

Geochemical Characteristic and Petrogenesis of Malumfashi Schist around Tandama Area, North-Western Nigeria

Abstract

Malumfashi schist which occurs in association with migmatite-gneisses and biotite granite, occupies about sixty per cent of Tandama area, and is constituted by medium to coarse grained mica schist in the green schist facies metamorphic grade. The A-CN-K diagram revealed a shale protolith which suffered moderate to high chemical weathering, prior to being metamorphosed. Obtained Rb/Sr ratio $>0.4\%$ and $\text{SiO}_2/\text{Al}_2\text{O}_3$ support the shale protolith hypothesis for the schist, diagnostic geochemical features like the $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ values, trace element ratios such as Th/U and REE patterns suggest that the protolith are predominantly derived from felsic igneous sources. Tectonically, $\text{SiO}_2/\text{Al}_2\text{O}_3$ versus $\text{K}_2\text{O}/\text{Na}_2\text{O}$ plot revealed the protolith to have evolved within passive margin environment.

1. Introduction

The Basement Complex of Nigeria, which forms part of the Late Archean to early Proterozoic Pan-African mobile belt, is made up of three lithological units namely; the migmatite-gneisses, the schist belts and the Pan-Africa granites (Elueze and Okunlola, 2003). The schist belts occur dominantly in the western half of the Basement Complex of the country, exhibiting distinct petrological and structural features and they are made up of mainly low to medium grade metasediments. The schist belt form essentially north-south trending belts, composed largely of metamorphosed pelitic and psamitic assemblages.

The schists of the study area, which lies between latitudes $11^\circ 22'$ to $11^\circ 30'N$ and longitudes $07^\circ 23'$ to $07^\circ 30'E$ and covers a total area of 195km^2 , belong to the Malumfashi schist belt located in the NW of Nigeria. It is one of the twelve schist belts so far recognized in Nigeria, comprising basically of schists, migmatite-gneiss, quartzite, and Older granite with aplite and pegmatite forming minor lithologies. Malumfashi schist belt consists mainly of muscovite and biotite schist and phyllite interbedded with thin quartzites (McCurry, 1976). The pelitic rocks include minor graphitic and feldspathic schists, and contain frequent quartz and quartz-tourmaline veins. Interbedded quartzites are dominantly massive. Well-bedded quartzite units, sometimes several tens of metres thick, also occur. Minor rocks are spessartite quartzite, calc-silicate rocks and anthophyllite cordierite schist. Amphibolite form occasional discontinuous bands, with the largest occurrence being only approximately 12 m thick. The Malumfashi schist belt has been compared lithologically with the Kushaka schist belt (Grant, 1978). But there are other important differences: (1) the quartzites are detrital and not chemically precipitated iron-silica formations; and (2) rocks of basic igneous composition are much less important. The rocks represent a fairly well differentiated sequence of muds and fine-grained sands. Structurally, the Malumfashi belt appears similar to the Zungeru-Birnin Gwari Schist belt, matching it closely in size and form (Grant, 1978).

Different models had been put forward for the evolution of the schist belts in Nigeria. McCurry (1971) is in favour of the evolution of the schist belts through ensialic processes. Ajibade and Wright (1989) favoured the evolution through ensimatic processes, Ogezi (1977) and Bafor (1982) suggested the formation of rift zones where sufficient extension led to the production of small basin. Holt (1982) favoured formation through both ensialic and ensimatic. Geochemical features presented by Danbatta (2001) suggested the Kazaure Schist Belt to be of sedimentary origin, probably generated from the metamorphism of shale-greywacke.

The Malumfashi schist belt has been studied by McCurry (1976) and Grant (1978) on a regional scale on the basis of petrography and not geochemistry. The research conducted by the Nigerian Geological Survey Agency (NGSA) has not been published yet. This study investigates the geochemical and petrogenetic features of part of Malumfashi schist belt, around Tandama area, in order to reconstruct its evolution.

2. Materials and Methods

Field study and laboratory work constitute the research methodology. The field study involved mapping of all the lithological units within the study area. The study was carried out utilizing rock exposures along roads and stream channels. Spatial relationship, texture and structural characteristics of the rock exposure were studied. A base map was used to mark the corresponding points where rocks occur in the field and were sampled. Detail observation of lithological contacts was also done by careful studying of areas in the field where lithologies change from one type to another.

In the laboratory, rock thin sections were prepared from representative rock samples collected from the field and the thin sections were prepared and used for petrographic studies. Both the thin section preparation and the petrographic study were done in the Department of Geology laboratory, Federal University of Technology, Minna, Nigeria.

Thirteen rock samples obtained from the field were taken to the Department of Geology and Mining, University of Jos, for sample preparation. The samples were broken into smaller pieces using geologic hammer, the smaller fragments were crushed and reduced to powder using FRITSCH Pulverisette 7. The powdered samples, pulverised to 85% passing 200 mesh, and measured to 5g were transferred into labelled dispersing gloves for transportation to Acme laboratory at Vancouver, Canada, where the whole rock geochemical analyses were done using X-ray fluorescence (XRF) for major oxides and Inductively coupled plasma mass spectrometry (ICP-MS) for trace elements.

3. Results and Interpretation

3.1. Lithology and petrography

The study area comprises of migmatite-gneisses, schist and biotite granite (Figure 1). The migmatite-gneisses occupy the western part of the study area. The schists occupy the eastern part and cover half of the study area, and are intruded by the biotite granite in the southern part.

The mica schist is generally soft, fine to medium grained, strongly weathered and poorly exposed. It is exposed mostly along river channels and road cutting. It is extensive and constitutes about 60% of the entire study area; it is in spatial contact with migmatite, granite gneiss, augen gneiss, and the intrusive biotite granite.

The schists fall within the class of pelitic schist. In hand specimen, the rocks consist of greater than fifty percent micaceous minerals and less than fifty percent quartz and feldspar. This mineral composition qualifies it to be mica schist.

The schist is light grey to silver grey in colour, well foliated and mostly weathered to rusty brown or reddish brown. The pelitic schist generally shows a NE-SW orientation (strike) and with an average dip value of 54°W. Quartz veins within the pelitic schist are concordant and parallel to the original fabrics of the pelites, and are between 0.05 to 0.15mm wide.

In thin section, quartz occurs as coarse-grained, stretched, and white to greyish anhedral blasts. Biotite occurs as light brown leaflet sometimes slender and prismatic with occasional stumpy laths and is pleochroic from light brown to reddish brown, showing alignment in the foliation plane (Figure 2). The feldspar mineral grains present are mainly plagioclase and minor K-feldspar. The plagioclase displays a narrow albite twin lamellae characteristic of more sodic plagioclase, probably oligoclase. The K-feldspar is colourless and the crystal form

is subhedral to anhedral displaying cross-hatched twinning, typical of microcline. They sometimes exhibit poikiloblastic texture and are characterized by inclusion of fine quartz and some mica. The quartz mineral grains vary in sizes from large to small (0.5 to 1.0mm) in length with some having preferred orientation. There is widespread undulose extinction in the quartz grain.

3.2. Geochemistry

Whole-rock major and trace elements data of representative rock samples of the mica schists are represented in Tables 1 and 2 respectively.

The mica schist displays a wide range in SiO_2 content 43.94-76.4 wt% (an average 66.97 wt%), and high Al_2O_3 content in a range of 17.2-11.29 wt% (an average of 15.44 wt%). The Al_2O_3 content is higher and the K_2O content (1.81-6.64 wt%, an average of 4.37 wt%) is in excess of NaO content (0.01-0.43 wt%, an average 0.21 wt%). The high Al enrichment in the Al_2O_3 reflects the control of their composition by aluminous clay minerals. $\text{K}_2\text{O}/\text{Na}_2\text{O}$ reflects probable secondary addition of potassium (K-metasomatism) during metamorphism (Fedot *et al.*, 1995). The $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ ratios of terrigenous sedimentary rocks can be used as an indicator of the original composition of ancient sediments because $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ ratios for clay minerals and feldspars are different. $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ ratios for clay minerals range between 0.0 and 0.3 while that of feldspar range between 0.3 and 0.9 (Cox and Lowe, 1995). In the present study, the $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ ratio of the mica schist (0.43 ± 0.11) with majority falling within the 0.0 and 0.3 mark suggests that it contain considerable amounts of clay minerals. The $\text{SiO}_2/\text{Al}_2\text{O}_3$ values vary from 2.55-6.59wt% (an average of 4.18wt%), reflecting different degree of maturation of the metasediments, with those $>5\text{wt}\%$ providing evidence of sedimentary maturation (Roser *et al.*, 1996). It has Fe_2O_3 content in the range of 2.43-14.63 wt% (Average 5.60 wt%) and MgO content in range of 0.04-8.9 wt% (Average 1.65 wt%), the MgO content is in excess of CaO content which is in the range of 0.01-0.24 wt% (Average 0.097). Since MgO content is in excess of CaO content which is typically $< 0.6\text{wt}\%$, it is perhaps indicating the almost carbonate-free nature of the protolith (Ekwueme, 1985). The low Ca content results from the decomposition of plagioclase in the source material during weathering.

The mica schist has fairly high Ba in a range of 262-1164ppm (an average of 674.92 ppm), Rb 90.2-743.8ppm (an average 230.26ppm), Zr 115.6-326.5ppm (an average of 230.35ppm). These concentrations are within the range of supracrustal rocks (Brown *et al.*, 1979). Zr concentration is a reflection of the presence of detrital zircon in the rock (Elueze, 1981). Sr content is in the range of 5.4-47.2ppm (average 25.64ppm). Zn (2-284ppm, Average 72ppm), Cu (5-58.6ppm, Average 24.76ppm), and Co (2.4-54.4ppm, Average 14.34ppm) concentration is low. The concentration of Rb is similar to their derivation from shales or metapelites, which is a reflection of their origin (pelite). Rb/Sr ratio which is $>0.4\%$ is typical of pelitic metasediments (Van De Kamp, 1968), high Ba indicates K-feldspar rich source rock.

The patterns from the normalized REE Primitive mantle (after Sun and McDonough, 1995) of the mica schist show gentle curves of decreasing relative abundances towards the heavy rare earth elements (HREEs) (Figure 7). The light rare earth elements (LREEs) are enriched with distinct Eu anomalies. The HREEs are weakly fractionated with slight inclined to flat patterns. It has slightly high degree of LREE fractionation ($(\text{La}/\text{Yb})_N = 2.03-16$) with weaker negative Eu anomalies ($\text{Eu}/\text{Eu}^* = 0.34-1.03$). The mica schists have high La_N/Sm_N (1.64-4.23, an average of 2.91) and low Gd_N/Lu_N (0.81-2.12, Average 1.58) which is an indication of predominance of light REE over the heavy REE in the mica schist. The plot shows the curve to have a gentle trend with relative depletion of HREE relative to LREE.

4. Discussion

The petrogenetic character of the mica schist as indicated on the $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ against $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ diagram (after Garrels and Mackenzie, 1971) shows the mica schist to be of sedimentary origin (Figure 3), and thus has a sedimentary protolith. Sedimentary petrologists have shown that virtually all shales have lower $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ values than the lowest limits for this ratio found in igneous rocks, whether mafic or felsic (Garrels&MacKenzie, 1971), as thus indicated in the plot.

The chemical composition of the mica schist provides insight into the nature of chemical weathering that gave rise to the source rock (shale). During weathering, large cations (Al_2O_3 , Ba, Rb) remain fixed in the weathered residue in preference to smaller cations (Ca, Na, K, Sr) which are selectively leached (Nesbitt et al., 1980). These chemical signatures are ultimately transferred to the sedimentary record (e.g., Nesbitt and Young, 1982; Wronkiewicz and Condie, 1987), thus providing a useful tool for monitoring source-area weathering conditions. During the initial stage of weathering, Na_2O and CaO are leached out from the earlier dissolved plagioclase. With increasing weathering intensity of the source rocks, the plagioclase are destructed which resulted in the loss of Ca and Na from plagioclase feldspar and the resulted sediments plot closer to the A-K axis of A-CN-K plot (Figure 4). Likewise, the samples plot nearer to apex A, suggesting the abundance of kaolinite and gibbsite over primary minerals such as feldspar in the source rock (Figure 5). It is an indication that these sediments underwent intense chemical weathering in the source region. Those that follow the A-K trend line and plot between K-feldspar and muscovite fields imply that their source area experienced moderate intensity of chemical weathering. This typically shows that clay minerals are one of the major constituents of the source rock as represented in the A-CN-K diagram, which is characteristic of shale.

The chemical composition of the mica schist plotted in the ACF diagram (Figure 5) points to shale protolith. The plot shows the mica schist falls in the fields of shale-graywackes (Miyashiro, 1973), which suggests they originate from shale. This is confirmed in Pettijohn (1957) who noted that the average composition of shale contains abundance of Al_2O_3 and K_2O which is generally in excess of Na_2O . $\text{K}_2\text{O} > \text{Na}_2\text{O}$ is used to indicate shale, and high proportion of K-bearing rock forming minerals such as mica, K-feldspar, illite, compared to Na-feldspar which is unstable prior to metamorphism.

The TiO_2 - K_2O - P_2O_5 plot (Figure 6) (after Pearce et al., 1975) of the mica schist confirms the continental nature of the sediments. The schist on the continental field is a confirmation of the continental nature of the sediments which underwent metamorphism.

The geochemical signatures of clastic sediments have been used to determine their provenance (Taylor and McLennan, 1985; Cullers, 1995; Madhavaraju and Ramasamy, 2002; Armstrong-Altrin et al., 2004, 2013; Al-Juboury and AlHadidy, 2009; Perri et al., 2011; Shadan and HosseiniBarzi, 2013; Madhavaraju, 2015). Elements concentrated in mafic (Sc, Cr, and Co) and in silicic (La, Th, and REE) sediments, REE patterns, and the size of the Eu anomaly have been used widely to understand the provenance signatures' interpretation (e.g., Shynu et al., 2011). The REEs and certain trace elements (Th, Sc, and Cr) can provide an insight into the provenance and are thus useful to constrain the average source-area composition (e.g., Taylor and McLennan, 1985; Floyd et al., 1991; McLennan et al., 1993; Fedo et al., 1996; Cullers and Berendsen, 1998).

Th/U ratio is also a useful parameter in determining the source characteristics of clastic sedimentary rocks (Roddaz et al., 2006). This ratio ranges between 4.25- 4.30 in present day crust, while its values 2.6 and 3.8 have been assigned to upper and lower mantle respectively (Cullers et al; 2002). Higher Th/U ratios can also increase in response to oxidative weathering and/or removal of U. Nevertheless, clastic sedimentary rocks derived from the upper crust are characterized by ratio ≥ 4 , whereas ratio < 4 has been related to a mantle

contribution (Roddaz et al, 2006). In the mica schist, Th/U ratio varies from 0.9–10.7(average 4.96). Most of the samples show high values of Th/U ratio of >4 which suggest that probably there have been significant proportion of the felsic rocks in the source region.

The REE patterns and the size of the Eu anomalies in the sediments provide useful information regarding source rock characteristics (Taylor and McLennan, 1985), because mafic igneous rocks have low LREE/HREE ratios and little or no negative Eu anomalies, whereas felsic igneous rocks have higher LREE/HREE ratios and negative Eu anomalies (Cullers, 1994a, 1994b). In the present study, most of the sedimentary rocks show higher LREE/HREE ratios and negative Eu anomalies which suggests the felsic nature of the source rocks.

There is Eu depletion in the mica schist as indicated in the small negative Eu anomalies Eu/Eu* of 0.34-1.03 (Average 0.5). All post-Archeanclastic sedimentary rocks of shale composition have negative Eu anomaly with average composition of Eu/Eu*=0.66 of the upper crust (Taylor and McLennan, 1985). Thus, the curves on the plot are similar to those of normalized REE of post-Archeanshales known in the world (Haskin *et al.*, 1960; Martin and Meyneck, 1979; Taylor and McLennan, 1985).

Taylor and McLennan (1985) deduced that the absence of anEu anomaly (Eu/Eu*=1) or even the presence of local positive Eu anomaly indicate Archean sedimentary rocks. On the other hand, Nance and Taylor (1977) ascribed the negative Eu anomaly in the clastic sedimentary rocks of post-Archean to detrital sources, during the formation of Eu depleted feldspar granites, after its formation by chemical fractionation.

The Eu/Eu* values which is comparable between the mica schist in the study area and that of upper crust suggests the rocks were derived from similar source area with typical clay sediments.

Roser and Korsch (1986) have shown that sandstone–mudstone suits from different tectonic settings can be distinguished on the basis of the K₂O/Na₂O and SiO₂/Al₂O₃ values and SiO₂ contents. On the SiO₂/Al₂O₃ versus K₂O/Na₂O plots (Figure 8), all samples of the mica schist plot in the passive continental margin. Thus, in terms of tectonic setting, the mica schists are of passive margin rocks.

5. Conclusion

Geochemical evaluation of part of Malumfashi schist belt around Tandama has revealed that the schist was generated from metamorphism of a shale protolith. A-CN-K plot reflects that the shale attained maturity and suffered moderate to intense chemical weathering before being subjected to metamorphism. Pattern of REE values, LREE and HREE characteristics, as well as Eu negative anomaly suggest considerable felsic component in the shale. Tectonic setting from the SiO₂/Al₂O₃ versus K₂O/Na₂O plot suggests the protolith to have evolved within passive margin environment.

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412 **Table 1: Major oxides in wt% of Mica schist**

	Samples												
	ALA 3	ALA 5	ALA 7	ALA 8	ALA 9	ALA 10	ALA 11	ALA 12	ALA 13	ALA 16	ALA 19	ALA 20	ALA 22
SiO ₂	74.42	75.09	70.83	62.89	76.4	75.82	68.72	72.03	70.02	43.94	62.93	57.68	59.89
Al ₂ O ₃	11.29	13.36	15.41	19.26	12.76	12.77	16.77	16.13	15.51	17.2	17.09	17.08	16.13
Fe ₂ O ₃	5.46	3.05	2.54	4.88	2.43	3.04	3.15	3.25	5.26	14.63	8.2	8.71	8.23
CaO	0.07	0.01	0.08	0.05	0.19	0.08	0.05	0.01	<0.01	0.18	0.03	0.24	0.17
MgO	1.09	0.28	0.39	0.64	0.22	0.34	0.56	0.16	0.23	8.9	1.51	3.15	3.95
Na ₂ O	0.24	0.1	0.43	0.25	1.02	0.15	0.22	0.02	0.05	0.07	0.04	0.19	0.01
K ₂ O	3.03	4.44	6.64	7.69	3.66	4.86	5.63	1.81	2.9	6.41	2.14	4.76	2.89
MnO	0.11	0.01	0.02	0.03	0.02	0.04	0.06	0.01	0.01	0.22	0.1	0.38	0.12
TiO ₂	0.6	0.31	0.33	0.32	0.21	0.25	0.29	0.41	0.37	1.34	0.98	0.85	1.01
P ₂ O ₅	0.08	0.03	0.04	0.01	0.03	0.04	0.03	0.05	0.09	0.04	0.05	0.04	0.04
Cr ₂ O ₃	0.026	0.051	0.031	0.019	0.018	0.024	0.009	0.027	0.029	0.133	0.064	0.036	0.045
TOTAL	96.416	96.731	96.741	96.039	96.958	97.414	95.489	93.907	94.469	93.063	93.134	93.116	92.485

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416 **Table 2: Trace elements in ppm (Au in ppb) of Mica schist**

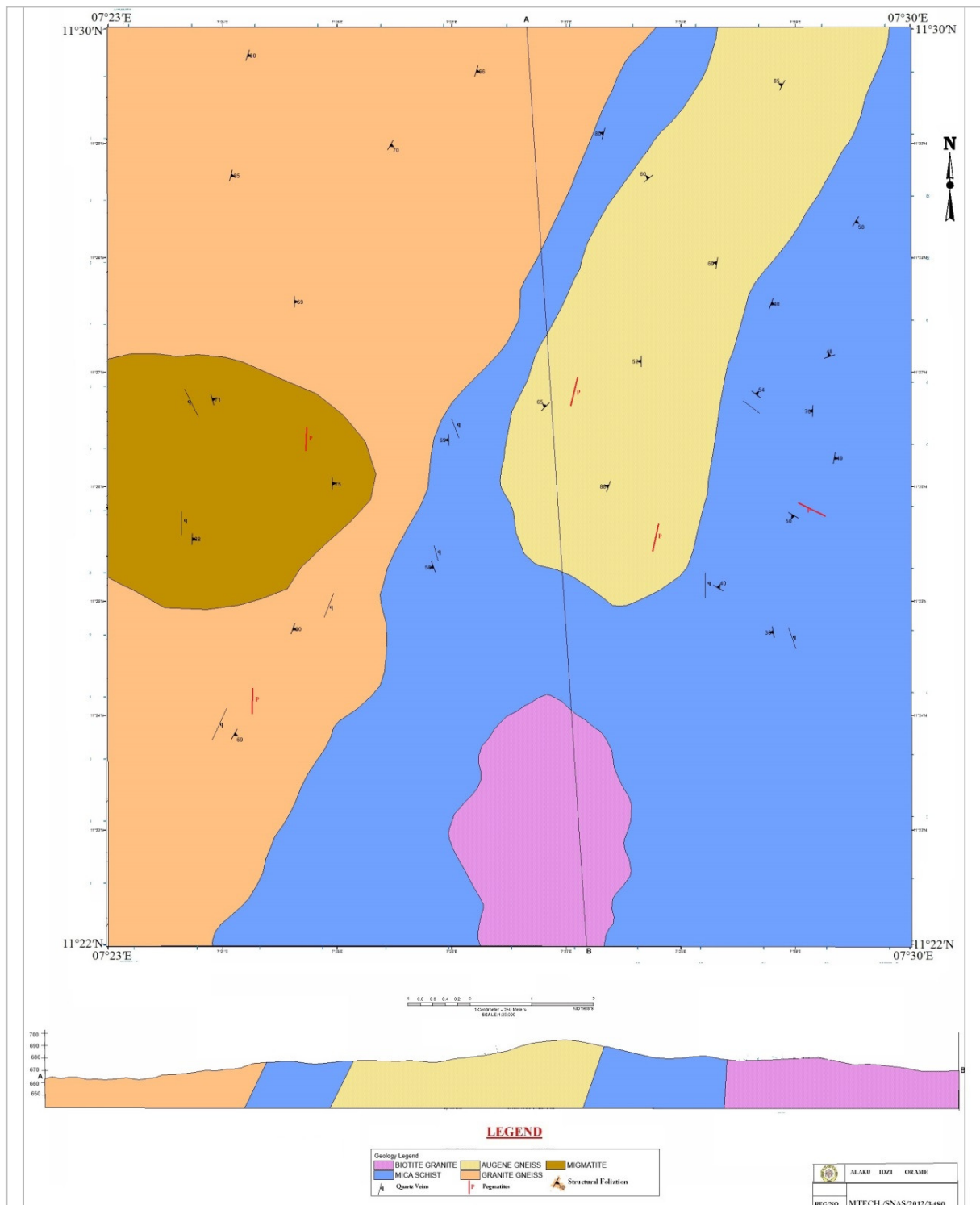
	Samples												
	ALA 3	ALA 5	ALA 7	ALA 8	ALA 9	ALA 10	ALA 11	ALA 12	ALA 13	ALA 16	ALA 19	ALA 20	ALA 22
Ba	522	367	948	1164	834	660	679	262	424	813	631	957	513
Be	<1	2	2	9	4	2	4	2	<1	3	<1	6	2
Co	19.8	4.2	3.6	6	2.4	3.1	5.7	2.3	2.2	54.4	18.5	40.8	23.4
Cs	9.9	7.5	8.5	20.4	6.7	6.6	11.9	0.4	0.7	34.7	22.7	19.7	10.4
Ga	16.9	19.3	22.1	27.7	17.7	16	22.1	21.8	21.7	30.1	21.7	21.4	19.9
Hf	4.5	7.5	8.2	9.5	6.3	5.7	7.7	9.3	7.8	3	5.7	5.7	4.8
Nb	6.4	15.2	19.4	21.2	15.9	15.3	18.1	23	20.5	13.5	12.3	11.1	12.5
Rb	176.6	198.8	260.2	345.7	145.6	194	225.6	53.3	90.2	743.8	197.1	220.2	142.3
Sn	3	5	7	8	6	6	6	7	9	6	3	3	3
Sr	25.1	25.3	41.3	47.2	27.4	29.7	30.4	5.4	12.1	19.3	10.4	40.1	19.6
Ta	0.5	1.1	1.6	1.2	1.4	1.1	1.1	1.6	1.3	0.4	0.8	0.7	1.2
Th	7.8	18.2	25	26.5	17.8	16.2	24.1	19.9	20.4	5.5	10.8	11.5	7.8
U	2.6	1.7	4.3	3.6	4.3	2.4	4	2.8	4.4	6	4.9	2.8	4.1
V	103	18	17	17	<8	11	15	28	29	214	141	164	155
W	2.2	3.4	4.1	4.8	1.7	2.2	2.8	2.6	5.1	1.4	1.9	5.2	0.7
Zr	158	268.5	265.3	272.4	187.7	181.7	246.7	326.5	281.3	115.6	230.1	244.8	215.9
Y	28.7	46.4	65.6	33.1	71.1	49	64.6	84.4	111.7	17	74.5	31.7	43.1
La	34.7	36.4	68.5	30.6	63.9	50	70.1	54.2	36.6	36.2	54.4	41.2	27.9
Ce	93.9	89.9	117.8	66.7	142.8	100.4	117.8	99.7	66.1	110.5	64.3	188.3	54
Pr	7.87	10.36	15.43	8.42	14.43	12.46	17.36	21.56	11.17	8.28	19.21	9.49	7.63
Nd	30.5	45.9	61.2	34.9	57.5	49.1	67.5	94.4	46	32.9	88.1	39.3	34.3
Sm	6.01	9.85	12.32	6.74	12.56	10.64	13.61	20.65	11.17	5.36	18.61	6.4	7.13
Eu	1.31	1.37	1.54	0.92	1.48	1.23	1.63	3.27	1.87	1.23	4.25	1.32	2.45
Gd	5.77	8.59	12.55	6.36	13.67	9.93	13.14	17.39	11.97	4.57	15.95	6.42	7.4
Tb	0.87	1.45	2.03	1.01	2.23	1.52	2.15	2.86	2.3	0.52	2.29	0.91	1.04
Dy	5.13	8.26	11.63	6.38	13.02	8.82	12.33	15.48	16.23	2.83	13.3	5.61	6.05

Ho	1.04	1.77	2.48	1.32	2.55	1.7	2.38	3.1	3.8	0.54	2.63	1.26	1.4
Er	3.06	4.99	6.92	4.05	7.99	5.99	7.03	8.62	12.49	1.69	7.15	3.59	3.77
Tm	0.46	0.84	1.01	0.62	1.1	0.81	1.03	1.28	1.92	0.24	1.08	0.57	0.54
Yb	2.96	5.52	6.48	4.38	6.89	5.31	6.51	8.37	12.25	1.54	7.24	3.64	3.28
Lu	0.45	0.84	0.95	0.65	1.04	0.8	0.95	1.22	1.84	0.27	1.05	0.55	0.53
Mo	3.1	3.6	2.4	1.9	1.2	2.9	0.6	0.7	1.7	0.9	1.4	1.1	1.3
Cu	34.4	11.7	11.6	19.9	7	16.4	5	11	21.7	46	47.2	58.6	31.4
Pb	8.5	2.3	5.1	8.7	14.2	6.8	9.8	4	5	38.2	18.7	28.8	20.2
Zn	88	2	25	62	11	24	32	5	18	284	125	110	150
Ni	49.2	121.2	68.8	39.8	25.9	46.8	9	20	33.3	293.2	107.3	78.1	136.2
LaN	53.55	56.17	105.71	47.22	98.61	77.16	108.18	83.64	56.48	55.86	83.95	63.58	43.06
CeN	56.06	53.67	70.33	39.82	85.25	59.94	70.33	59.52	39.46	65.97	38.39	112.42	32.24
PrN	30.98	40.79	60.75	33.15	56.81	49.06	68.35	84.88	43.98	32.6	75.63	37.36	30.04
NdN	24.4	36.72	48.96	27.92	46	39.28	54	75.52	36.8	26.32	70.48	31.44	27.44
PmN	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SmN	14.8	24.26	30.34	16.6	30.94	26.21	33.52	50.86	27.51	13.2	45.84	15.76	17.56
EuN	8.51	8.9	10	5.97	9.61	7.99	10.58	21.23	12.14	7.99	27.6	8.57	15.91
GdN	10.61	15.79	23.07	11.69	25.13	18.25	24.15	31.97	22	8.4	29.32	11.8	13.6
TbN	8.79	14.65	20.51	10.2	22.53	15.35	21.72	28.89	23.23	5.25	23.13	9.19	10.51
DyN	7.61	12.26	17.26	9.47	19.32	13.09	18.29	22.97	24.08	4.2	19.73	8.32	8.98
HoN	6.98	11.88	16.64	8.86	17.11	11.41	15.97	20.81	25.5	3.62	17.65	8.46	9.4
ErN	6.99	11.39	15.8	9.25	18.24	13.68	16.05	19.68	28.52	3.86	16.32	8.2	8.61
TmN	6.76	12.35	14.85	9.12	16.18	11.91	15.15	18.82	28.24	3.53	15.88	8.38	7.94
YbN	6.71	12.52	14.69	9.93	15.62	12.04	14.76	18.98	27.78	3.49	16.42	8.25	7.44
LuN	6.62	12.35	13.97	9.56	15.29	11.76	13.97	17.94	27.06	3.97	15.44	8.09	7.79
Eu/Eu*	0.68	0.45	0.38	0.43	0.34	0.37	0.37	0.53	0.49	0.76	0.75	0.63	1.03
LaN/YbN	7.98	4.49	7.19	4.75	6.31	6.41	7.33	4.41	2.03	16	5.11	7.7	5.79
LaN/SmN	3.62	2.32	3.48	2.84	3.19	2.94	3.23	1.64	2.05	4.23	1.83	4.03	2.45
GdN/LuN	1.6	1.28	1.65	1.22	1.64	1.55	1.73	1.78	0.81	2.12	1.9	1.46	1.75
EuN/YbN	8.35	4.29	4.79	4.01	5.46	4.98	4.76	3.14	1.42	18.89	2.34	13.62	4.33

CeN/YbN	3.79	2.21	2.32	2.4	2.76	2.29	2.1	1.17	1.43	5	0.84	7.13	1.84
CeN/SmN	1.27	0.71	0.68	0.6	0.62	0.66	0.72	1.12	0.44	2.29	1.68	1.04	2.14

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422 **Figure 1: Geological map and cross section of the study area**

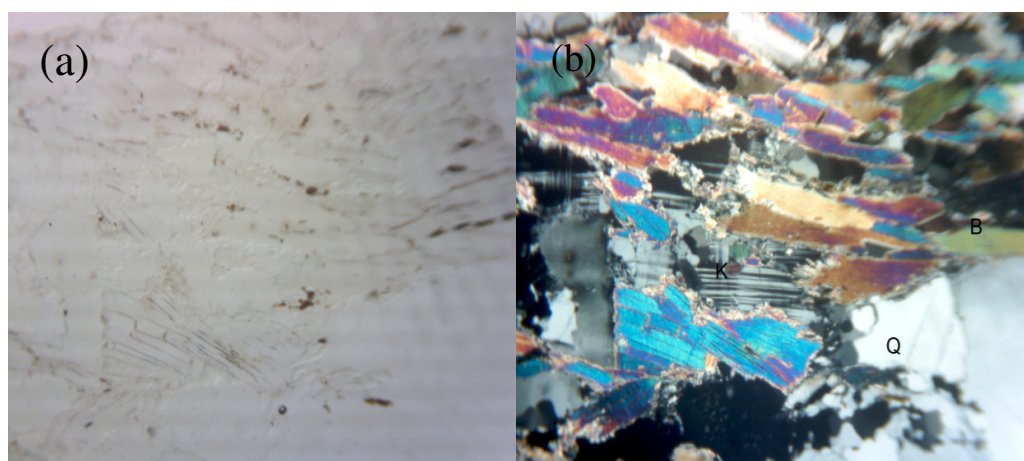


Figure 2: Photomicrograph of Mica schist under(a) plane polarized light and (b) cross polarized light. Magnification = X10

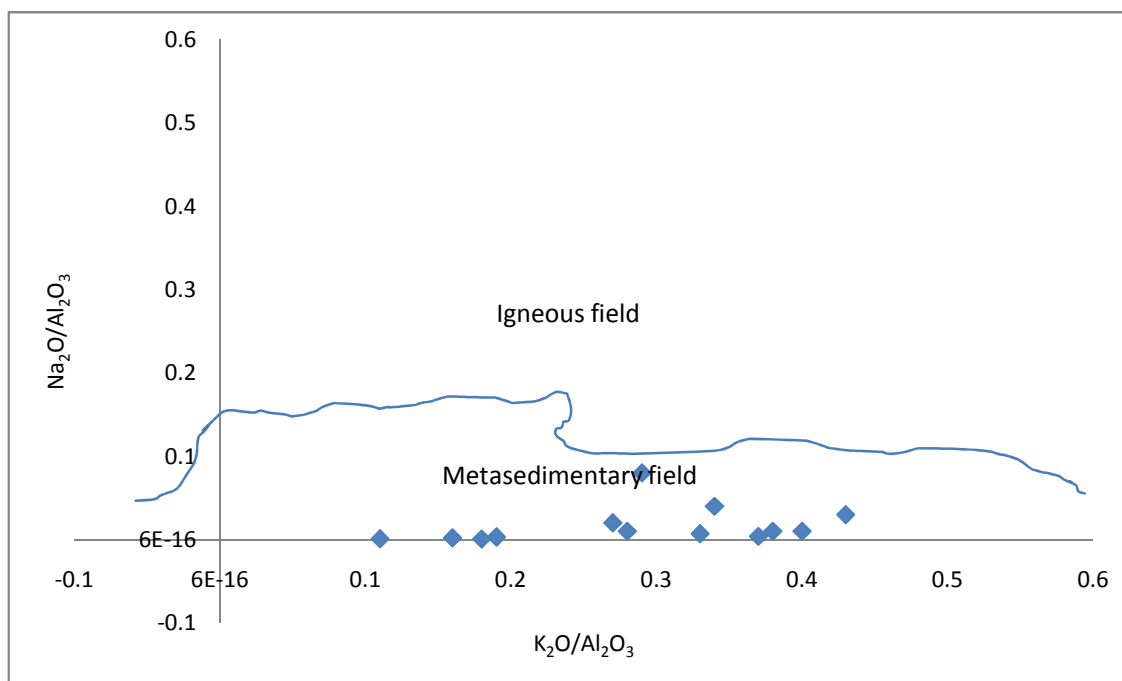


Figure 3: $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ versus $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ plot for the mica schists of Tandama area (after Garrells and Mackenzie, 1971)

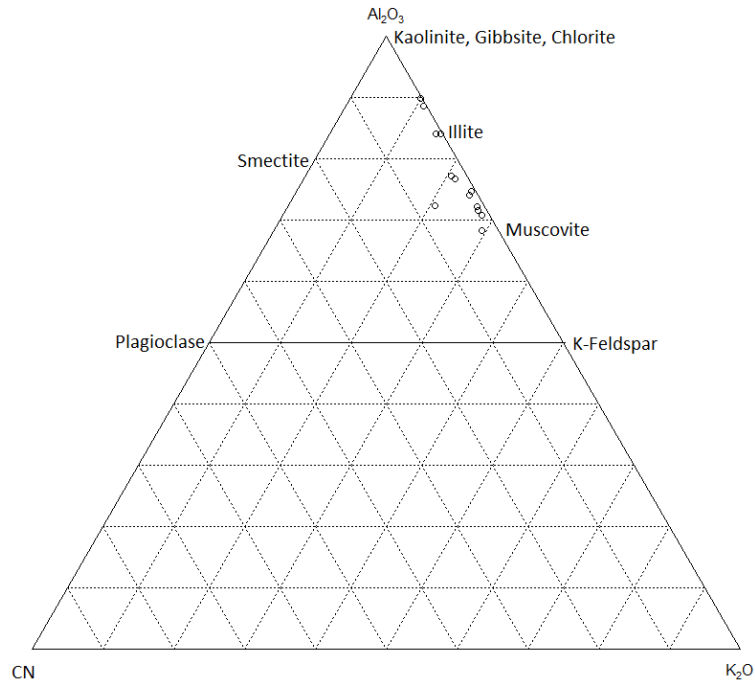


Figure 4: A-CN-K diagram showing the weathering trend of the mica schist (after Nesbitt and Young, 1982). A: Al_2O_3 ; CN: $\text{CaO} + \text{Na}_2\text{O}$; K: K_2O .

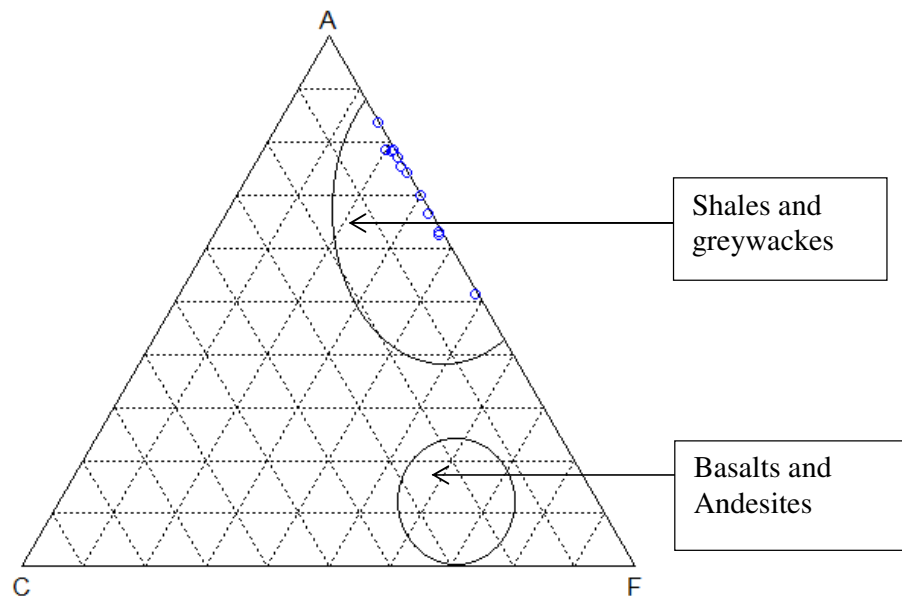


Figure 5: Field of mica schist in the ACF diagram (after Miyashiro, 1973)
 $A = \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 - \text{Na}_2\text{O} + \text{K}_2\text{O}$, $C = \text{CaO}$, $F = \text{Fe}_2\text{O}_3 + \text{MgO} + \text{MnO}$

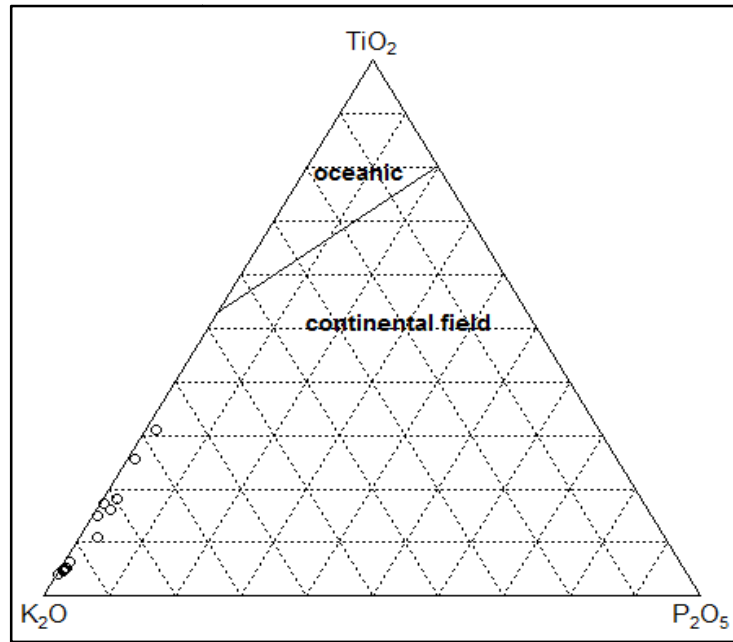


Figure 6: TiO_2 - K_2O - P_2O_5 diagram for the mica schist (After Pearce, 1975)

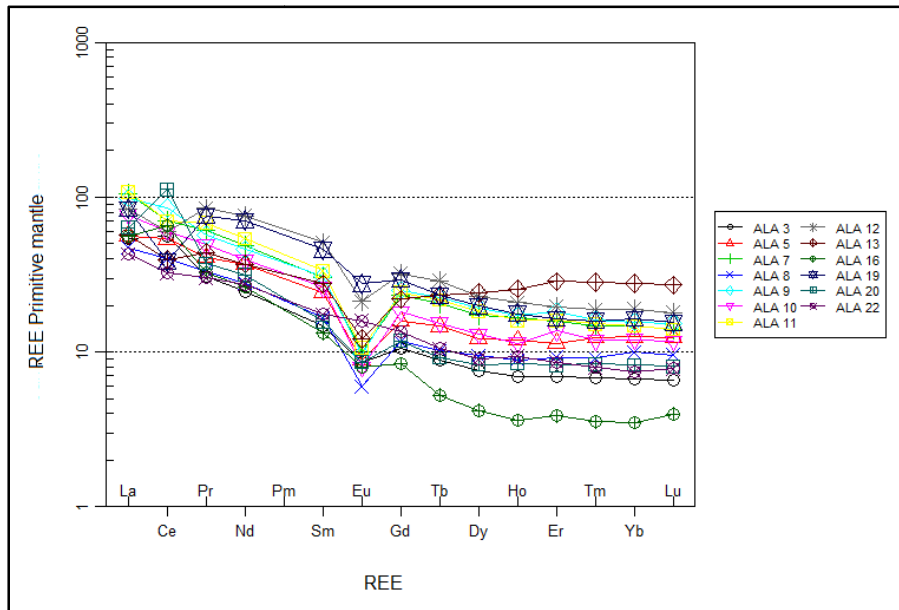


Figure 7: The Rare Earth Elements (REE) spider plot(after Sun and McDonough, 1995)of the mica schist displaying enrichment in LREE, a negative Eu anomaly and a flat HREE pattern.

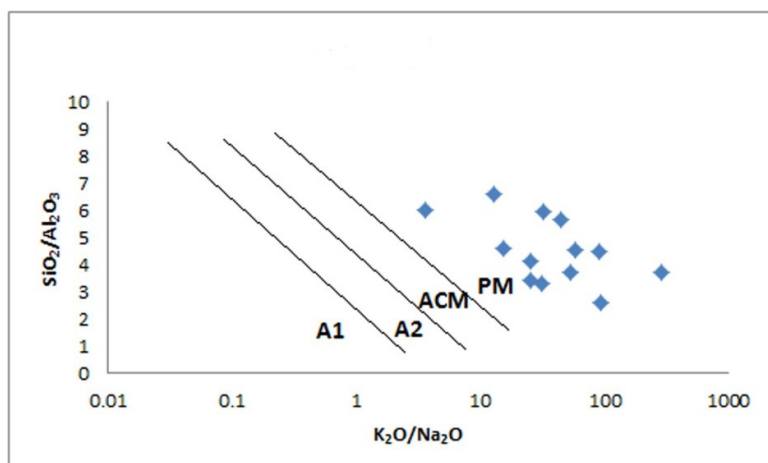


Figure 8: $\text{SiO}_2/\text{Al}_2\text{O}_3$ versus $\text{K}_2\text{O}/\text{Na}_2\text{O}$ (after Roser and Korsch, 1986). PM, passive margin; A1, arc setting, basaltic and andesitic detritus; A2, evolved arc setting, felsic-plutonic detritus.