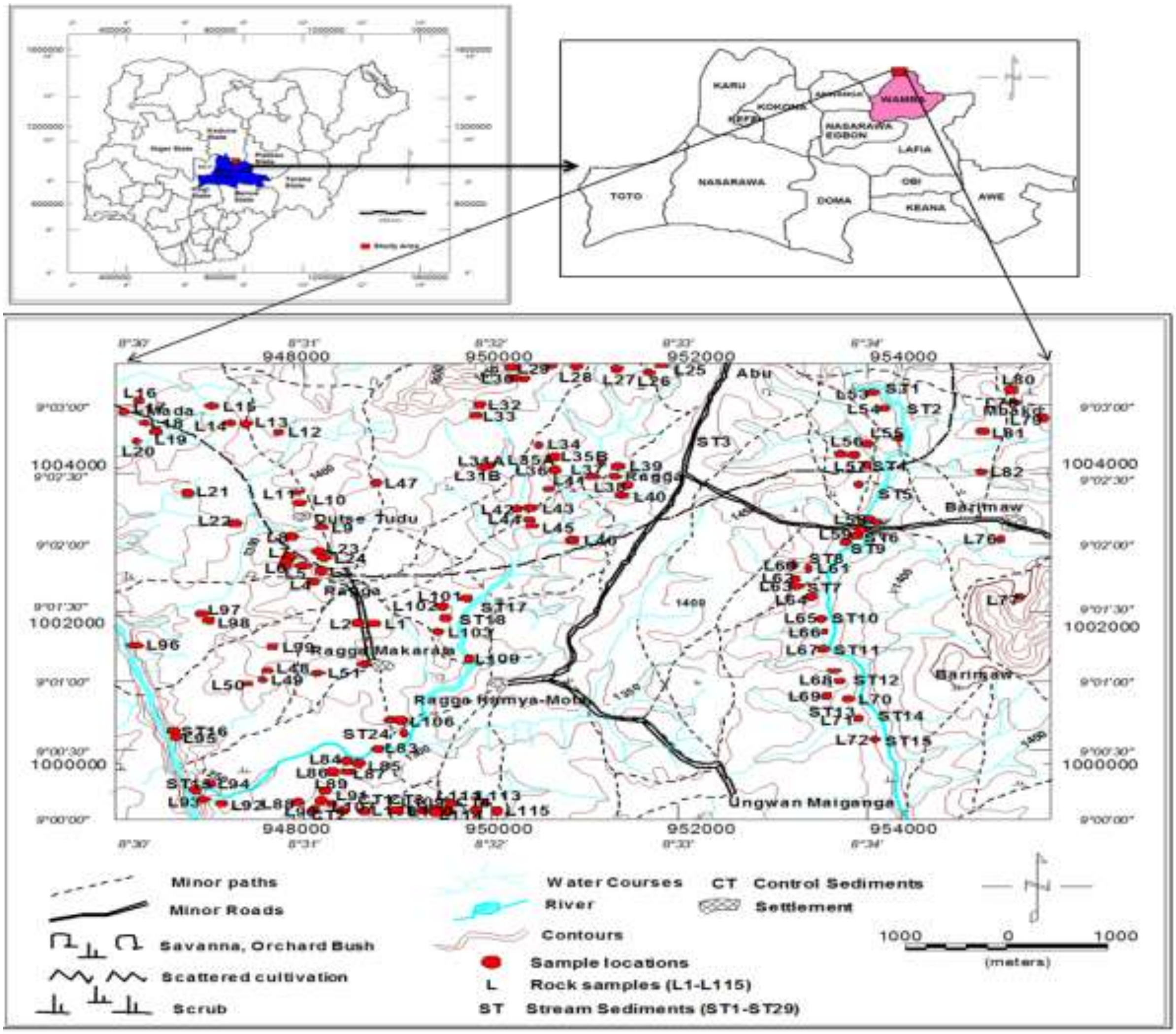

Figure 1. Map showing samples location in the study area (Modified, Federal Surveys Nigeria, 1967).

RESULTS AND DISCUSSION

Results

Geology of the study area

Five main lithologic units were discovered during geologic field mapping of the area and these are medium grained banded gneiss, medium grained leucocratic gneiss, medium grained melanocratic gneiss, basalt, amphibolite and pegmatite. The medium grained leucocratic and medium grained melanocratic gneisses occupied about 80 % of the rocks in the study area. The medium grained banded gneiss occupied about 17 % of the rocks, the basalts occupied about 2.3 %, while amphibolite occupied up to 0.7 % of the rocks outcropping in the study area (Fig. 2). The medium grained banded gneiss and basalts are more prominent in the area and are occasionally seen in contact with basalt in the south-western part of the map. The pegmatites in the study area mostly occurred as veins within the host rocks with general orientation of NE-SW..

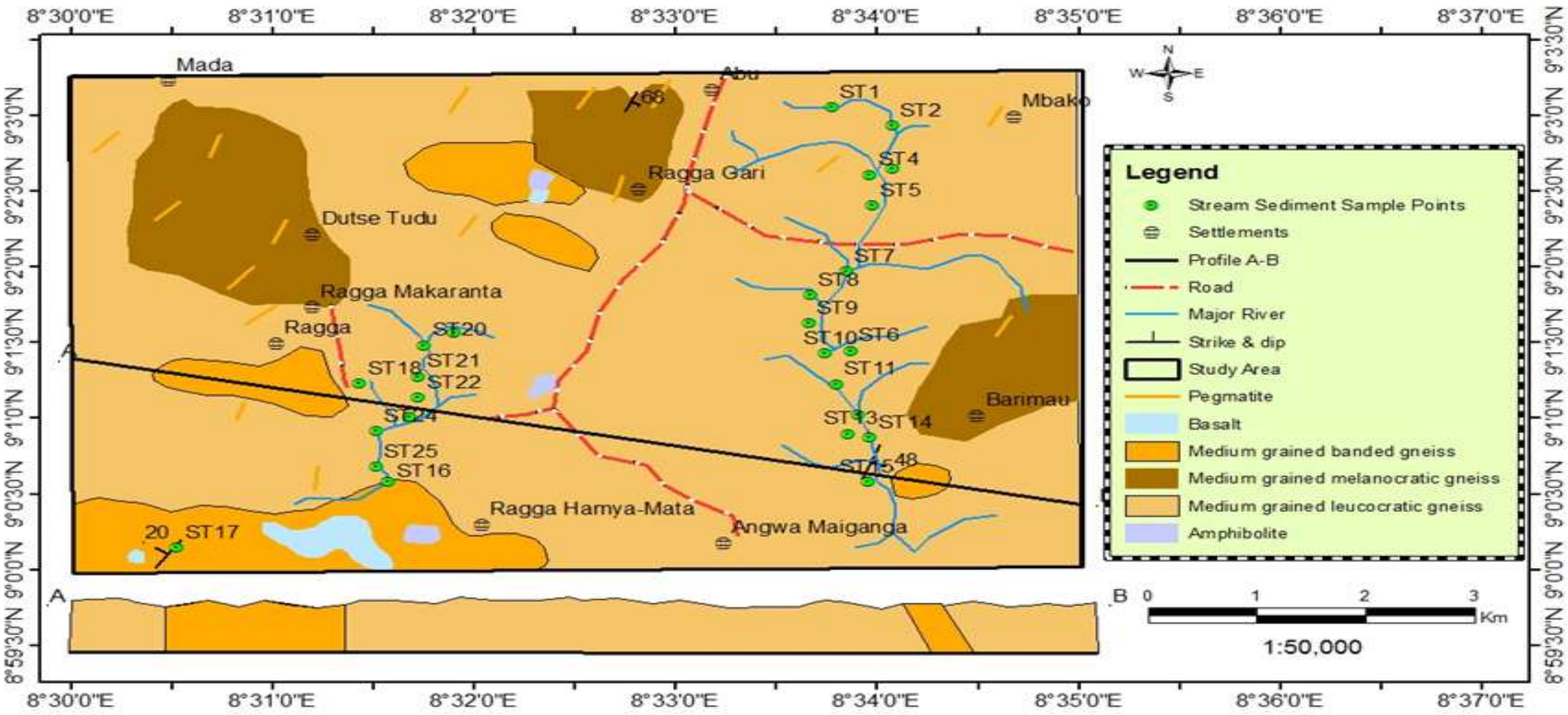

Figure 2. Geological map and cross section of the study area

Petrography

Petrographic studies were conducted under plane polarized light (PPL) and cross polarized light (XPL) on the prepared thin sections of rock samples (Figure 2).

Gneisses

The gneisses in the study area are medium grained, foliated, with bands of light and dark minerals. The light bands consist of felsic minerals, quartz and feldspars, while the dark bands are made up of mafic mineral, biotite. In hand specimen, the rock consists of quartz, feldspar and biotite. There are quartz veins running concordantly to the rock surface and some cross cutting. There are three different types of gneisses encountered in the area; medium grained leucocratic gneiss, medium grained melanocratic gneiss and medium grained banded gneiss. The medium grained leucocratic gneiss are the light coloured type of gneiss, themedium grained melanocratic gneisses are the dark coloured gneiss whereas the banded gneisses are the gneiss with bands of felsic and mafic minerals, as observed and differentiated based on their mineral alignment (that is white and dark coloured bands of minerals). In hand specimen the rock consists of quartz, feldspar and biotite. Petrographically, the medium grained banded gneiss exhibited variable mineral grains closely packed with preferred orientation. Table 3 depicts the mineral composition in medium grained leucocratic gneiss and medium grained melanocratic gneiss.

Table 3: Mineral composition of the gneisses in the study area

Minerals	% Mineral composition of the gneisses	
	Sample L29	Sample L3
Quartz	17	10
Plagioclase feldspar	35	15
Muscovite	18	25
Hematite	5	-
Biotite	15	30
Magnetite	-	15
Garnet	7	-
Total	97	95

Pegmatite

Most of the pegmatites in the study area as near vertical dykes and intrude into the older lithology of gneisses. The pegmatites occurred as coarse grained rocks with euhedral crystal of quartz, feldspar, mica and rarely tourmaline. Some of the pegmatites are fractured and weathered. The size of the pegmatite veins varied from about 10 - 110 cm in length and 2-10 cm in width. The petrographic study of the pegmatite in the study area showing coarse grained sheared/ brecciated quartz grains the predominant constituents of the pegmatites are plagioclase feldspar and quartz. Under plane polarized light, the quartz is colourless with euhedral shape (some grains almost occupy the field of view), non-pleochroic, no cleavage, and not fractured nor altered. The plagioclase feldspar is colourless (cloudy), anhedral in shape, non-pleochroic, some grains occupy more than the field of view in the slides, not fractured but slightly altered and only patches showed grain type. The muscovite showed perfect cleavage in one direction, not fractured but undergoing alteration and is anhedral to subhedral in shape. Under cross polarized light, the quartz exhibiteded undulose extinction, no twinning and showed grey to white interference colour. The plagioclase feldspar exhibiteded polysynthetic twinning with extinction angle ranging from about 30^{o}-56^{o}. The muscovite showed oblique extinction, no twinning with bluish green to pinkish yellow on rotation of the microscope stage. The mineral composition of the pegmatites are shown in Table4.

Table 4: Mineral composition of pegmatites in the study area

Minerals	% Mineral composition of the rocks			
	Sample L13	Sample L35A	Sample L79	Sample L87
Quartz	20	30	15	10
Plagioclase feldspar	55	60	75	80
Biotite	5	5	7	5
Muscovite	5	3	-	-
Total	85	98	97	95

Basalt

The basalts in the study area intrude the gneisses and mostly occurred as dykes and occasionally as sills. The basalts were not all of the same rock type; and varied from being olivine rich through tholeiitic composition to granophyres. The minerals within the rocks are noted by their differences in colour. The proportion of the basalts to the host rock is seen to have varied in the study area. Some areas were noted to have more of basalt than the host rock and in some cases, the basalt was seen quite less than the host rock. This could be attributed to the fact that some areas experienced much of magmatic activity than other areas. Under the microscope (thin section study), the basalt was fine, near porphyritic with fine phenocryst of euhedral iron oxide (magnetite) and laths of plagioclase, many and few grains of pyroxene (augite) and fayalite respectively. The main mineral contents were phenocryst of magnetite, plagioclase, quartz, olivine and groundmass of clinopyroxene.

Amphibolite

The amphibolites were sparsely distributed in the study area, andoccurred as dark greenish rock, comprising of some plagioclase and quartz in the groundmass and fine grains of biotite which are scattered in the rock. Also, large grains of opaque oxides existed, and were generally

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anhedral, while some were ilmenites. Petrographic study of the thin section under PPL and XPL, showed that the hornblende had light green colour, high relief, double cleavage in some grains and measured at about 54^o and 122^o. Some of the grains were hexagonal (anhedral), while others are prismatic and pleochroic, varying from light green to brown. The quartz was greyish with anhedral shape, non-pleochroic, no cleavage and inclusions, not fractured nor altered, and sometimes had straight boundaries with other mineral grains.

Structural Geology

The noticeable structures encountered in the area include; foliation, fractures, veins, lineation, joints, folds and minor faults that showed cataclasis. The predominant structures trend N-S to NE-SW and conforms to Pan-African structural pattern (Annor *et al.*, 1990; Annor and Freeth, 1985). Shear fractures observed on the gneisses were either filled by late pegmatite veins or displayed evidence of free aperture. Lineation and foliation also occurred in most of the gneisses encountered. They probably developed as a result of tectonic differentiation. The preferred orientation of the foliation was NW-SE trending; an indication of an imprint of the Pan-African orogeny (Olasehinde *et al.*, 1990).

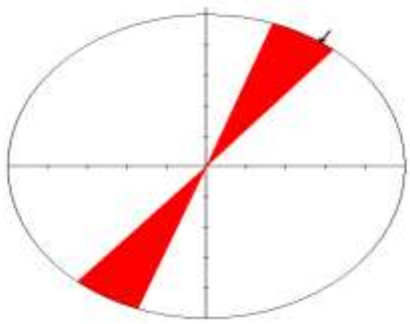

Figure 3. Rose diagram of foliation showing the NE-SW dominant trend in the gneiss of the study area.

Table 5: Major element oxide composition of whole rock samples (%)

S/N	Sample ID	SIO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	MnO	TiO_2	P_2O_5	LOI	TOTAL
1	L67	73.50	14.44	3.01	3.03	2.49	0.84	0.76	0.26	1.06	0.01	0.60	100.00
2	L102	68.55	14.91	4.69	4.69	3.53	0.82	0.46	0.11	1.92	0.02	0.82	100.52
3	L40	75.55	13.51	2.84	3.02	1.47	1.02	0.59	0.05	1.08	-	0.53	99.66
4	L44	73.06	15.01	3.02	2.43	0.46	2.42	1.43	0.03	0.66	-	0.48	99.00
5	L88	53.32	15.87	9.68	6.62	4.66	1.93	3.52	0.17	1.94	0.71	1.58	100.00
6	L101	55.05	15.06	10.28	8.58	3.92	0.96	2.71	0.26	1.33	0.49	1.36	100.00
7	L29	74.55	13.64	1.02	1.63	0.53	5.11	2.43	0.02	0.47	0.01	0.59	100.00
8	L31A	75.16	13.74	1.01	0.93	0.62	5.02	2.51	0.03	0.34	0.01	0.63	100.00
9	L1	66.06	16.08	5.52	2.43	0.58	2.57	5.44	0.05	0.82	-	0.45	100.00
10	L3	57.84	14.91	11.40	3.29	3.48	1.43	2.49	0.22	1.67	0.63	1.69	99.05
11	L35A	75.10	13.84	1.02	1.87	0.19	4.70	2.18	0.04	0.49	0.01	0.56	100.00
12	L13	76.92	14.44	0.71	0.43	0.31	4.36	2.09	0.12	0.01	-	0.61	100.00
13	L79	76.34	14.61	0.81	0.12	0.59	4.28	2.41	0.18	0.04	-	0.56	99.94
14	L87	73.50	13.44	0.93	1.06	2.48	5.64	2.19	0.11	0.02	-	0.63	100.00
15	L95	57.69	15.22	10.52	3.43	4.06	1.79	3.46	0.14	1.83	0.04	1.82	100.00
16	L31B	73.41	14.05	3.87	2.36	0.39	1.21	2.38	0.15	0.68	0.01	0.49	99.00
17	L35B	62.28	14.93	8.61	5.02	1.58	1.82	2.64	0.26	1.93	-	0.93	100.00

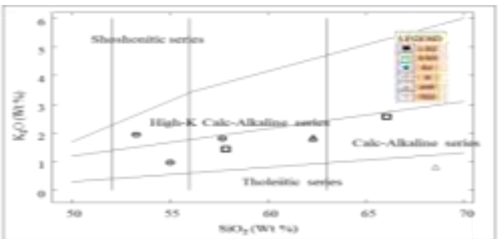

Figure 4. Plot of K_2O versus SiO_2 showing the calc-alkaline Natureof the samples (AfterPeccerillo and Taylor,1976)

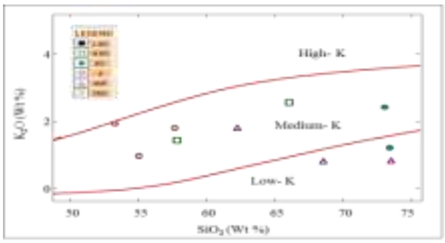

Figure 5. Plot of K_2O versus SiO_2 (wt %) (After Rickwood, 1989)

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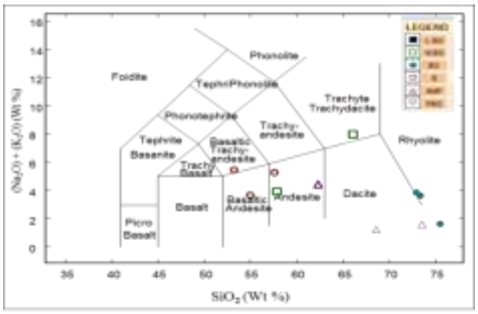
Most of the samples plot in the Calc-alkaline series



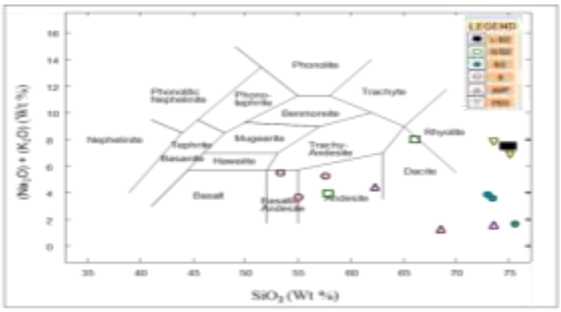
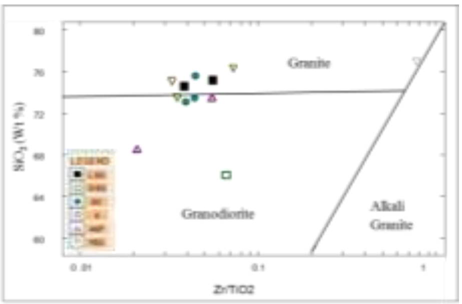


Figure 6. Plot of Total Alkalis-Silica (TAS) diagram for Figure 7. Plot of Total Alkalis-Silica (TAS) rock samples (Le Bas *et al*.,1986) diagram for rock samples (Cox-Bell-Pank,1979)



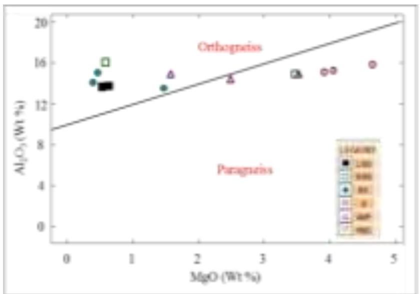
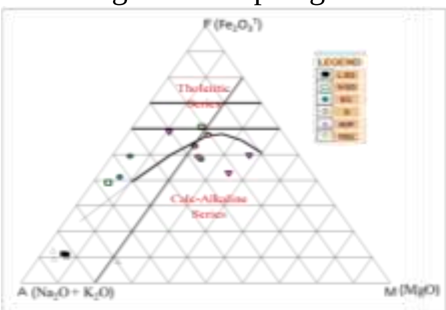


Figure 8: Plot of SiO_2 versus Zr/TiO_2

Figure 9: Plot of Al_2O_3 versus MgO(Marc, 1992).(Winchester & Floyd, 1977)

Figure showed that the medium grained leucocratic gneiss andmedium grained banded gneiss plotted in the orthogneiss field, while the medium grained melanocratic gneiss plotted in both the orthogneiss and paragneiss fields.



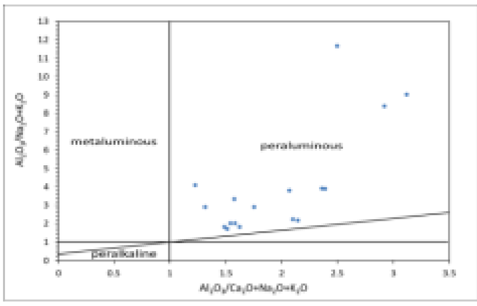


Figure 10. AFM ternary plot depicting the tectonic classification Figure11. Binary plot of Al_2O_3/Na_2O+K_2O against $Al_2O_3/Ca_2O+Na_2O+K_2O$ of the rock samples for the rock samples (Maniar & Piccoli (Kuno, 1968) showing peraluminous nature of samples

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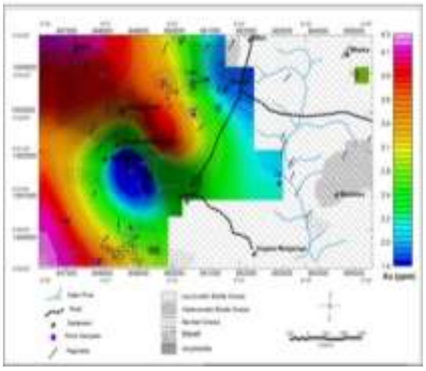
AFM ternary plot with the dividing line of Kuno (1968) to discriminate between tholeiitic and calc-alkaline suites. (Fig. 11) revealed that the basalt, medium grained melanocratic gneiss and medium grained banded gneiss falls within the line demarcating tholeiitic series from calc-alkaline series.

Geochemical analysis (Ternary Images)



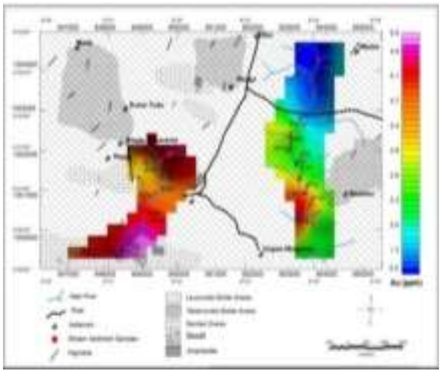
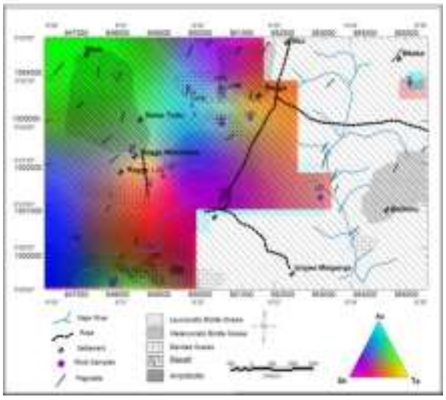


Figure 12. Map showing the relative abundance of gold (Au) Figure 13. Map showing the relative abundance of gold (ppm) in the rock samples overlain on the geology in the stream sediments overlain on the geology



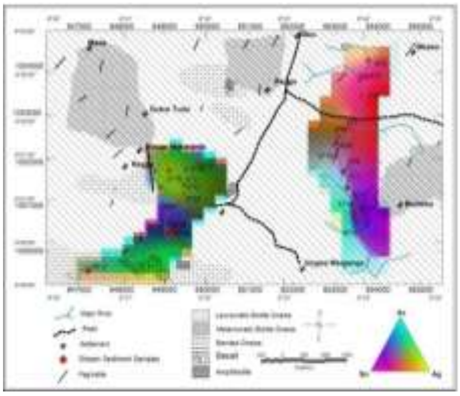


Figure 14. Ternary image for the relative abundance of Figure 15. Ternary image for the relative abundance of
gold (Au), tin (Sn) and tantalum (Ta) gold (Au), silver (Ag) and tin (Sn) in the stream sediments
in the rock samples

DISCUSSION

The study area is a typical example of the Precambrian Basement Complex of Nigeria as it is underlain by rocks of the Basement Complex comprising medium grained banded gneiss, medium grained leucocratic gneiss and medium grained melanocratic gneiss, amphibolite basalt and pegmatite. These host rocks are intruded by veins, which are pegmatite, quartz or quartzo-feldspathic veins and occurred as discordant low lying dykes. Thin section petrographic studies conducted under plane polarized light (PPL) and cross polarized light (XPL) show that the medium grained banded gneiss exhibiteded variable mineral grains, closely packed with preferred orientation.The medium grained leucocratic gneiss and medium grained melanocratic gneiss revealed that quartz, plagioclase feldspar, biotite, and muscovite are the dominant minerals (Cerny, 1989). The amphibolite contains plagioclase feldspar, hornblende, quartz, pyroxene and biotite. The main mineral contents in basalt are phenocryst of magnetite, plagioclase, olivine, quartz and groundmass of clinopyroxene. Meanwhile, the pegmatites which trend majorly in a NE-SW contained mainly quartz, plagioclase, biotite and muscovite with little or no trace of mineralization.

The medium grained leucocratic gneiss and medium grained melanocratic gneiss which covers almost 80 % of the study area were generally siliceous with maximum SiO_2 content of about 75.16 wt. % (Table 5). Geochemical plots on discriminatory diagrams to establish the geochemical evolution (Figsures 4-11) of the rock revealed that most of the pegmatite and medium grained leucocratic gneiss samples falls within the calc-alkali field. The basalt and medium grained melanocratic gneiss samples plotted in the alkali-calcic field. The plot of K_2O versus SiO_2 indicated a medium-K for the basalt and the medium grained melanocratic gneiss, while some of the amphibolite and medium grained banded gneiss plotted within the Low-K field. The plots of K/Rb versus Rb and Ta versus Ga showed that the pegmatites are apparently poor or barren in terms of mineralization. The plot of Na_2O/Al_2O_3 versus K_2O/Al_2O_3 indicated that the pegmatites are of igneous rocks (Matheis and Kuster,1989) In addition, the pegmatite also plotted within the syn-collisional granite field. The plot of Rb versus Sr showed that all the pegmatite plotted in the $\geq$ 30 km depth field, indicating great depth of origin and its exposure to the earth surface could have being through erosional activities.

The ternary images (Figures12-15) for the relative abundance of gold (Au), tin (Sn) and tantalum (Ta) for both rocks and streams sediment show that the central part of the study area is relatively rich in tin. Gold is not very prominent in the map and where it is seen the concentration was low, especially around DutseTudu.The concentration ranges of the other associated elements were narrow except for Ba and Zr, and to some extent Rb and Sr. The significantly positive correlation between Fe and Mn with the other analyzed elements (Cr, Cu, Mo, Ni, Pb, Rb, Sn and Zn) indicated that the oxides of both elements contributed to the concentrations of such elements in the rocks and sediments. This probably suggests that these elements could have been adsorbed by hydrated Fe- and Mn- oxide grains dispersed in the secondary environment, reflecting that either Fe-/Mn- oxy-hydroxides enrich the mentioned elements, or due to co-precipitation processes of these elements with the authigenic Fe- and Mn- oxy-hydroxides (Ibrahin *et al.*, 2008). The insignificant role of the oxides of both elements to the concentrations of Ag, As, Au, Ba, and Mo may point to the mobile presence of Au-Ag granules in oxidized iron oxides and to the different behaviour of both elements during dissolution and transportation processes in secondary environment (London, 1990). The positive correlation of Au possibly indicate that the Au may exist as free particles, supporting the bulk fraction of the studied stream sediment. It is remarkable of the distribution of As, Rb, Ag, Au, Ba and Cu values in the stream that trend in the N-S direction at the west and east of the study area. This probably connotes that the areas are probably derived from a new extension of the mineralized parts trending in the N-S directions parallel to the prevailed strike directions in the area (NE-SW and ENE-WSW).

Gold was detected in nearly all stream sediments but not on all rocks samples analyzed, indicating that in this region, the bulk fraction is suitable for making regional geochemical survey for gold using stream sediments in the area of study. The concentrations of metals like Au, Ag, Pb, Zr, Sn and Ba are generally high in the stream sediments that lies in the north-western part of Ungwan Maganga, whilst the streams sediments around Ragga Makaranta are associated with low concentrations of the metals. Ternary image for the relative abundance of gold (Au), silver (Ag) and tin (Sn) also shows that tin is dominant in the sediments along the streams in the north-western part of Ungwan Maiganga, whilst silver tend to be more dominant in the sediments along the streams around Ragga Makaranta. The correlation of the topographic map and the maps that shows the relative distribution of the mineral elements in the rock samples as well as the stream sediments show that areas with low elevation (topographic or basement lows) generally have high concentration of the rare metals, whilst areas with high elevation (topographic or basement highs) tend to have relatively low concentration of the rare elements.

The trace elements were more concentrated or higher in the stream sediments than the host or underlying rocks, probably due to weathering of the host or underlying rocks (mostly biotite gneiss). Mineralization in the study area tends to be concentrated in the north-western part of Ungwan Maiganga and around Ragga Makaranta. Clastic materials containing these trace elements were probably transported by the rivers from basement high areas and deposited in basement low areas where the minerals were more concentrated. The streams and rivers that flow in the study area, especially in the north-western part of Ungwan Maganga, could also have been mobilized and transported proportion of the metals in solution. The metalliferous ore-forming fluids might be derived from the underlying granitic provenance and transported by the rivers, thus resulting in the high concentration of the minerals in the stream sediments compared to the host rocks or underlying rocks (mostly biotitegneiss).

CONCLUSION

The concentrations of Au, Ag, Pb, Zr, Sn and Ba were generally higher in the stream sediments compared to the rock samples. The high concentration of metals in the stream sediments could be linked or attributed to weathering of the host or underlying rocks and the deposition of their rare metals in sediments along stream channels.

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