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Geochemical Composition and Petrogenesis of Schists and Amphibolites of Parts of Sheets 203 (Lafiagi) SW and 224 (Osi) NW, Southwestern Nigeria

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Abstract

Precambrian meta-sedimentary rocks are widely exposed and are interbanded with amphibolitic rocks in Sheets 203 (Lafiagi) SW and 224 (Osi) NW, southwestern Nigeria. They are underlain by migmatitic and granitic gneisses and intruded by Late- to Post- Pan African granitoids. Petrographic and geochemical studies show that the meta-sediments are para-schists of arkosic to greywacke parentage which were sourced from a moderately weathered feldspathic igneous rock(s) while the amphibolitic rocks are sub alkaline Island Arc tholeiites whose original chemistry have been significantly altered during and after the emplacement. Derivation of the schists from K feldspar-rich protoliths is indicated by the enhancement of Ba over Rb while the presence of significant amount of mafic constituents is signified by relatively high amount of Cr and, sometimes, Ni. Low level of weathering of the protolith is suggested, based on the calculated CIA values. The geochemical characteristics of the amphibolites indicate a possible origin from a basaltic magma under an oxidizing condition. The study area shows similar petrological, structural and geochemical characteristics with the Ilesha Schist Belt to the south and to which it is considered to be the northern extension.

Keywords: Petrogenesis, schists, amphibolites, tholeiitic, sub-alkaline

1. Introduction

The study area is part of the Basement Complex of southwestern Nigeria (Fig. 1). The area is bounded by Longitudes 5˚ 00'- 5˚ 15' and Latitudes 8˚ 15'- 8˚ 37', covering about 1100km^2 northeast of Ilorin and southeast of Jebba. The dominant rocks in the area are the meta-sediments which include quartzite, schist and marble. These rock units are underlain by variably

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migmatised granodioritic-tonalitic and granitic gneisses with which they possess co-eval fabrics. Members of Late- to Post- Pan African granitoids intruded and cut the fabrics of both the gneisses and the meta-sediments. This scenario has also been reported from other parts of southwestern Nigerian schist belt (Okonkwo and Winchester, 1996).

Schistose rocks immediately north of the present study area were described by Ajadi (2008) and Garba (2011) to have been sourced from felsic igneous rocks and that the amphibolites rocks are Island Arc tholeiitic basalts. Adekoya (1996) and Annor et al (1996) have constrained the depositional ages of the meta-sediments in Nigeria to neo-proterozoic on the bases of field and geochemical evidences. Precambrian schist belts, inclusive of those of Nigeria are noted for hosting metallic and non-metallic mineral deposits of economic significance. Hence, knowledge of geochemical characters of schist belts will not only be of petrogenetic importance but as well contribute to successful mineral exploration.

2. Materials and Methods

The methods adopted in carrying out the research include desk study of related subjects, geological field mapping, sampling and geochemical analyses. Geological mapping of the study area was done on scale 1:25,000. Random samplings of big, fresh, representative rocks were done. Rock samples for thin-section analyses were taken, using the methods of Paschier and Trouv (2005).

Eight representative samples of pelitic to semi-pelitic schists and ten samples of amphibolitic rocks were analysed by atomic absorption spectrometry (aas) and inductively coupled plasma (Mass Spectroscopy and Optical Emission Spectrometry) for their major, trace and rare earth elements compositions. The samples were hammer-milled and quartered at the Laboratory/workshop of the Department of Geology and Mineral Sciences, University of Ilorin. They were then pulverized to ≤40μ using carbide-coated milling machine. The aas analysis was carried out at the Laboratory of the Nigerian Geological Survey Agency, Kaduna while the ICP (Ms/OES) analyses were undertaken at the Activation Laboratories Ltd (ACTABS), Canada.

3. Results and Discussion

Geological Setting

Gneisses

The variably migmatised granodioritic-tonalitic gneisses and the granitic gneisses are well exposed in the eastern half of the study area. Migmatization increases towards the east where distinct bands of dark coloured, older basic paleosome alternate with the lighter, younger felsic neosome. The gneisses generally strike between WNW and NE. There xenoliths of schist in the gnisses. The dominant minerals include quartz + plagioclase (An 28- An40) + microcline + biotite + muscovite ± hornblende. Accessory minerals include opaque ± apatite ± allanite ± sphene ± zircon

Meta-sediments

The meta-sediments comprise rocks whose earliest and metamorphic fabrics are co-eval with those of the gneisses upon which they lie. They grade imperceptibly into, and are often intercalated wih each other. Foliated and massive varieties of quartzites are the most dominant meta-sediments. They occupy the central, southwestern and the northwestern parts. Quartzite is in contact with mica schist, amphibolite, gneisses, marble, granite and pegmatite. Quartz constitutes over 90% of the mineralogical assemblage with minor feldspar, muscovite, pinitized biotite and, as well, occasional garnet and opaque. Quartz-mica- schist and pelitic to semi-pelitic quartz-mica-sillimanite- schists occur in the western segment of the area. Evidences of crenulation, garnet overprinting, and crude contact metamorphic aureoles abound. The quartz-mica-schist is light coloured and locally phylitic especially in high strain areas. The assemblage comprises quartz + muscovite + biotite + plagioclase ± garnet ± microcline ± opaque. Pelitic to semi- pelitic schists of variable compositions are patchily exposed, and mostly constrained to the western and northern parts. The mineral constituents are biotite + quartz + muscovite + sillimanite + plagioclase + microcline + garnet ± kyanite ± opaque. Garnet is widespread and often shows internal fabrics, signifying tectono-thermal deformations under regional conditions. Sillimanite and kyanite commonly occur in areas of contact metamorphism.

Amphibolite

Two varieties of amphibolites, massive and foliated types, which are essentially fine-grained, occur in the nothcentral, eastern, and western parts as narrow, low-lying rocks interbanded with the meta-sediments except in the east, around Owa-Kajola, where the rock is interbanded with migmatitic gneiss and marble. They also occur as xenolithic and boudinaged inclusions in the migmatitic gneisses. The amphibolites in the northcentral and the eastern parts of the study area, especially around Budo-Idowu and Owa-Kajola are foliated while those from the west are massive. Hornblede + plagioclase + quartz + actinolite-tremolite + biotite ± garnet ± calcite ± sphene mineral assemblage characterized the amphibolites. Chalcopyrite occurs as a notable accessory mineral in the amphibolites around Owa-Kajola (See Table 1 for the modal percentages of the schists and amphibolites).

Marble

Two deposits of lenticular or pod-like marble bodies, which are inter banded with biotite gneiss, mica schist, quartzite, amphibolite, calc-silicate gneiss and pegmatite occur in the eastern part, about abouth 1.7km east of Oreke and 2km south of Owa-Kajola. They seem to be continuous into each other.the marble deposit at Owa-Kajola is essentially calcitic while that at Oreke is dolomitic (Adedoyin et al, 2012). The Oreke marble is strongly deformed with signatures of refolded folds. The marbles are characterized by presence of dispersed graphite.

Granitoid

Mesocratic to melanocratic varieties of granodiorite are well exposed in the northwestern corner of the area, with sporadic occurrences in other places. They are medium to coarse grained and contain quartz + plagioclase + biotite + hornblende + microcline assemblage. Opaque, sphene and alanite are the the associated accessories. Porphyritic to mesoporphyritic and fine-medium grained granites are widespread and constitute the major granitoids in the area. Quartz+ microcline + plagioclase + biotite + hornlende ± muscovite + opaque + alanite + sphene ± zircon mineral assemblage these granites.

Geochemical Results

Results of the analyzed samples are presented in Tables 1and 2. The schists show moderate to high silica contents (51.7-76.7%) with an average of 64.7%. Alumina content is moderate (8.29%) to very high (27.49%) while the alkali contents vary between 3.62 to 8.79%, averaging 2.69%. Enhancement of Ba over Rb in the meta-sediments signifies derivation from a K-feldspar rich protolith. High Ba, Rb and Sr also supports this claim. Cr and, occasionally, Ni are also high and indicate significant amount of mafic contents in the original sediments. CIA values calculated for the samples indicate low to moderate level of weathering of the sources.

The geochemical composition of the amphibolites is dominated by silica (46.2-54.01%), alumina (4.08-28.54%), lime (11.55-20.22%), magnesia (1.4-15.64%) and a uniformly 11-15% iron oxide. This points to derivation from a basaltic magma in an oxidizing environment. The plot of silica against total alkali (Fig.2) shows that the amphibolites are essentially sub-alkaline. The amphibolite from around Owode-Ofaro (2L2) is unusually different with rather very low iron oxide (2.79%), lime (0.28%), but higher 28.54% alumina and 9.28% potash. This is probably due to the effect of widespread migmatization of the amphibolites in the area. This is also reflected in the modal quartz content of 10-15% .Na_2O is usually higher than K_2O except for sample 2L2. Fe_2O_3 and TiO_2 are high except for sample 2L2 while CaO is higher than the total alkali.

Discussion

The interleaved and gradational contact relationships of the schists with the quartzite and between the various types of schist indicate sediment deposition under unstable flow regimes. This implies that high flow regimes alternated with low flow regimes so that heavier sediments were deposited alternately with lighter ones, respectively. The interleaved character of the meta-sediments demonstrates this phenomenon vertically while the gradational contacts show this in a lateral sense. Such field occurrences have been described by Rahaman (1976) and Oluyide et al (1998) from other parts of the basement complex of Nigeria. The schists are inferred to be of sedimentary origin (para-schists) in contrast to those of igneous protoliths. The petrographic studies have also shown presence of significant amount of graphite in the associated marbles, at both Owa-Kajola and Oreke, which strongly supports a sedimentary origin.

This field evidence is supported by the discriminant plot of K_2O/Al_2O_3 vs Na_2O/Al_2O_3 (Fig.3) in which the schist samples plot in sedimentary and meta-sedimentary fields. It was further deduced that the sediments (now metamorphosed) were derived from arkosic to sub arkosic rocks as seen in the plot of Na_2O vs K_2O (Fig.4) and corroborated by the Log (Fe_2O_3/K_2O) vs Log (Si_2O/ Al_2O_3) which constrains the schistose rocks to the fields of wacke and arkose (Fig.5). The enhancement of Ba over Rb in the meta-sediments is also a signature of K-feldspar-rich protoli ths, especially, rocks of granitic compositions. The high Ba, Rb and Sr contents of most of the rocks compare with the compositions obtained by Okonkwo and Winchester (1996) and Okonkwo (2005) for the metasediments. Similarly, the plot of the rocks on the SiO_2/CaO (Fig.6) shows that they belong essentially to the field of Francisian Greywacke and they thus support the earlier stated sedimentary origin deduction.

The original sediments would have contained significant amounts of feldspar, clay minerals, carbonates, and organic matter. Enhancements of Cr and, occasionally, Ni in the rocks indicate presence of some amounts of mafic constituents in the in the sediments. The Cr and Ni would have accompanied or be components of the organic matter deposited with carbonates for the marble. The arkosic grey wacke or feldspathic grey wacke protolith is typical of psamitic to semi-pelitic schists. Presence of detrital zircon, derived from the feldspathic sediments, is likely the cause of enhancement of Zr in the geochemical results of some of the schist samples. This shows that zircon was an accessory mineral in the pre-existing granitic rock, from which the sediments were sourced. The degree of source rock weathering and sediment maturity of the protolith were estimated through the Chemical Index of Alteration (Nesbitt and Young, 1982) and the Index of Compositional Variability (Table 4). From the CIA, it can be deduced that the protolith of the study area has suffered a low degree of weathering (Fig.7).

The amphibolites are either of different petrogenetic sources or there have been significant contaminations from continental materials. Amphibolites are known to have basic-ultrabasic protoliths and contaminations of the protoliths during or after the emplacement could have altered the original chemistry. The high probability of of such inference can be supported from the plots of the $Al_2O_3/(Na_2O+K_2O+CaO)$ vs K_2O/ Al_2O_3 (Fig.8) in which the rocks are separated into the S-type and the I-type sources while the geotectonic setting, would have been oceanic (Pearce, 1975) as shown in Fig.9. They are most possibly from tholeiitic and sub-alkaline (Fig.10) magmas of basaltic compositions (Fig.11). The amphibolitic rocks possess similar chemical affinities with those from a few kilometres north of the study area which Ajadi (2008) and Garba (2011) constrained to Island Arc tholeiites. Tholeiitic characters have also been identified in the amphibolites of Jebba (Okonkwo,and Winchester, 1996) and Ilesha (Olade and Elueze, 1979; Elueze, 1992) areas of southwestern Nigeria. Oluyide et al (1998) advanced that the present study area belongs to the Oro Formation and which is a northern extension of Ilesha schist Belt. High Al_2O_3, Rb and Y and correspondingly low CaO, Na_2O and Sr in semi-pelites indicate that the original argillite contained some plagioclase while the relatively low Na_2O, CaO and Sr concentrations, together with high K_2O point to fairly matured sediments (Lambert, et al 1982). However, an enhancement of Zr and Y in the meta-sediments may be attributed to derivation from igneous sources. Such oceanic affinity deductions for the amphibolite would be in agreement with the origin obtained for the Ile-Ife-Ilesha Schist Belt to the south and the Egbe Schist Belt to the east (Rahaman, 1988) of the study area. Hence, the earlier proposition of Oluyide et al (1998) that the Oro Formation being a northern extension of the Ilesha Schist Belt is strongly supported by this study.

Conclusions

Schistose rocks of parts of Sheets 203 (Lafiagi) SW and 224 (Osi) NW are arkosic to greywacke para-schists that were probably derived from a mildly to moderately weathered feldspathic igneous souces. The original sedimentary load was moderately matured but later separated into the different units as a result of fluctuations in flow regime. The amphibolites are essentially sub-alkaline Island Arc tholeiites that were probably contaminated by crustal materials.

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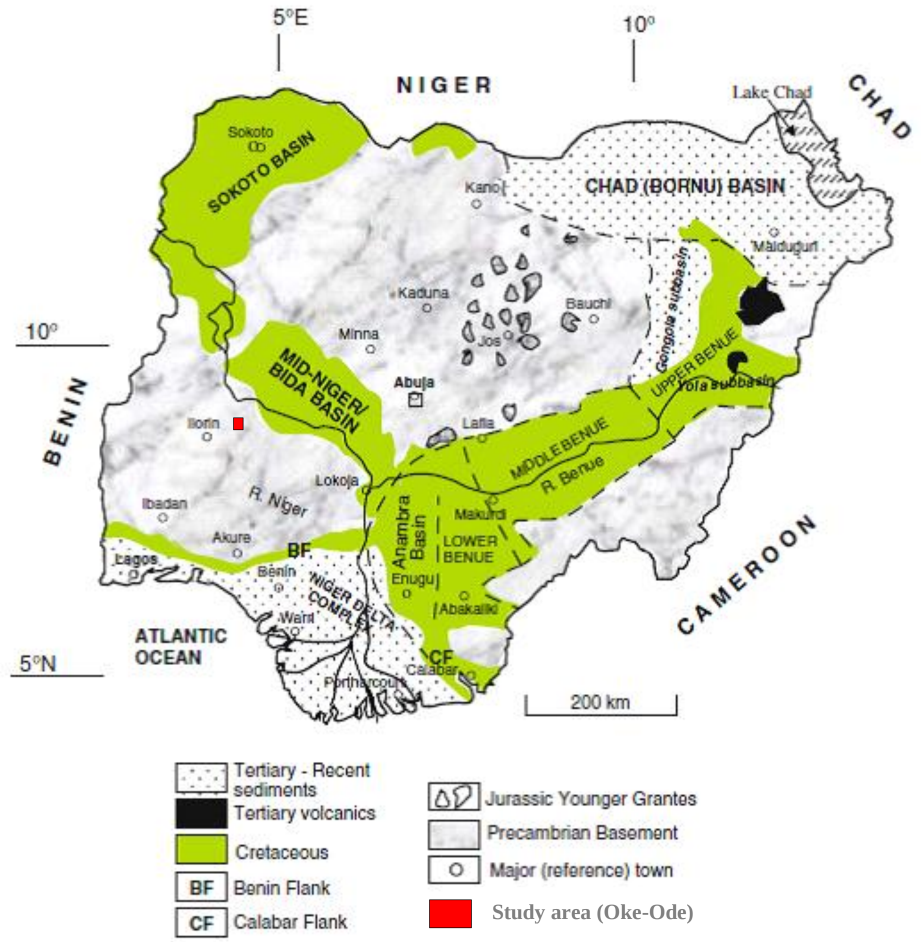

Fig.1: Geological map of Nigeria showing the study area (modified Obaje, 2009).

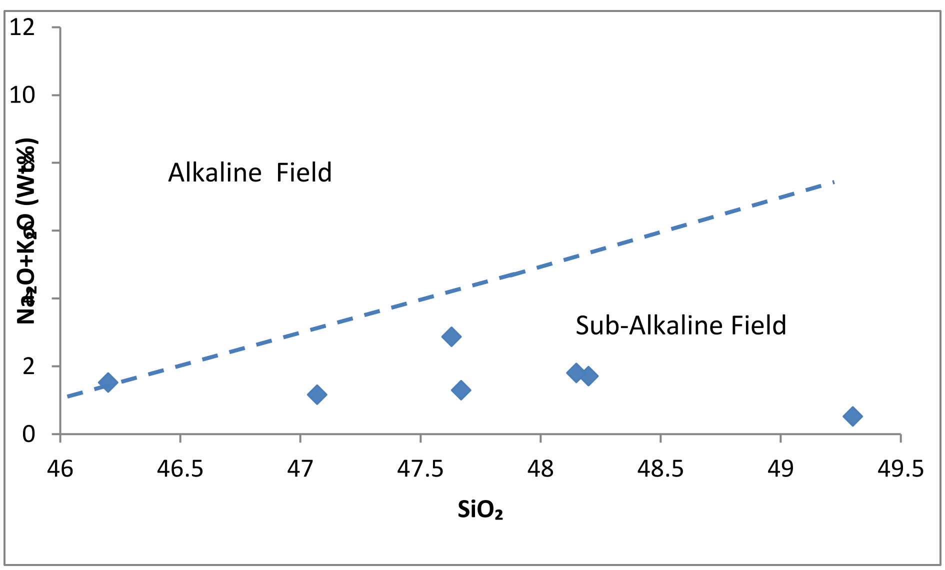

Fig. 2: Discriminant figure of the alkalinity index of the amphibolites.

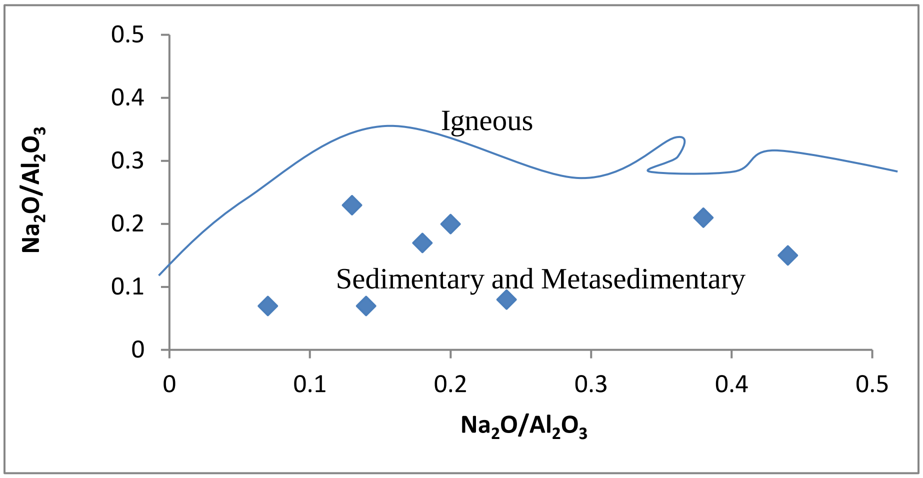

Fig.3: Na_2O/Al_2O_3 against K_2O/Al_2O_3 plot for the schists in the study area (Garrells and Mackenzie, 1971). All the rock samples plot in the inference field of sedimentary/ metasedimentary rocks.

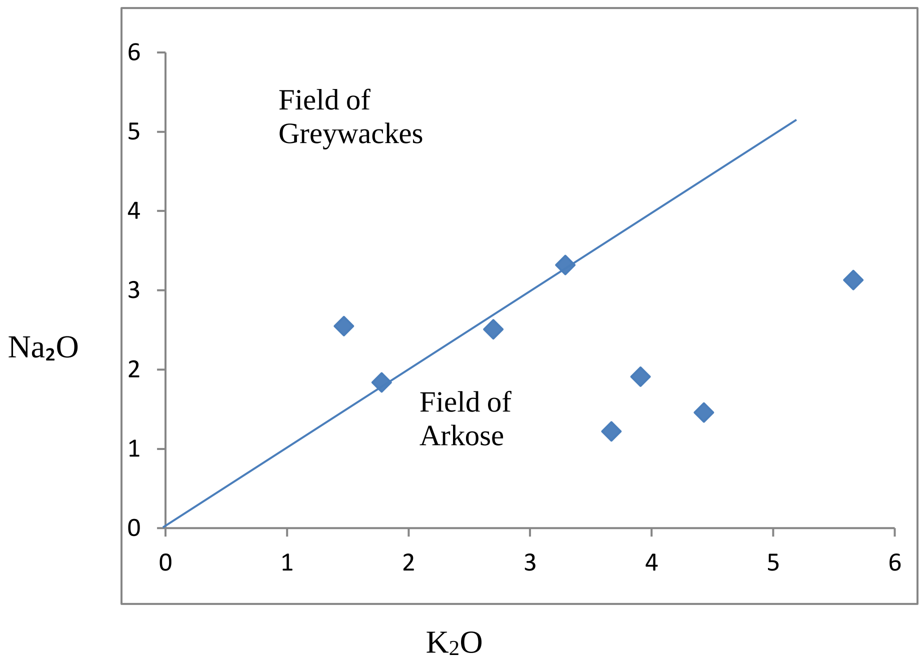

Fig.4: Na_2O against K_2O plot for the schists in the study area (Pettijohn, 1975). One sample plots in the field of grey wacke while the rest are in the arkose or arkose/wacke interface. This suggests that the arkosic protolith have a little greywacke characteristics.

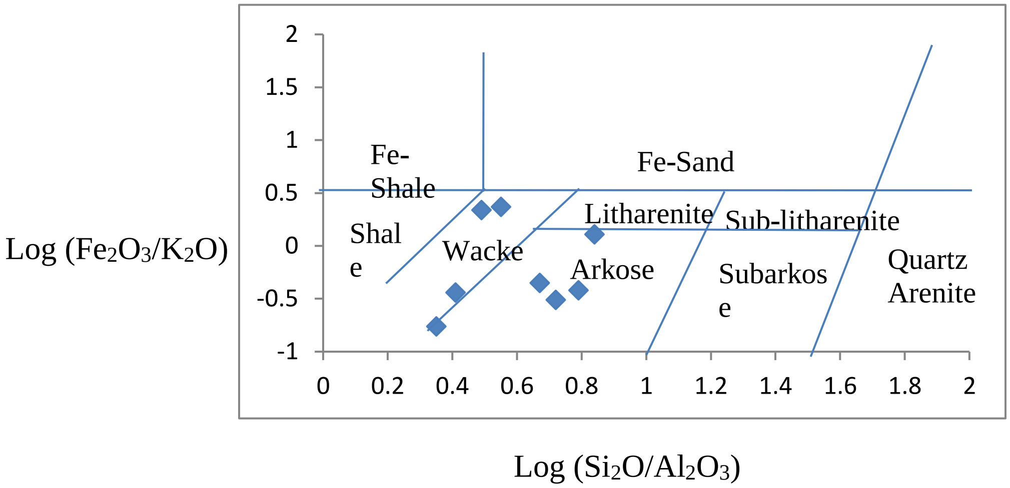

Fig.5: Log (Fe_2O_3/K_2O) against Log (Si_2O/Al_2O_3) plot for the schists in the study area (Herron, 1988). The samples are dominantly arkosic but with significant amount of greywacke.

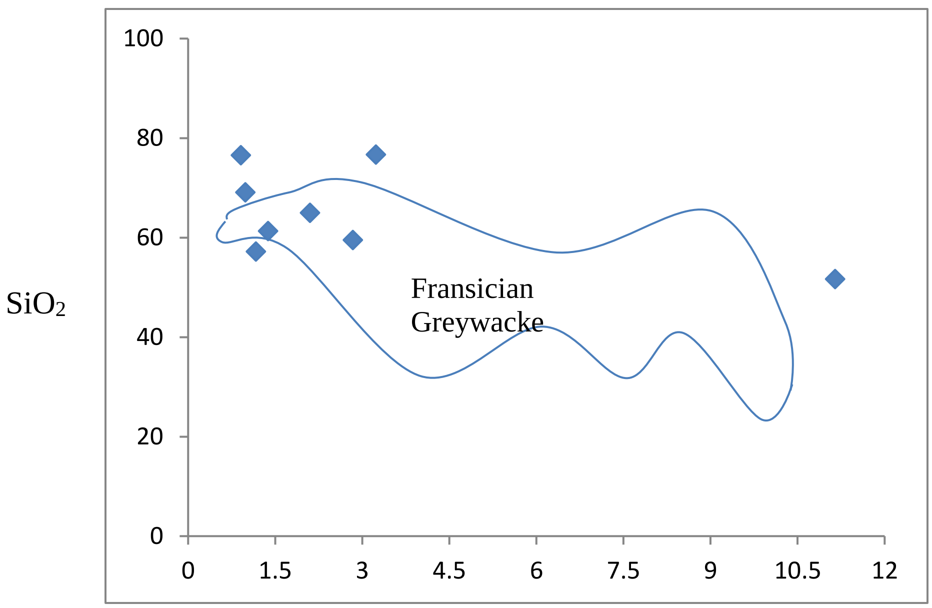

Fig.6: SiO_2 against CaO plot for the schists in the study area (Brown et al., 1979). The schists share a little similarity with the Franciscan Greywacke, which shows affinity for wacke class of sedimentary protolith as indicated above.

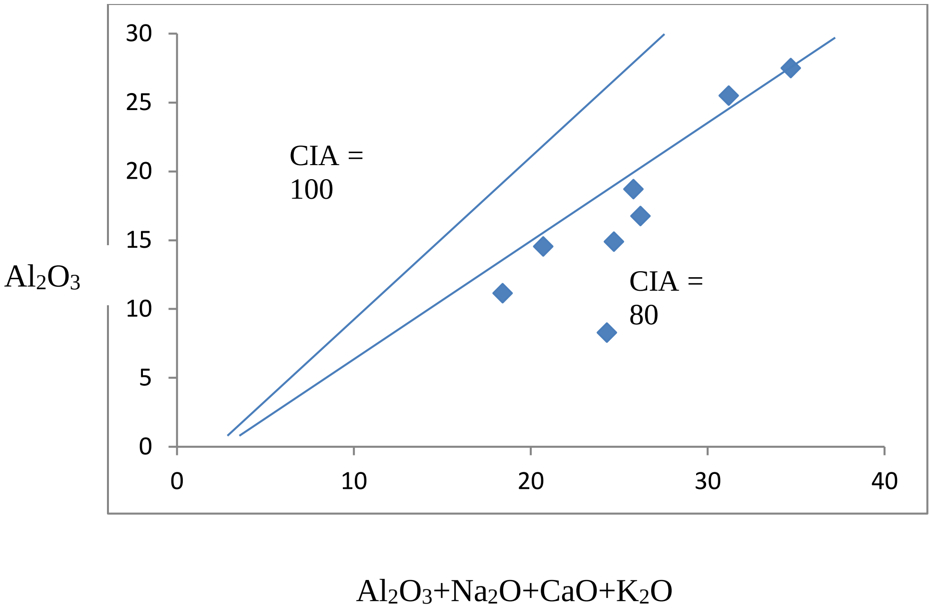

Fig. 7: Al_2O_3 against Al_2O_3+Na_2O+CaO+K_2O plot for schists in the study area). About 90% of the samples plot in the Low CIA inference field (CIA=80).

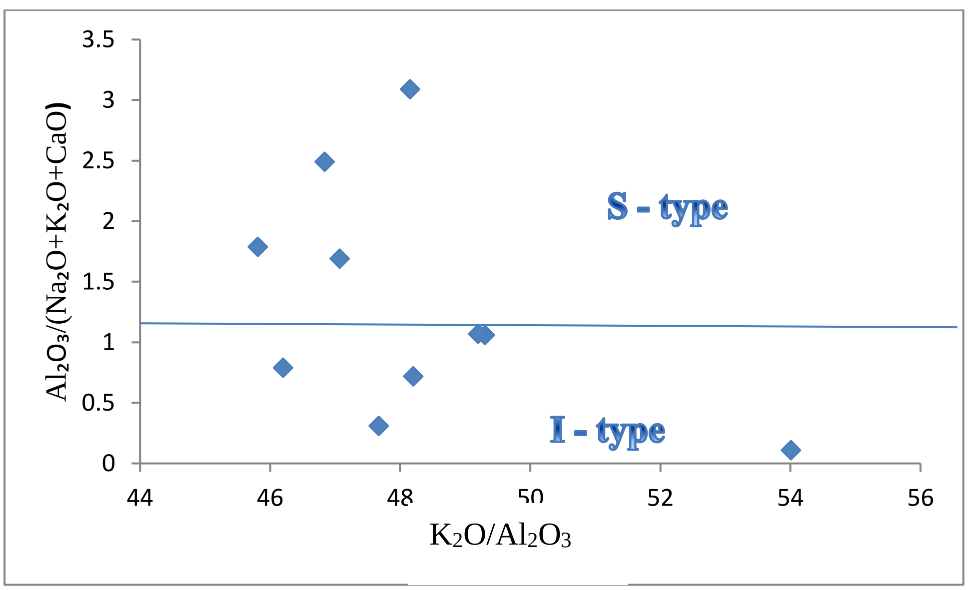

Fig. 8: Al_2O_3/CaO+Na_2O+K_2O versus SiO_2 diagram (after White and Chappell, 1977) showing the classification of the amphibolites. This probably indicates a mixed origin for the amphibolites.

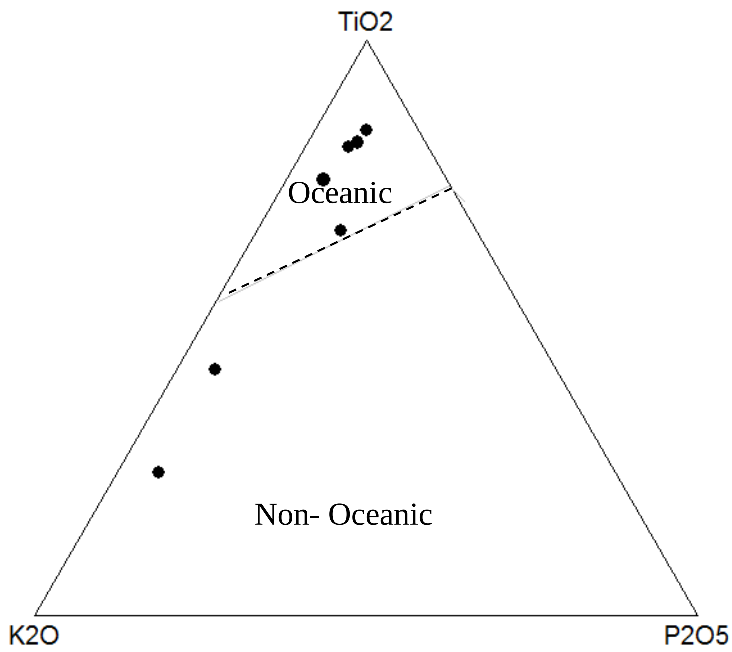

Fig. 9: TiO_2-K_2O-P_2O_5 diagram for the amphibolites and diorite (After Pearce, 1975). This plot strenghtens the possibility of a mixed origin for the amphibolites.

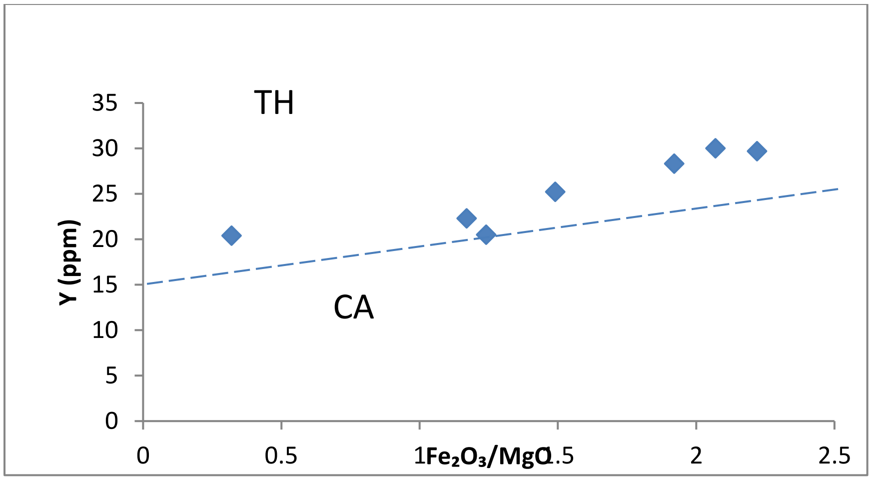

Fig.10: Discrimination plot for the amphibolite (after Beckinsal, 1978). That the amphibolite samples plot in the tholeiitic field implies derivation from basalts rich in orthopyroxene ± pigeonite in addition to clinopyroxene and calcic plagioclase. (TH = Tholeiitic; CA = Calc alkaline)

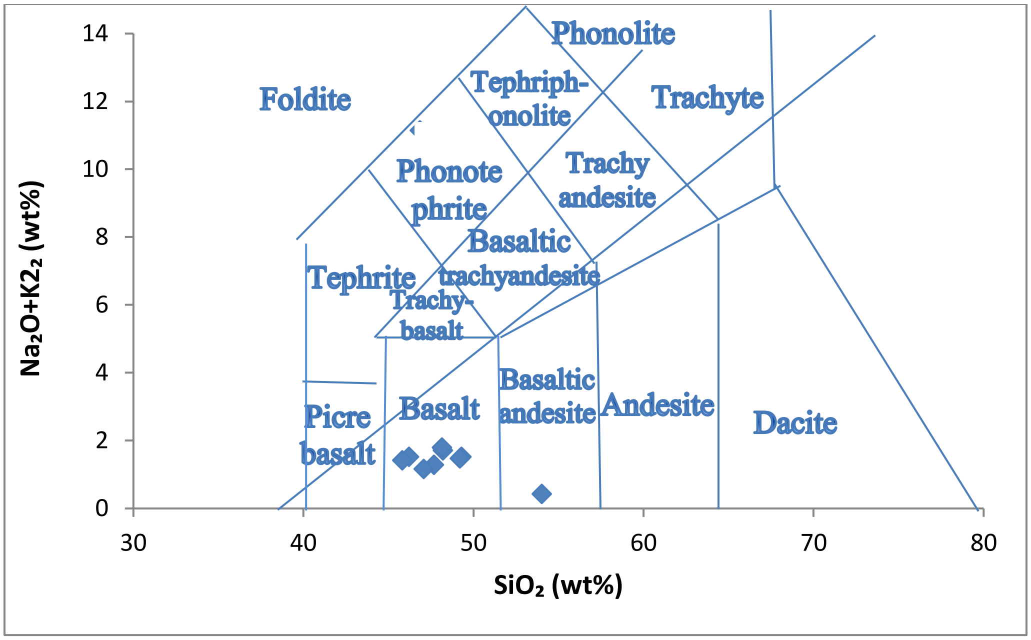

Fig.11: Na_2O+K_2O vs. SiO_2 (Total Alkali vs. Silica,) plot for the amphibolite samples (after Le Maitre et al., 1989). The samples are mainly from a basaltic progenitor.

Table 1: Average modal percentage of minerals in schists and amphibolites

Mineral	**1** *n=6*	**2** *n=12*	**3** *n=18*
Quartz	55	15	12
Plagioclase	4	3	20
Biotite	8	35	6
Microcline	1	5	-
Hornblende	-	-	55
Muscovite	30	10	-
Garnet	.5	2.5	.5
Opaque	1.5	.5	1.5
Sillimanite	-	25	-
Kyanite	-	4	-
Sphene	-	-	1
Calcite	-	-	3
Trem-act	-	-	8

KEY
1. Quartz-muscovite- Schist
2. Quartz- mica-sillimanite- Schist
3. Amphibolite

Table 2: Geochemical composition of selected Schist samples

Sample No.	2L12X	2L14X	3L24	3L10R	3L38	3L25	6L30	V14	VR
Major Oxides									
SiO_2	51.7	76.7	65	59.5	57.7	61.3	76.6	69.13	64.7
TiO_2	0.15	0.21	0.4	0.85	1.12	0.06	0.03	0.38	0.4
Al_2O_3	8.29	11.15	25.5	16.75	18.7	27.49	14.55	14.9	17.17
Fe_2O_3	1.4	1.9	0.64	7.77	9.76	0.68	0.83	2.5	3.19
MnO	0.02	0.04	0.15	0.13	0.15	0.13	0.03	0.07	0.09
MgO	7.09	1.02	1.6	3.55	3.29	1.1	2.51	1.96	2.77
CaO	11.15	3.24	2.1	2.84	1.17	1.38	0.91	0.99	2.97
Na_2O	1.22	2.55	1.84	3.32	1.46	1.91	2.51	3.13	2.2
K_2O	3.67	1.47	1.78	3.29	4.43	3.91	2.7	5.66	3.36
P_2O_5	0.06	0.09	TR	0.19	0.15	ND	0.22	0.16	0.15
LOI	15.6	1.5	1	1.79	2.19	1.5	1.3	0.8	3.21
TOTAL	100.5	100	100.01	100	100	99.46	99.8	99.68	100.21

Table 3: Geochemical composition of amphibolites

Sample No	KJ3	KJ4	KJ5	L19	L22	2L2	2L4	2KJ4	2KJ5	Y5	AR
Major Oxides											
SiO_2	48.2	46.2	49.3	48.15	47.67	46.84	47.07	45.81	49.2	54.01	48.25
TiO_2	1.3	1.37	0.89	TR	0.15	ND	0.04	1.41	0.94	0.11	0.78
Al_2O_3	13.37	15.5	15.2	24.16	4.08	28.54	23.68	15.09	15.22	2.43	15.73
Fe_2O_3	11.36	11.35	10.65	11.18	16.7	2.79	15	11.37	10.53	4.97	10.6
MnO	0.2	0.19	0.16	0.05	0.25	ND	0.05	0.2	0.17	0.18	0.16
MgO	5.931	5.11	8.62	1.4	18.04	5.81	1.4	5.49	8.99	15.63	7.64
CaO	16.69	17.9	12.7	12.76	11.5	0.28	12.84	17.77	12.7	20.82	13.59
Na_2O	1.55	1.32	1.25	1.12	1.11	1.33	1.05	1.29	1.25	0.32	1.16
K_2O	0.16	0.2	0.27	0.68	0.18	9.82	0.11	0.13	0.23	0.11	1.19
P_2O_5	0.12	0.11	0.07	0.02	0.02	0.04	0.01	0.13	0.07	0.09	0.07
LOI	1.1	0.7	0.99	ND	ND	ND	ND	1	0.3	1	0.93
TOTAL	99.98	99.95	100.3	99.92	99.7	95.45	101.25	99.69	99.6	99.7	99.55

Trace Elements

Elements	2L12X	2L14X	3L10R	3L38	6L30	V14	2KJ4	2KJ5	Y5	AR
Ba	710	501	481	523	33.6	1275	112	45	43	66.7
Cr	140	250	220	240	24.7	30	138	368	6	171
Mo	1	1.62	1	1.5	1	.18	0.71	.47	.29	.5
Ni	9	13	74	71	7	19.7	78.2	181.2	7.1	88.8
Rb	178.5	137.5	142	189	173	278.6	4.8	7.6	4.4	6
Sr	79	115	211	100	19	165	208	101	.27	10
Y	9.1	17	31	33	8	6.7	30	22.3	20.4	24
Zr	78	11	184	214	36	46.1	18.1	.006	7.7	5.8

Table 4: Chemical Index of Alteration (CIA) and Index of Compositional Variability (ICV) wt% of the Schists in the study area

Samples	CIA (%)	ICV (wt%)
2L12X	44.7	2.98
2L14X	70.4	0.93
3L24	86.7	0.33
3L10R	71.7	1.29
3L25	83.3	0.33
3L38	76.9	1.14
6L30	76.3	0.65
V14	66.0	0.98