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Preliminary Investigation of Petrographic and Geochemical Characteristics of Crystalline Rocks in Jebba, Central NigeriaO. A. Omotoso^{1*}, O. J. Ojo², A. I. Aina¹, J. I. Udeafor¹, M. T. Alebiosu¹¹Department of Geology and Mineral Sciences, University of Ilorin, Ilorin, Nigeria²Department of Geology, University of Oye-Ekiti, Nigeria*Corresponding Author:* *Dr. O. A. Omotoso; deletoso2002@yahoo.co.uk; +2348067780267**Abstract**

The preliminary investigation of petrographic and geochemical characteristics of crystalline rocks in Jebba, central Nigeria was carried out in order to establish the various rock types in the area. Petrographic studies were carried out using thin sections of the rock samples and geochemical analysis was carried out using X-ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Field mapping indicated that the area is underlain by granite (porphyritic granite), granite gneiss, quartzite and schist. The petrographic studies indicated the main mineral assemblages in the crystalline rocks as: quartz, plagioclase, microcline and biotite. Results of geochemical analysis established SiO₂ and Al₂O₃ as dominant major oxides in the investigated rocks ranging from 46.66 to 97.6 wt. % and 0.25 to 17.48 wt. % respectively. Average values of CIA (Chemical Index of Alteration), PIA (Plagioclase Index of Alteration) and CIW (Chemical Index of Weathering) of the rocks are 59.2, 65.0 and 72.8 (granite gneiss); 58.4, 62.9 and 70.6 (granite); 67.7, 79.9 and 83.3 (quartzite); 57.9, 61.4 and 66.4 (schist) respectively. The intensive weathering of the rocks would have contributed to the concentration of metals in the water phase of the study area. Most of the rare earth elements in granite gneiss are highly enriched with respect to abundance in the earth crust having values greater than 1 ppm while granite and quartzite are depleted in these elements.

Keywords: rock types, petrography, geochemistry, weathering indications and enrichment.

Introduction

Rocks are considered as aggregates of one or more minerals formed from cooling of molten magmas, consolidation of sediments, and/or alteration of pre-existing rock materials under high pressures and temperatures (Pelig-Ba. 2012; Hatch *et al.*, 1979). As reported by Pelig-Ba 2012, minerals may be either amorphous or crystalline and also vary in grain size and morphology. However, it may be very difficult to trace the origin of minerals in rocks to the original magma since the

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original composition may have changed due to the loss of volatile substances during exposure leaving behind residual materials (Pelig-Ba, 2012; Hatch *et al.*, 1979). The type of crystalline rock formed and its mineralogical content depends on the mode of formation and the host environment as a whole. Hence, the chemical make-up of rocks depends on the original chemical composition of the magma as well as the processes occurring during or after the cooling, duration and geochemical environments in which the crystalline rock was initially deposited. This is the reason why various rock types are found with varying compositions ranging from minimal chemical differences to very different rock types. There are many different types of rocks with varying mineralogical and geochemical compositions and these determine their respective suitability for man's uses. Hence, there is the need to critically examine their mineralogical and geochemical compositions.

The study area forms part of the Nigerian basement complex (Fig. 1). The Nigerian basement complex is a part of a late Proterozoic to early Paleozoic mobile belt east of the West Africa craton. This basement complex comprises gneisses, migmatites, psammitic rocks, schists, amphibolites and intrusive igneous rocks. It is reported that the basement complex is polycyclic and bears the imprint of four thermo-tectonic events (Liberian- ca 2700 Ma, Eburnean- ca 2000 Ma, Kibaran- ca 1100 Ma, and Pan African- ca 600 Ma (Van Breemen, *et al.*, 1977; Grant, 1978; Fitches *et al.*, 1985; Ekwueme, 1987; Rahaman, 1988; Okonkwo, 1992). Jebba area lies at the northern margin of the south-western sector of the basement complex and is separated from the north-western sector by the Cretaceous to Tertiary sedimentary rock of the Bida Basin. Okonkwo (1992) discussed the lithostratigraphic units of Jebba area as migmatitic gneiss, granitic gneiss, metagreywacke, quartzite, quartz-biotite schist and post-tectonic granitic rocks.

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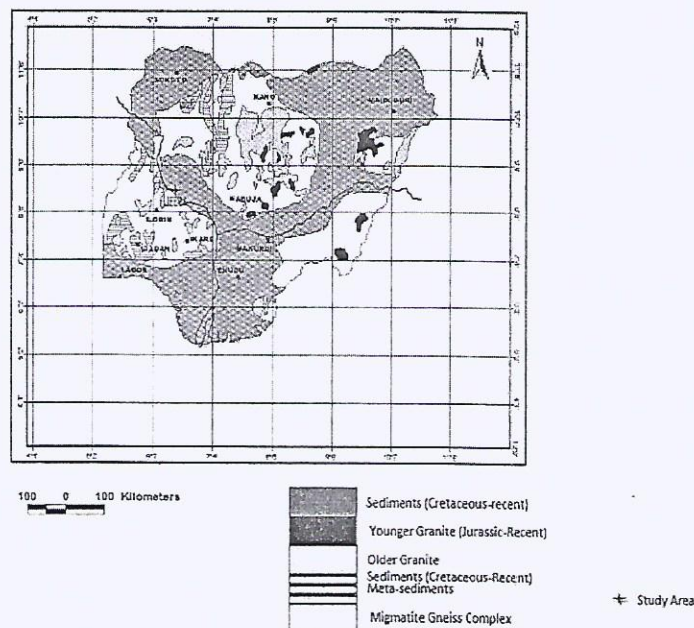


Figure 1: Generalized geological map of Nigeria showing study location (*Geological Survey of Nigeria, 2004*)

Methodology

The mapped area is situated within longitude $4^{\circ} 43' E$; $4^{\circ} 52' E$ and latitude $9^{\circ} 07' N$; $9^{\circ} 11' 29'' N$ (Fig. 2). Geological mapping was undertaken to determine the rock types, their distribution and lithological boundaries. Accessibility was facilitated by roads and foot paths. At each location, rock samples were examined and located on the base map using Global Positioning System (GPS). *Field measurement* of strikes, dips, joint directions and faults were taken for structural study with compass clinometers. Foliations, joints, mineral lineation and intrusions were some of the observed features. Twenty three samples were selected from representative rock types in the study area and subjected to geochemical analysis to determine the concentrations of the major oxides, trace elements and the rare earth elements and to assess their weathering history. The rock samples were pulverized in the Geology laboratory of University of Ilorin, Nigeria prior to geochemical analysis in ACME Laboratory, Canada using Inductively Coupled Plasma- Mass Spectrometry (ICP-MS). The petrographic preparation of the rock slides was carried out in Geology Laboratory of University of Ibadan, Nigeria. It involved cutting the respective rock

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sample into small rectangular pellet of 3 mm, mounted on glass slide using resin araldite. The slide was then lapped on a glass plate using medium-grain carborundum as abrasive in order to create friction between the rock pellet and the glass. This automatically reduced the slide thickness to a thickness of 0.3 mm. The thinned rock was sealed using Canada balsam.

Results and Discussion

The main rock types mapped in the study area consist of granite, granite-gneiss, quartzite, biotite schist and schist (Fig. 2).

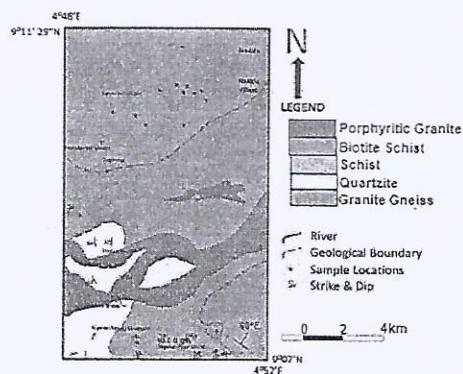


Figure 2: Geological map of the study area

Granite-Gneiss

Granite-gneiss is not well exposed in the area and generally occurs in the south eastern part of the study area (Fig. 3). They are generally low lying, weakly foliated and strongly mineralogical lineated. Occasionally, there are minor intercalations of hornblende-biotite gneiss which are generally enclosed in the granite gneisses. The granite gneisses are intruded by granite and pegmatite while the contact between granite gneiss and quartzite are gradational. Augen structures (eye-like structure) and asymmetry folds are prominent on the granite gneiss (Fig.3). Generally, joints trend NW-SE direction. The planar surfaces mainly dip towards the east. Quartz vein and quartzo-feldspathic intrusions (average width of 4 cm) are observed on the granite-gneiss. In hand specimen, the rocks are medium to coarse grained and in some places dissected with quartzo-feldspathic veins. In thin section, modal analysis (Table 1) shows that the granite-gneiss is chiefly comprised of quartz (24 %), plagioclase (31 %), biotite (35 %) and chlorite (7 %). Similarly, the light and dark-coloured minerals representing quartz and biotite respectively are clearly seen in the photomicrographs of the granite-gneiss (Fig.8). The quartz is colourless under plane polarized light and occurs as euhedral prismatic crystals. The plagioclase is characterized with its distinguished polysynthetic twinning according to Albite law.

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Biotite is brownish in thin section and exhibits pleochroism. It occurs as plates and laths which show preferential alignment with the foliation plane.

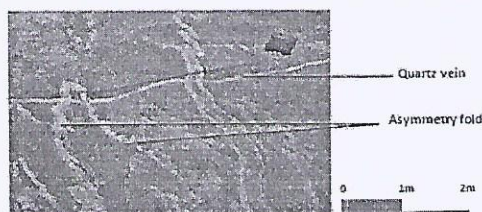


Figure 3: Field photograph showing Asymmetry folds and, augen structures defined by quartz veins and foliation planes ($9^{\circ}8'30''N$; $4^{\circ}49'30''E$)

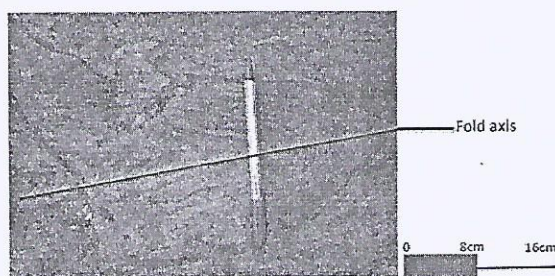


Figure 4: Field photograph showing Open folds in granite gneiss showing fold axis ($9^{\circ}8'0''N$; $4^{\circ}49'0''E$)

The SiO_2 content of the granite gneiss ranges from 48.82-73.47 wt % (average, 65 wt %) which corresponds to an intermediate to felsic composition. Al_2O_3 ranges from 11.85-15.85 wt % (average, 13.7 wt %) while Fe_2O_3 ranges from 3.22 – 15.35 wt % (average, 7.1 wt %). MgO varies from 0.17 – 5.62 % (average, 1.9 wt %), Na_2O content ranges from 1.99 – 3.68 wt % (average, 2.6 wt %), K_2O from 1.09 – 6.25 % (average, 4.1 wt %) and CaO from 0.53 – 8.94 wt % (2.9 wt %). MnO ranges from 0.003 - 0.21 wt % (average, 0.08 wt %) while TiO_2 ranges from 0.26 - 2.02 wt % (average, 0.8 %). P_2O_5 ranged from 0.04 – 0.58 wt % (average, 0.2 wt %), Cr_2O_3 varied from 0.002 – 0.04 wt % (average, 0.02 wt %), Table 2. The TiO_2 -values were generally less than 1 wt % in the granite gneiss but some samples showed values up to 2.02 wt %. This confirmed the presence of mica and feldspar groups of minerals in the rock (Pelig-Ba, 2012). The Na_2O concentration in the rocks is consistently lower than K_2O . K_2O/Na_2O ratios are consistently higher than 1 which reflects abundance of potassium bearing rock forming silicate e.g. biotite (Oyinloye, 2011). The concentration of SiO_2 , Al_2O_3 , Na_2O and K_2O in granite-gneiss indicates abundance of felsic silicates.

The trace elements concentrations are presented in Table 3. The level of Rb ranges from 26.2 to 260 ppm (average=146.76 ppm) while Sr and Ba range from 89.1 to 3317 ppm (average=173.6 ppm) and 310 to 1148 ppm (average=714 ppm)

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respectively. In the granite gneiss, the moderately high average value of Rb indicates high plagioclase mineral concentration as observed in the thin section study (Oyinloye, 2011). The ratio of trace element concentration of the rock samples with the corresponding average value in the earth crust (Krauskopf and Bird, 1995) was obtained to determine the enrichment value. The mean ratios of Rb for all the samples selected for granite-gneiss was 2.4 which was more than unity suggesting high enrichment value of Rb in the rock. The range of the enrichment value was from 0.4 to 4.3 for Rb, 0.73 to 2.7 for Ba and 0.2 to 0.9 for Sr. The average enrichment value for Ba and Sr were 1.7 and 0.5 respectively depicting that Ba is enriched and Sr is less enriched (< 1). Table 5 presents the average enrichment values for trace metals in the samples analyzed. There is significant enrichment of Au in the granite-gneiss in the study area. Pb shows a significant enrichment of more than 1. This may enhance its contributions to its concentration in the water phase during weathering and dissolution. Fig. 9 illustrates the UCC-normalized averages in trace element concentrations in the granite gneiss of the study area. Rare earth elements analyzed in the rock samples of the study area include Th, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu (Table 4). Th, Y and Ce ranged from 1.6 to 93.4 ppm, 15.2 to 50.4 ppm and 66.1 to 162.7 ppm respectively. It has been reported that REEs most especially Dy, Ho, Er, Tm, Yb and Lu reside in refractory minerals such as zircon, sphene and garnet phases and their levels could be attributed to the presence of these minerals in the granite gneiss (Sahoo *et al.*, 2011). Their enrichment values were determined with respect to Upper Continental average Concentrations (UCC) (Krauskopf and Bird, 1995). The enrichment value for the rare elements were more than 1 except Dy and Eu which shows unity value respectively (Table 5). This implies that granite gneiss in the study area is highly enriched in most of the rare earth elements. The enrichment values of these rare earth elements are highest in granite-gneiss compared to granite, quartzite, and schist/biotite schist. The high enrichment value recorded for the elements in granite-gneiss could contribute to their concentrations in the water phase during weathering and dissolution. Fig. 10 illustrates the UCC-normalized averages in rare earth element concentrations in the granite gneiss of the study area.

Quartzite

Quartzite occurs in well exposed outcrops in the area where it forms prominent ridge trending N –S which extends west of Jebba town, very close to the River Niger. It varies between massive to foliated quartzite (Fig. 5). The massive types of quartzite are not well enriched in muscovite compared with the foliated quartzite. They are probably thought to be produced by regional metamorphism of sandstones during Orogenic activities (Okonkwo, 1992). The foliation planes dip toward the west. Micro-folds are observed on the massive quartzite and the joints trend NW-SE direction.

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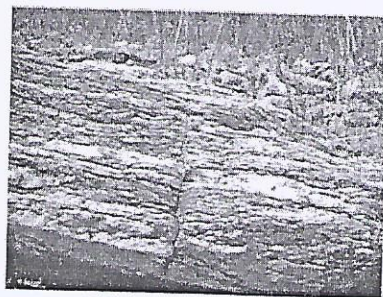


Figure 5: Field photograph showing Foliation of quartzite in south west Jebba, joint cuts across the foliation trend. ($9^{\circ}7'30''\text{N}$; $4^{\circ}49'0''\text{E}$)

In thin section, the rock contains quartz (90 %) which is colourless under plane polarized light and also exhibits itself as euhedral prismatic crystals. Trace of muscovite is also observed with modal composition of 9 %. The photomicrograph is presented in Fig. 8. The SiO_2 content ranges from 78.22 – 97.6 %, Al_2O_3 ranges from 0.25 – 11.75 %, Fe_2O_3 ranges from 1.18 – 2.06 % and MgO varies from 0.02 – 0.71 %. Others major oxides like CaO varies from 0.04 to 0.33 %, Na_2O varies from 0.02 to 4.67 %, K_2O varies from 0.06 to 2.4 %, TiO_2 ranges from 0.01 to 0.18 %, P_2O_5 ranges from 0.02 to 0.08 % and Cr_2O_3 ranges from 0.02 to 0.003 %. Only MnO is below detection limit of 0.01 %. The relatively high values of silica in the rock samples are characteristic of quartzite. The geochemical data of the analyzed rock samples in the study area is presented in Table 2. The descriptive statistics of the trace elements is presented in Table 3. Ba, Rb, Sr and Pb range from 30 to 645 ppm, 2.2 to 52.9 ppm, 3.8 to 148.1 ppm and 0.5 to 1.4 ppm respectively. The values obtained are less than those obtained for granitic rocks. In terms of relative enrichment Pb, Rb and Sr indicate low enrichment except Ba that has an average value of unity and may probably decrease their contributions to the water phase during weathering and dissolution. Fig. 9 illustrates the UCC-normalized averages in trace element concentrations in the quartzite of the study area. The concentrations of the rare elements are presented in Table 4. The average values of almost all the elements in quartzite are relatively less than their corresponding elements in the granitic rocks. Consequently, they have low enrichment values. The relative loss of the less mobile elements such as Nb and Y suggested that samples had undergone some early metamorphism or deformation to some extent. Fig. 9 illustrates the UCC-normalized averages in rare earth element concentrations in the quartzite of the study area.

Schist

The schist in the study area is a highly massive weathered outcrop with different joints. Schist is formed in the area due to constant high temperature of rock during metamorphism. They composed of visible platy pattern with mineral alignments

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trending NW – SE direction. The schists are leucocratic quartz mica schist in which white bands is alternating the grayish ones. The schist also contains thin, more siliceous bands possibly to be a reflection of original sedimentary grading (Okonkwo, 1992). Biotite schists are also identified on the field. Pinch and swell structures were observed on the quartz-mica schist which cut cross joint and asymmetric folds (Fig. 6). Joints trend NW-SE and the dip of foliation planes is toward the west.

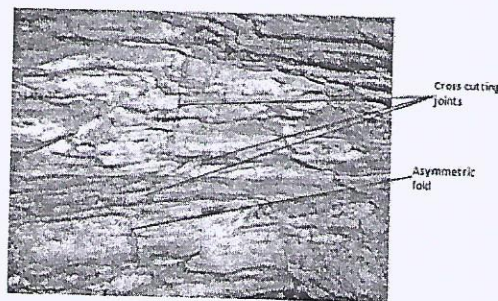


Figure 6: Field photograph of Pinch and swell structure on quartz-mica schist. Note also the cross-cutting joint as well as an asymmetric fold. ($9^{\circ}7'28''N$; $4^{\circ}50'12''E$)

Thin sections were prepared and examined under the petrographic microscope to determine the mineralogical compositions of the biotite schist/schist. The following minerals were observed: Quartz (32 %), plagioclase (26 %), microcline (27 %) and biotite (12 %). The biotite schist (sample BL10) is impoverished in silica (53.75 wt %) but enriched in Al_2O_3 , Fe_2O_3 , MgO and CaO which is consistent with mafic characteristics. The low value in silica content is compensated by its enrichment in TiO_2 (2.02 wt %). The TiO_2 content is low in all the samples, generally < 1 wt %. However, some samples in granite-gneiss, schists and biotite-schist are relatively richer in TiO_2 with levels > 1 wt %. Titanium is believed to be associated with mica and feldspar groups of minerals and its level could be attributed to the presence of these minerals (mica and feldspar groups of minerals) in the rocks. Other sources of Ti are from minerals where it can substitute for Al, Mg or Fe (Deer et al, 1996; Pelig-Ba, 2012). Some of the schist and biotite schist samples have higher percentage of CaO and MgO contents up to 4.88 and 2.5 wt % respectively suggesting the availability of mafic minerals.

The results of geochemical analysis and the statistics of the trace elements are presented in Table 4.3. Ba, Co, Cs, Ga, Hf, Nb, Sn, Sr, Ta, U, V, Zr, Mo, Cu, Pb, Zn, Ni, As, Au and Tl were detected in the geochemical analysis of the meta-sedimentary rocks. However, Be, W, Cd, Sb, Bi, Ag, Hg and Se are below detection limits. The relatively high value of Rb reflects an evidence of plagioclase minerals in the samples. On the basis of enrichment value, Zr, Sn, Rb, Hf and Ba are enriched in

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relation to their respective average compositions in the earth crust. Others are less enriched. The enrichment of Ba, Zr, Sn, Rb and Hf may constitute their solubility in the water phase during weathering of the rocks thereby increasing their natural composition in water phase. Fig. 9 illustrates the UCC-normalized averages in trace element concentrations in the schist of the study area. The Rare elements detected in Biotite schist/schist are: Th, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. Their respective concentrations and statistics are presented in Table 4. Based on the enrichment values, Dy, Ho, Pr and Th are depleted and others are enriched. They could therefore contribute to their respective concentration in the water phase during weathering and dissolution. Fig. 10 illustrates the UCC-normalized averages in rare earth element concentrations in the schist of the study area.

Granite

Granite occurs in the northeastern and northwestern part of the study area (Jebba North). It occurs as high-rising exfoliated and rounded bodies usually called inselbergs or small low-lying exposures. The rock is medium to coarse grained and mesoporphyritic in texture (Fig. 7). The outcrops have sharp contacts with the surrounding metamorphic rocks and the pegmatitic and quartz veins found within them. The width of the veins ranges from about 4 cm to 7 cm and they mainly trend NE-SW. In outcrops, the rock is leucocratic to mesocratic, depending on the ferromagnesian contents.

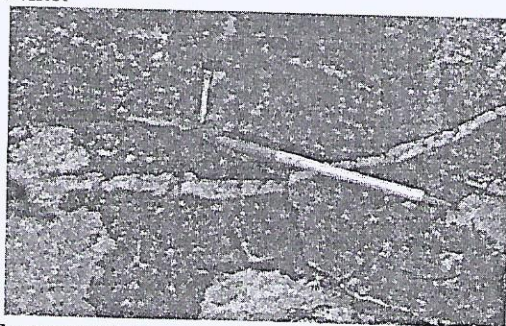


Figure7: Field photograph showing Porphyritic granite and pegmatitic vein
(9°8'30''N; 4°49'30''E)

The following minerals were identified: quartz, plagioclase, microcline, biotite, chlorite, scolecite and epidote. The modal composition of the minerals under the petrographic microscope indicates the percentages of the minerals as follows: quartz (25 %), plagioclase (10 %), microcline (40 %), biotite (14 %), chlorite (5 %), scolecite (2) and epidote (3). The photomicrograph and modal compositions of the minerals observed are presented in Figure 8 and Table 1 respectively.

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The concentrations and the statistics summary of the major oxides in the granite rock samples of the study area are presented in Table 2. The SiO_2 content of granite varies from 60.07 – 72.58 wt % (Average, 67 wt %). This denotes that majority of the granite rocks may be classified as felsic igneous rock. Al_2O_3 ranges from 14.76 – 17.48 wt %, Fe_2O_3 from 0.04 – 2.95 wt %, CaO from 1.02 – 5.2 wt %, Na_2O from 3.22 – 5.27 wt % and K_2O from 3.4 – 6 wt %. Others like TiO_2 vary from 0.03 – 0.74 wt %, P_2O_5 from 0.02 – 0.31 wt % MnO from 0.04 to 0.09 wt % and Cr_2O_3 from 0.02 to 0.03 wt %. $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio ranges from 0.6 – 1.5 which reflects almost the same compositions of potassium bearing rock forming silicate (Alkali feldspar – microcline) and sodium rock forming silicate (plagioclase feldspar – Albite) in the granite (Oyinloye, 2011). The trace elements in the granite samples are presented in Table 3. Ba, Rb and Sr ranged from 130 to 3056 ppm, 48.2 to 238 ppm and 145.7 to 1635.8 ppm respectively. The average values of Ba and Sr in granite is higher than those of granite-gneiss but the concentration of Rb is less in granite than in granite-gneiss. This is due to the fact that the rocks have undergone some early metamorphism or deformation to some extent. In terms of relative enrichment values, Ba, Rb and Sr are highly enriched having values greater than unity (> 1). Certain degrees of these elements are dissociated into the water phase thereby increasing their respective concentration. More important is lead, having a concentration of range of 2.2 to 41 ppm and enrichment of 1.3. The granitic rock could contribute part of the Pb concentrate into water phase during weathering. In general, about 50% of the elements show high enrichment in granite elements. Fig.9 illustrates the UCC-normalized averages of trace element concentrations in the granite of the study area. The statistics of the rare elements are presented in Table 4. Th, Y and Ce ranged from 0.5 to 12.1 ppm, 4.7 to 17.4 ppm and 6.4 to 39.4 ppm respectively. The average values obtained are lower than those obtained in granite-gneiss. On the basis of enrichment value, the rare elements are less enriched in granite (Table 5). Fig. 10 illustrates the UCC-normalized averages of rare earth element concentrations in the granite of the study area.

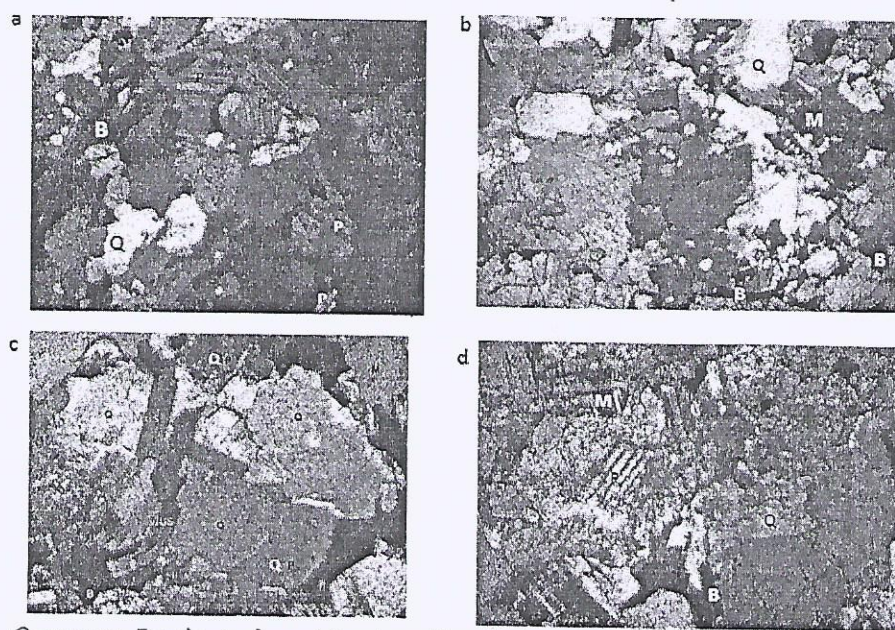
Weathering Indications

These are determined in this research using Chemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA) and Chemical Index of Weathering (CIW) as suggested by Nesson and Young (1982). The CIA, PIA and CIW are calculated using the molecular proportions as follows; $\text{CIA} = [\text{Al}_2\text{O}_3 * 100 / (\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})]$, $\text{PIA} = (\text{Al}_2\text{O}_3 - \text{K}_2\text{O}) / (\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O} - \text{K}_2\text{O}) * 100$ and $\text{CIW} = (\text{Al}_2\text{O}_3 / (\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O})) * 100$. The CaO content was assumed to be derived from silicate fraction since carbonate and apatite were negligible. Fresh rocks or minerals such as albite, anorthite or K-feldspars have CIA up to 50%, fresh basalts have between 30 and 45% while granite and granodiorites range from 45 to 55% and fresh muscovite having values up to 75%. Clay minerals which are weathered products of fresh rocks have higher values, illites and

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montmorillonites have a range from 75 to 85%, kaolinites have up to 100% (Nessbitt and Young, 1982). These values suggest that the higher the CIA value the more weathered the rock. The CIA values obtained in this study for granite-gneiss, granite, quartzite and biotite schist/schist range from 52.7 to 70 % (average=59.2 %), 57 to 59.3 % (average, 58.4 %), 61.4 to 74.1 % (average, 61.36 %) and 51 to 63.7 % (average, 57.9 %) respectively (Table 4.6). The PIA values computed for granite-gneiss, granite, quartzite and biotite schist/schist range from 52.9 – 76.4 % (average, 65 %), 61.9 – 64.6 % (average, 62.9 %), 65.2 – 98.6 % (average, 79.9 %) and 51.6 – 68.3 % (average, 61.4 %) respectively Table 4.2. Similarly, the CIW values calculated for granite-gneiss, granite, quartzite and biotite schist/schist varied from 55 – 79.6 % (average, 72.8 %), 67.6 – 72.5 % (average, 70.6 %), 70.1 – 99.1 % (average, 83.3 %) and 52.6 – 76.2 % (average, 66.4 %) respectively.

Quartzite has the highest average value of CIA, PIA and CIW while Schist/biotite schist has the lowest. This shows that quartzite has highest degree of weathering. Hence, there is contribution of weathering of some minerals in the water phase of the study area.



Q=quartz, P=plagioclase, M=microcline, B=biotite, Mus=muscovite, C=chlorite, S=schist, E=epidote

Figure 8: Photomicrograph of (a) granite gneiss, (b) granite (c) quartzite and (d) schist

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Table 1: Average modal analysis of mineralogical compositions of the crystalline rocks in the study area

Minerals (%)	Granite-gneiss	Granite	Quartzite	Schist
Quartz	24	25	90	32
Plagioclase	31	10	-	26
Microcline	-	40	-	27
Biotite	35	14	-	12
Muscovite	-	-	9	-
Chlorite	7	5	-	-
Scolecite	-	2	-	-
Epidote	-	3	-	-
Total	97	99	99	97

Table 2: Chemical Compositions of Major Oxides in wt % of analyzed Rock samples in Jebba environs and their weathering indications

Granite-Gneiss														
Sample ID	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	Cr ₂ O ₃	CIA	PIA	CIW
3L3X	63.8	15.35	8.24	2.35	1.81	2.24	2.75	1.11	0.17	0.12	0.04	69.98	76.38	79.65
K112	68.6	14.6	3.22	0.74	1.96	2.57	6.02	0.46	0.12	0.003	0.03	53.05	65.45	76.32
BL4	71.60	12.68	4.19	0.54	1.32	1.99	6.25	0.37	0.09	0.04	0.002	57.01	66.02	79.30
BL9	73.47	11.85	4.66	0.17	0.53	3.60	4.28	0.26	0.04	0.03	<0.002	58.26	64.26	73.79
LP1	48.82	13.73	15.35	5.62	8.94	2.31	1.09	2.02	0.58	0.21	0.011	52.67	52.91	54.96
average	65.314	13.742	7.132	1.884	2.912	3.558	4.078	0.844	0.2	0.0806	0.02075	59.2	65.0	72.8
min	48.82	11.85	3.22	0.17	0.53	1.99	1.09	0.26	0.04	0.003	0.002	52.7	52.9	55.0
max	73.47	15.35	15.35	5.62	8.94	3.68	6.25	0.58	0.21	0.04	0.04	70.0	75.4	79.6
stdev	9.92	1.57	4.97	2.25	3.42	0.66	2.19	0.74	0.22	0.08	0.02	6.4	8.3	10.3
Granite														
Sample ID	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	Cr ₂ O ₃	CIA	PIA	CIW
JN11	60.07	17.48	4.09	0.9	5.2	5.06	5.43	0.27	0.23	0.09	<0.002	52.70	54.01	63.01
JN2	65.81	15.61	4.1	1.22	3.01	4.93	3.73	0.34	0.11	0.07	0.005	57.22	59.94	66.28
JN6	68.93	15.61	2.41	0.52	1.9	4.77	4.76	0.2	0.06	0.04	0.002	57.73	61.93	70.06
JN8	68.03	15.42	3.04	0.65	2.11	4.53	4.82	0.22	0.06	0.05	0.002	57.37	61.48	69.90
JN13	70.21	15.32	2.42	0.59	2.2	5.13	3.4	0.18	0.05	0.05	0.002	58.81	61.92	67.64
KRS	66.22	15.29	2.69	0.64	1.93	4.53	4.8	0.24	0.05	0.06	0.002	57.59	61.89	70.30
R1	66.91	16.97	2.43	0.27	1.58	4.87	6	0.15	0.08	0.06	<0.002	57.68	62.97	72.46
R2	72.56	14.76	1.95	0.04	1.02	5.27	4.07	0.03	0.02	0.04	<0.002	58.76	62.96	70.12
2L19X	61.2	16.35	5.66	2.95	4.62	3.22	3.63	0.74	0.31	0.09	0.03	53.77	61.87	67.59
1L7X	65.7	15.55	3.72	1.6	2.66	3.26	4.74	0.39	0.15	0.07	0.03	59.33	64.61	72.43
average	66.824	15.836	3.251	0.938	2.623	4.557	4.538	0.276	0.11	0.063	0.01	58.4	62.9	70.6
min	60.07	14.76	1.95	0.04	1.02	3.22	3.4	0.03	0.02	0.04	0.002	57.6	61.9	67.6
max	72.56	17.48	5.66	2.95	5.2	5.27	6	0.74	0.31	0.09	0.03	59.3	64.6	72.5
stdev	3.86	0.84	1.13	0.64	1.33	0.73	0.83	0.19	0.09	0.02	0.01	0.8	1.1	2.0
Quartzite														
Sample ID	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	Cr ₂ O ₃	CIA	PIA	CIW
JR35	89.01	5.37	2.06	0.36	0.05	1.83	0.18	0.04	<0.01	0.002	0.002	74.07	98.61	99.08
JR3Q	97.6	0.25	1.77	0.02	0.04	0.02	0.06	0.01	<0.01	<0.002	0.002	67.57	76.00	80.65
R4	78.22	11.75	1.18	0.71	0.33	4.67	2.4	0.14	0.08	<0.01	0.003	61.36	65.16	70.15
average	88.277	5.790	1.670	0.363	0.185	1.580	1.430	0.110	0.047	BDL	0.003	67.7	79.9	83.3
min	78.22	0.25	1.18	0.02	0.04	0.02	0.06	0.01	0.02	0.002	0.003	61.4	65.2	70.1
max	97.6	11.75	2.06	0.71	0.33	4.67	2.4	0.18	0.08	0.003	0.003	74.1	98.6	99.1
stdev	9.711	5.761	0.443	0.345	0.205	2.676	1.220	0.089	0.031	0.001	0.001	6.4	17.1	14.6
Schist and Biotite Schist														
Sample ID	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	Cr ₂ O ₃	CIA	PIA	CIW
AL2	75.52	11.44	3.18	0.78	1.24	2.34	4.46	0.29	0.09	0.03	0.005	56.73	66.10	76.17
AL7	46.66	13.74	17.28	4.55	9.85	2.53	0.52	3.15	0.26	0.26	0.004	51.58	51.64	52.60
AL8	77.27	11.23	2.74	0.93	1.01	3.18	2.21	0.33	0.13	0.02	0.005	63.70	68.23	72.83
BL10	53.75	14.46	14.4	2.5	4.88	3.22	2.5	2.02	0.75	0.15	0.003	57.70	59.62	64.10
average	63.3	12.7175	9.4	2.19	4.245	2.8175	2.4225	1.4475	0.3075	0.115	0.00425	57.9	61.4	66.4
min	46.66	11.23	2.74	0.78	1.01	2.34	0.52	0.29	0.09	0.02	0.003	51.6	51.6	52.6
max	77.27	14.46	17.28	4.55	9.85	3.22	4.46	3.15	0.75	0.26	0.005	63.7	68.3	76.2
stdev	15.412	1.625	7.531	1.755	4.136	0.449	1.615	1.392	0.304	0.113	0.001	5.0	7.5	10.5

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Table 3: Geochemical Results of Trace elements in the crystalline rock of the study area in ppm

Sample ID	Granite-Granite																												
	Ba	Be	Co	Cr	Cu	Hf	Nb	Ni	Sr	Ta	U	V	W	Zr	Mn	Co	Pb	Zn	Ni	As	Cd	Sb	Bi	Ag	Au	Hg	Tl	Se	
303A	426		42.3	7.55	20.9	6.4	117	3	126		2.28	134	146	249	<1	122	24	115	60										
4012	564		17	1.34	20.6	3.6	260	1	231		1.93	34	31	339	<1	5	30	63	8										
501	722	4	55	41	11.3	9.9	17.8	210.2	4	89.1	0.7	2.8	25	0.6	3623	1.4	29.7	12.6	34	75	<0.5	<0.1	<0.1	0.1	<0.1	<0.5	<0.01	0.2	<0.5
502	1145	4	15	1.2	18.7	9.4	13.2	120.4	4	30.1	0.6	1.7	<0.5	376.7	1.6	16.2	15	30	5.8	2.7	<0.1	0.2	0.1	<0.1	<0.5	<0.01	<0.1	<0.5	
171	330	1	45	11	15.9	3.4	7.4	26.2	1	317.7	0.4	0.4	256	<0.5	123.9	0.3	133.4	1.6	51	<0.7	<0.5	<0.1	<0.1	<0.1	<0.1	1.2	<0.01	0.1	<0.5
average	774.0	17	22.5	3.3	17.4	7.7	12.6	145.8	2.8	173.6	0.6	1.6	215.3	79.2	502.7	1.1	65.3	13.9	56.6	24.2	2.7	60.1	0.7	0.3	60.1	1.2	60.1	0.2	60.1
min	512.0	3.0	1.5	1.2	11.3	3.4	7.4	26.2	1.0	89.1	0.4	0.4	130.0	0.6	123.9	0.3	5.0	15	30.0	5.8	2.7	60.1	0.1	0.1	60.1	1.2	60.1	0.1	60.1
max	1145.0	4.0	46.0	7.6	20.9	9.9	17.8	260.0	4.0	331.7	0.8	2.8	256.0	146.0	333.0	1.6	122.0	30.0	115.0	60.0	2.7	60.1	0.2	0.1	60.1	1.2	60.1	0.2	60.1
stdv	333.6	0.6	20.6	2.7	4.1	1.8	5.2	90.8	1.3	105.7	0.2	0.9	113.6	75.4	111.7	0.7	55.6	12.9	34.2	25.0	60.1	0.0	60.1		60.1	0.1	60.1		
Sample ID	Granite																												
	Ba	Be	Co	Cr	Cu	Hf	Nb	Ni	Sr	Ta	U	V	W	Zr	Mn	Co	Pb	Zn	Ni	As	Cd	Sb	Bi	Ag	Au	Hg	Tl	Se	
101	2630	2	4.4	0.7	14	4	11	83.7	3	1655.8	0.6	2	47	<0.5	177.4	0.5	6.5	5.5	6	2	<0.5	<0.1	<0.1	<0.1	<0.1	<0.5	<0.01	<0.1	<0.5
102	2550	4	6.8	0.2	15.1	2.9	5.6	48.2	2	1493.8	0.4	0.3	37	<0.5	121.2	0.8	3.1	2.2	13	5.3	<0.5	<0.1	<0.1	<0.1	<0.1	<0.5	<0.01	<0.1	<0.5
103	2712	3	2.9	1.1	15.3	3.7	5.1	79.7	4	1358.0	0.3	0.3	18	<0.5	150.4	0.5	7.1	4	10	3.5	<0.5	<0.1	<0.1	<0.1	<0.1	0.7	<0.01	<0.1	<0.5
104	2756	1	5.8	1	15.2	3.5	6.6	95.4	2	1190.1	0.4	0.7	23	<0.5	138.2	0.8	21.7	5.6	13	12.5	<0.5	<0.1	<0.1	<0.1	<0.1	<0.5	<0.01	<0.1	<0.5
1013	1631	<1	3.2	0.5	15	2.8	4.3	56.4	2	1252.3	0.2	2	17	<0.5	108.9	0.5	7.3	3.8	11	3.1	<0.5	<0.1	<0.1	<0.1	<0.1	<0.5	<0.01	<0.1	<0.5
105	3656	3	4.6	0.8	15.6	3.6	7.6	86.9	1	1384	0.5	0.5	24	<0.5	131	0.4	4.4	4.1	8	5.1	<0.5	<0.1	<0.1	<0.1	<0.1	<0.5	<0.01	<0.1	<0.5
11	1476	4	2.4	1.5	17.5	3	3.3	140.0	<1	626.5	0.6	1.2	16	<0.5	96.7	0.5	7.1	16.7	16	3.2	<0.5	<0.1	<0.1	<0.1	<0.1	1.4	<0.01	<0.1	<0.5
12	130	3	0.6	2.3	12.9	4	6.1	113.9	1	145.7	0.4	1.7	<0.5	74.1	0.9	9.3	15.4	25	3.3	<0.5	<0.1	<0.1	<0.1	<0.1	<0.5	<0.01	<0.1	<0.5	
1135A	2070		30.9	13.7	30.6	6.2	124	2	922		1.26	101	174	266	<1	8	28	78	24	50.1	59.0	60.1	60.1	<0.1	60.1	60.1	60.1	60.1	
113A	1735		29.5	18.7	19.8	5.4	238	4	693		1.82	58	139	197	<1	6	41	36	24	60.1	60.1	60.1	60.1	<0.1	60.1	60.1	60.1	60.1	
average	2098.8	3.7	8.2	4.1	16.9	3.9	7.1	112.6	2.3	1655.7	0.4	1.2	37.9	101.5	145.0	0.6	6.7	12.6	21.5	8.4	60.1	60.1	60.1	60.1	0.9	60.1	60.1	60.1	
min	130.0	1.0	0.6	0.2	13.3	2.8	4.3	48.2	1.0	145.7	0.2	0.3	16.0	108.0	74.1	0.4	4.4	2.2	6.0	2.0	60.1	60.1	60.1	60.1	0.7	60.1	60.1	60.1	
max	3656.0	4.0	30.9	18.7	22.9	6.2	11.0	260.0	4.0	1655.8	0.6	2.0	171.0	166.0	266.0	0.9	21.7	41.0	78.0	24.0	60.1	60.1	60.1	60.1	1.4	60.1	60.1	60.1	
stdv	557.6	2.6	9.7	6.3	3.2	1.1	2.2	58.3	1.1	452.2	0.1	0.7	27.8	6.7	56.1	0.2	4.8	12.9	21.7	8.7	60.1	60.1	60.1	60.1	0.4	60.1	60.1	60.1	
Sample ID	Quartzite																												
	Ba	Be	Co	Cr	Cu	Hf	Nb	Ni	Sr	Ta	U	V	W	Zr	Mn	Co	Pb	Zn	Ni	As	Cd	Sb	Bi	Ag	Au	Hg	Tl	Se	
1055	547	2	1.5	1.1	8.5	4.3	3.9	52.9	<1	21.8	0.4	1	15	2.1	153.2	0.6	6.8	1.4	1	2.2	<0.5	<0.1	<0.1	<0.1	<0.1	1.1	<0.01	<0.1	<0.5
1060	33	<1	0.6	<0.1	3.4	0.4	0.6	2.2	<1	3.8	<0.1	0.2	<0.5	14.7	1.1	21.5	2.7	2	3.5	0.7	<0.1	<0.1	<0.1	<0.1	0.6	<0.01	<0.1	<0.5	
14	645	1	3.9	0.5	7.4	2.4	2.8	52.5	<1	148.1	0.2	0.7	<0.5	86.5	0.5	3.5	0.5	5	9.9	<0.5	<0.1	<0.1	<0.1	<0.1	1	<0.01	0.1	<0.5	
average	429.3	2.0	2.0	0.8	6.4	2.4	2.4	35.9	50.1	57.9	0.3	0.6	15.0	2.1	90.5	0.7	7.9	2.3	2.7	3.2	0.7	60.1	60.1	60.1	60.1	0.9	60.1	60.1	60.1
min	30.0	2.0	0.6	0.5	3.4	0.4	0.6	2.2	3.8	0.2	0.2	15.0	1.1	14.7	0.5	3.5	0.5	1.0	2.2	0.7	60.1	60.1	60.1	60.1	0.6	60.1	0.1	60.1	
max	645.0	2.0	3.9	1.1	8.5	4.3	3.9	52.9	148.1	0.4	1.0	15.0	2.1	160.2	1.1	116.5	1.4	5.0	9.9	0.7	60.1	60.1	60.1	60.1	1.1	60.1	0.1	60.1	
stdv	330.4	0.0	1.7	0.4	2.7	2.0	1.7	22.2	70.6	0.1	0.4			16.6	0.3	3.2	0.5	2.1	4.1		60.1	60.1	60.1	60.1	0.3	60.1		60.1	
Sample ID	Schist																												
	Ba	Be	Co	Cr	Cu	Hf	Nb	Ni	Sr	Ta	U	V	W	Zr	Mn	Co	Pb	Zn	Ni	As	Cd	Sb	Bi	Ag	Au	Hg	Tl	Se	
112	748	<1	4.5	1.5	11.8	3.3	5.6	108.2	2	187	0.4	0.9	30	<0.5	124.5	1.2	13.2	1.9	21	12.6	0.6	<0.1	0.1	<0.1	<0.1	3.1	<0.01	0.1	<0.5
117	105	<1	47.9	0.2	22.8	4.8	15.3	5.8	3	245.7	0.6	0.9	304	<0.5	158.8	0.7	155.5	1.9	31	9.9	<0.5	<0.1	<0.1	<0.1	0.2	7.4	<0.01	<0.1	<0.5
118	672	<1	5	1.6	10.5	5.1	5.5	67.9	8	148.7	0.5	1.4	19	<0.5	212.6	0.6	6.5	0.8	21	3.6	0.7	<0.1	<0.1	<0.1	<0.1	3.5	<0.01	0.1	<0.5
1110	335	<1	28.5	3.2	20.4	8.5	13	30.4	4	193.5	0.7	1	125	<0.5	349.6	0.5	15.6	3.7	107	20.9	0.6	<0.1	<0.1	<0.1	<0.1	2.7	<0.01	0.1	<0.5
average	605	60.1	21.55	1.625	16.005	5.495	9.85	68.005	4.25	261.975	0.6	0.9	164.75	60.1	116.625	0.75	66.7	14.75	50.25	13.2	0.53333	60.1	0.1	60.1	0.2	4.175	60.1	0.2	60.1
min	125	60.1	4.5	0.2	10.5	3.3	5.6	5.6	2	148.7	0.4	0.3	19	60.1	124.5	0.5	6.5	0.8	21	9.9	0.6	60.1	0.1	60.1	0.2	2.7	60.1	0.1	60.1
max	115	60.1	47.9	3.2	22.8	8.5	15.3	108.2	8	483.5	0.8	1.4	304	60.1	349.6	1.2	225.5	3.8	127	20.9	0.7	60.1	0.1	60.1	0.2	7.4	60.1	0.4	60.1
stdv	345.947	60.1	20.505	1.128	6.45265	2.29502	5.023	44.7944	2.63	145.524	0.19257	0.45461	174.378	60.1	94.3024	0.310291	111.839	1.21789	51.3639	5.23904	0.75774	60.1		60.1	2.17466	60.1	0.17321	60.1	

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Table 5: Enrichment values of trace and rare elements in rock samples of the study area

Element	Abundance in Earth Crust (ppm)	Trace Elements			
		Enrichment			
		Granite-Gneiss	Granite	Quartzite	Schist/Biotite-schist
Ag		BDL	BDL	BDL	BDL
As	2.1	1.3	BDL	0.3	0.3
Au	0.0031	387.1	301.1	290.3	1346.8
Ba	425	1.7	4.9	1.0	1.4
Be	1.9	1.4	BDL	BDL	BDL
Bi	0.025	4.0	BDL	BDL	BDL
Cd	-	BDL	BDL	BDL	BDL
Co	30	0.7	0.3	0.1	0.7
Cs	1.9	1.7	2.1	0.4	0.9
Cu	68	0.8	0.1	0.1	1.0
Ga	19	0.9	0.9	0.3	0.8
Hf	3.3	2.3	1.2	0.7	1.6
Hg	-	BDL	BDL	BDL	BDL
Mo	1.1	1.0	0.6	0.7	0.7
Nb	17	0.8	0.3	0.1	0.6
Ni	90	0.3	0.1	0.1	0.1
Pb	10	1.4	1.3	0.1	0.1
Rb	60	2.4	1.9	0.6	1.1
Sb	0.2	1.0	BDL	BDL	0.5
Se	-	BDL	BDL	BDL	BDL
Sn	2.2	1.3	1.1	BDL	1.9
Sr	360	0.5	3.0	0.2	0.7
Ta	1.7	0.4	0.3	0.2	0.4
Tl	0.53	0.3	BDL	0.2	0.4
U	1.8	1.0	0.7	0.4	0.5
V	190	0.6	0.2	0.1	0.9
W	1.1	72.0	94.1	1.9	BDL
Zn	79	0.7	0.3	0.0	0.6
Zr	130	2.3	1.1	0.7	1.7

BDL= below detection limit

Element	Abundance in Earth Crust (ppm)	Rare Elements			
		Enrichment			
		Granite-Gneiss	Granite	Quartzite	Schist/biotite schist
Ce	60	1.9	0.5	0.6	1.2
Dy	6.2	1.0	0.2	0.2	0.9
Er	3	1.3	0.3	0.3	1.1
Eu	1.8	1.0	0.3	0.2	1.0
Gd	5.2	1.4	0.3	0.3	1.2
Ho	1.2	1.2	0.2	0.2	0.9
La	34	1.7	0.4	0.4	1.0
Nd	33	1.4	0.3	0.3	1.0
Pr	8.7	1.4	0.4	0.3	1.0
Sm	6	1.3	0.3	0.3	1.1
Tb	0.94	1.2	0.3	0.2	1.0
Th	6	5.6	0.8	0.6	0.7
Tm	0.45	1.3	0.3	0.2	1.0
Y	29	1.1	0.3	0.3	1.0
Yb	2.8	1.1	0.3	0.3	1.0

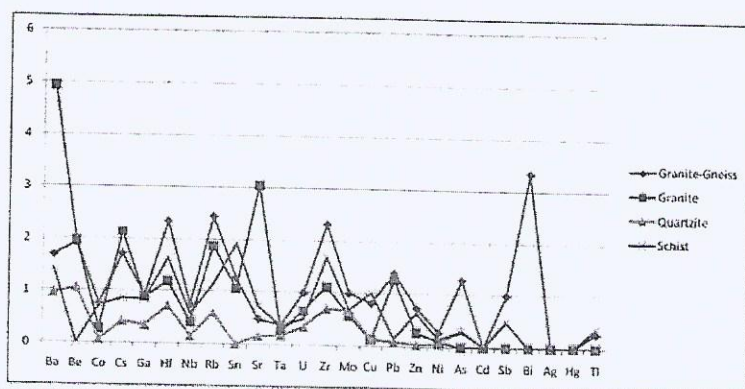


Figure 9: UCC-normalized averages of trace element concentrations for crystalline rocks in the study area (after Taylor and McLennan, 1985)

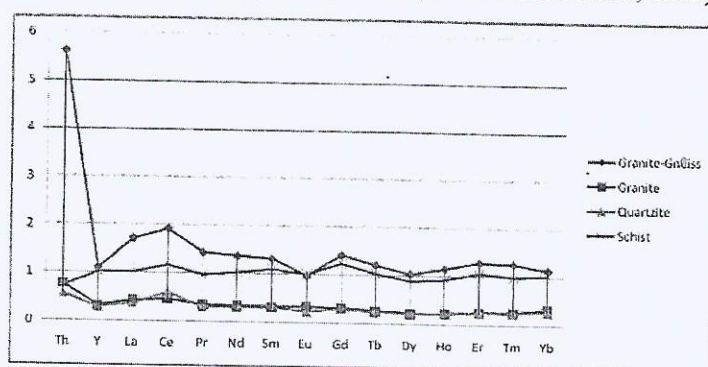


Figure 10: UCC-normalized averages of rare earth element concentrations for crystalline rocks in the study area (after Taylor and McLennan, 1985)

Conclusions

The petrological and geochemical characteristics of rocks in Jebba area were investigated in this study. Porphyritic granite, granite gneiss, quartzite and schist are the main rock types in the study area. The petrographic analysis of the rock samples revealed the main minerals constituent common to the rocks as quartz (modal composition=24% for granite-gneiss, 25% for granite, 90% for quartzite and 32% for schist), plagioclase (modal composition=31% for granite-gneiss, 10% for granite and 26% for schist), microcline (modal composition=40% for granite and 27% for schist) and biotite (modal composition=35% for granite-gneiss, 14% for granite and 12% for schist). Others include: muscovite, chlorite, scapolite and epidote. The rocks have undergone moderate to high degree of chemical weathering as revealed by the values computed for chemical index of alteration, plagioclase index of alteration and chemical index of weathering. This has direct influence on the water found around

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the vicinity of the country rocks. While Au, Ba and W are enriched in granite others trace elements are depleted. Also, Zr, Sn, Rb, Hf, Cu, Ba and Au are enriched in biotite schist/schist. The rare earth elements are enriched in granite-gneiss and schist/biotite schist but are generally depleted in granite and quartzite.

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