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RESEARCH ARTICLE

Petrochemistry of Phyllites from Patharkhola, Lesser Kumaun Himalaya with Reference to Tectonic Implications

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ABSTRACT

Phyllites from Patharkhola, Lesser Kumaun Himalaya have been studied to investigate the geochemical characteristics of these rocks and their formation processes and mechanism of emplacement. Petrographically, phyllites have been showing the mineral assemblages as Biotite (25% approx.)-chlorite (25% approx.)-muscovite (20% approx.)-quartz (10% approx.)-feldspar (10% approx.)-sericite (5% approx.). Geochemically, the analysed four samples of phyllites have high SiO_2 and Al_2O_3 values. Phyllites with higher alumina have more enrichment of trace elements. The enrichment of Zr and depletion of Y and Nb indicate preferential survival of zircon in extreme weathering conditions. The HFSE has shown variation in the ratios due to decoupling with the major oxides. The enrichment of LREE and depletion of HREE suggest mixing of the terrigenous sediments with the concominant magma. Discrimination plots to classify the tectonic settings suggested that the phyllites of Patharkhola have formed in active continental margins.

1. Introduction

The Himalaya, arc-shaped mountain belt covering the whole boundary of northern India is an example of an intercontinental collision between Indian and Asian plates around 55 Ma ago [1-7]. The structure, stratigraphy and tectonics of the Lesser Kumaun Himalaya have been described by Auden [8], Valdiya [9,10], Thomas & Thomas [11], Thomas & Thomas [12], Joshi et al. [13], Joshi et al. [14], Rana and Thomas [15]. The Almora group of rocks forms a part of the Lesser Himalayas bounded by North and South Almora thrust [9]. Almora Crystallines are disposed of in the form of a broad asymmetrical synformal nappe with its axis trending in NW-SE direction plunging due, south east. These comprise chiefly metamorphic derivatives of pelitic, semi-pelitic and psammitic sediments. The area of investigation, around Patharkhola, District Almora, forms the southern limb of Almora Crystallines [15-17] lying between longitude 79°09'E to 79°17'56"E and latitude 29°47'42"N to 29°56'69"N with an approximate area of around 120 square kilometres (Figure 1). The main rock types exposed in the area are gneisses, schists and phyllites. In this paper, the authors discuss the geochemical characteristics of phyllites to understand their process of formation.

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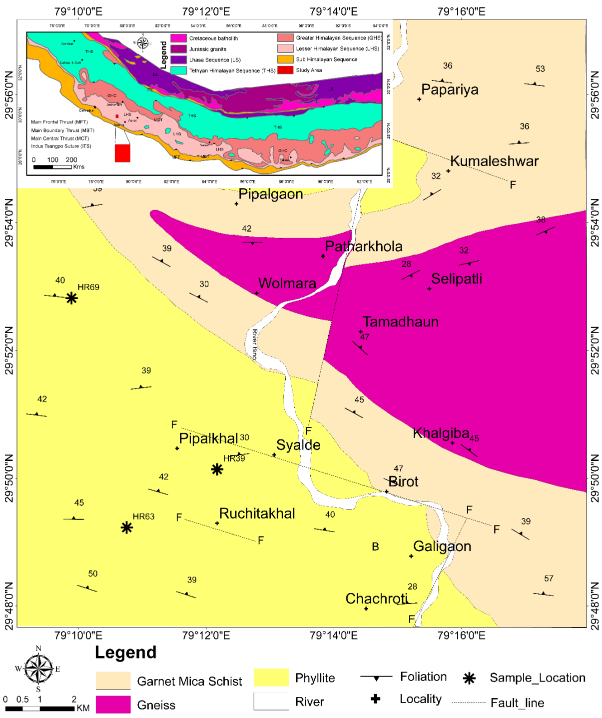

Figure 1. Detailed geological map around Patharkhola Kumaun Lesser Himalaya Uttarakhand India modified after Thomas and Thomas (2003) [12].

2. Geological Setting

In the Kumaun region, the Lesser Himalayan sequence is delineated by MCT from the Higher Himalayan in the north and by MBT from the Siwaliks in the south [18]. The Almora group of rocks forming the largest nappe dominantly consists of metapelites and meta-psammite. The sequence of these rocks has shown amphibolite grade of metamorphism [19] with maximum P-T estimates as 575 °C and 8 kbar. These metapelitic rocks are considered to be of Precambrian age [1,16,20]. In Kumaun Himalaya, the Munsiyari gneisses of Almora Group were dated 1830 ± 200 Ma. Old [21] by Rb/Sr isotopic data. Islam et al. [22] proposed Proterozoic granitoids of Lesser Himalaya be grouped into older clusters of 2200–1800 Ma and younger clusters of 1400–1200 Ma age. Kohn et al. [23] proposed a U-Pb zircon age of 1830 ± 50 Ma for the Paleoproterozoic edge arc of Lesser Himalayas. Mandal et al. [24] dated biotite augen gneiss for U-Pb zircon date as 1878 ± 2.4 Ma. The metamorphic terrain of Lesser Himalayas exhibits multiple deformation patterns and polyphase metamorphism [25], which is well exposed in the central part of Almora nappe. Phyllites are widely distributed in the area under investigation (Figure 1); exposed in the NW, S to SW and in the western part of the area. The phyllites are grey, greenish grey, brownish and greyish green and at places become compact and siliceous. At a few places, phyllites show more increase in the silica content giving a quartzitic appearance to these phyllites. The phyllites are composed of chlorite, mica, quartz and feldspar. At some localities, these phyllites exhibit iron enrichment or chlorite knots too. The phyllites are characterised by well-developed schistosity (S_2). At some localities, the colour bands in siliceous phyllites show bedding planes (S_1). Best exposures of crushed phyllites can be observed near villages Ruchiakhal, Syalde and Deghat. Phyllites of the area are highly folded [12]. Fold structures such as gentle folds, asymmetrical folds and chevron folds are well exposed at several places and can be easily seen on the motor road leading to Udaipur around Chachroti, Galigaon, Kueta and from Ruchaikhal to Pipalkhal. At a few localities, ptygmatic folds are also found associated with the quartz vein intruded in phyllites. Phyllites showing asymmetrical folds are exposed along the road to Ruchaikhal village (Figure 2). Chevron folds are commonly observed in this rock type (Figure 3). The phyllites of the area under investigation show a strike of WNW-ESE dipping towards the northern directions.

Figure 2. Asymmetrical fold developed in phyllite. Location Ruchiakhal Village.

Figure 3. Chevron fold exposed in phyllite. Location Ruchiakhal road.

3. Petrography

The dominant mineral assemblage of phyllites is biotite (25% approx.)-chlorite (25% approx.)-muscovite (20% approx.)-quartz (10% approx.)-feldspar (10% approx.)-sericite (5% approx.) along with ilmenite and magnetite as accessories. The preferred orientation of chlorite and micas defines the well-developed schistosity. Elongated grains of quartz and feldspar run parallel to the schistosity planes.

Chlorite shows yellowish green to light green pleochroism, first order interference colour is usually observed occurring as tiny specks which are fibrous in nature. It shows preferred orientation marking the schistosity along with the mica minerals. Two variants of muscovite have been distinguished based on the grain size and grain relationship with other minerals. Muscovite I show preferred orientation marking the schistosity along with the biotite and chlorite grains. Muscovite II showing angular relationship with the other mica grains has been observed due to the rock heterogeneities as feldspar and quartz have high strength behaviour as compared to phylosillicate, due to which some of the mica grains have rotated during the deformation process. Biotite based on mutual relationship and relation with schistosity, two different variants have been recognized. Biotite I along with muscovite I and chlorite grains defines the schistosity (Figures 4–6).

Quartz usually fine grained occurs with feldspar and biotite grains aligned parallel to the schistosity plane. Recrystallized quartz showing wavy extinction and inclusions of sericite and chlorite is observed at a few places.

Feldspar, both orthoclase and plagioclase feldspar is observed. Plagioclase feldspar mostly albite to oligoclase is observed to have anorthite content as An_{06} to An_{12}, measured during the microscopic study. At most of the places, both feldspars are showing alteration towards sericitization.

Sericite usually occurs as alteration products in feldspar (both orthoclase and plagioclase) along with in some grains of quartz.

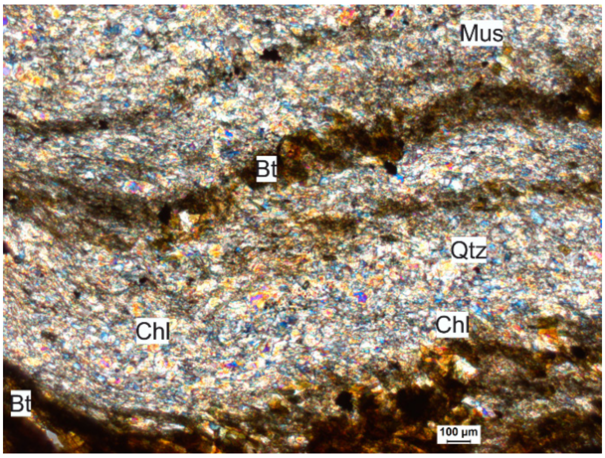

Figure 4. Mineral association of biotite, chlorite, muscovite and quartz in phyllite (HR39) under cross nicol. (Abbreviations are after Whitney and Evans, 2010) [26].

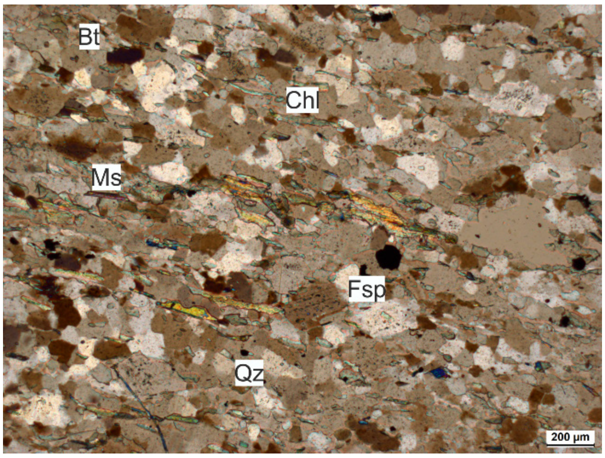

Figure 5. Phyllite (HR63) shows a mineral assemblage of biotite, muscovite, chlorite, feldspar and quartz (Abbreviations are after Whitney and Evans, 2010) [26].

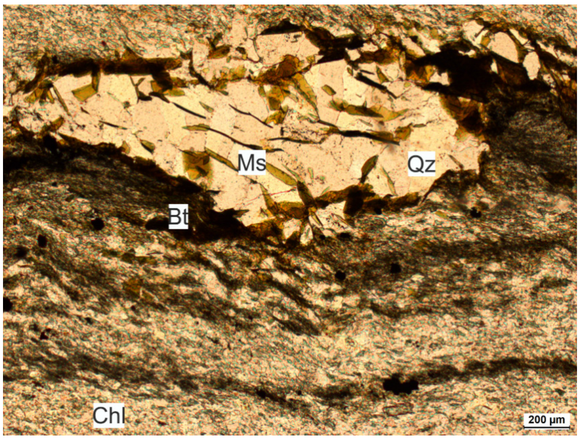

Figure 6. Phyliite (HR92) shows a mineral assemblage of chlorite, biotite, muscovite and quartz (Abbreviations after Whitney and Evans, 2010) [26].

4. Geochemistry and Petrogenesis

Four samples of phyllites analyzed by X-ray fluorescence method (XRF) and Inductively Coupled Plasma-mass Spectrometry (ICP-MS) method, respectively, at the Wadia Institute of Himalayan Geology, Dehradun are tabulated in Table 1.

The SiO_2 and Al_2O_3 content varies from 65.81 to 79.9% and from 10.13 to 16.82%, respectively. The FeO^T content varies from 3.15 to 10.97%. The average Na_2O and K_2O content in the phyllites is 3.38% and 3.25%, respectively. The average K_2O/Na_2O ratio of these rocks is 0.96 which is usually four times less than the mean value of PAAS standard [27]. TiO_2 content of the rocks varies from 0.13 to 0.83%, respectively. The K_2O/Al_2O_3 ratio is higher as compared to the Na_2O/Al_2O_3 ratio, clearly differentiated from igneous rocks [28] (Figure 7). Even though metamorphism may alter the original chemistry, changes are themselves related to plate tectonic environments and bulk composition should still reflect the tectonic settings. K and Na being mobile are easily affected by low grade metamorphism, but phyllites being dominantly composed of biotite along with a subordinate amount of feldspar compensate for K and Na in the system. It is evident that all samples fall within the field specified for sedimentary rock. Figure 8 [29] shows that the phyllites dominantly fall in the wacke-arkose field with higher SiO_2/Al_2O_3 ratio as compared to Fe_2O_3/K_2O. The plots between SiO_2 versus

Table 1. Major oxides, REE, trace elements and CIPW norm of phyllites.

Sample No.	HR69	HR39	HR63	HR97	Sample No.	HR69	HR39	HR63	HR97
					Trace elements				
SiO_2	73.41	65.81	79.9	73.79	**Sc**	2	8	3	11
Al_2O_3	15.85	16.82	10.13	12.3	**V**	9	59	11	42
Fe_2O_3	1.67	4.69	1.77	5.28	**Cr**	219	199	474	2605
FeO	1.48	4.17	1.57	5.69	**Co**	128	45	443	343
MnO	0.04	0.07	0.01	0.08	**Ni**	175	132	398	2227
MgO	0.2	1.13	0.12	0.8	**Cu**	4	28	19	37
Cao	0.57	0.69	0.22	0.58	**Zn**	49	87	12	51
Na_2O	3.59	2.74	4.23	2.98	**Ga**	15	19	4	10
K_2O	4.64	3.44	2.13	2.8	**Rb**	350	136	65	116
TiO_2	0.13	0.69	0.24	0.83	**Sr**	69	82	87	95
P_2O_5	0.26	0.04	0.03	0.03	**Y**	34	36	18	28
Total	101.84	100.29	100.35	105.16	**Zr**	50	367	133	511
FeO/MgO	7.4	3.69	13.083	7.112	**Nb**	14	21	4	17
K_2O/Na_2O	1.292	1.255	0.503	0.939	**Ba**	173	737	498	649
Na_2O/Al_2O_3	0.226	0.162	0.417	0.242	**Pb**	36	21	11	18
Rare Earth Elements					**Th**	4	24	8	25
La	12.413	76.69	21.965	102.22	**U**	BDL	6.6	BDL	2.8
Ce	21.874	146.17	55.35	178.17					
Er	1.575	8.263	1.758	4.72					
Tm	0.22	1.214	0.277	0.694					
Yb	1.32	7.71	1.723	4.31					
Lu	0.18	1.04	0.24	0.56					
LREE	58.485	356.902	109.613	419.558					
HREE	9.266	39.208	8.167	23.42					
REE total	67.751	396.11	117.78	442.978					
LREE/HREE	6.311	9.102	13.421	17.914					
La/Eu	17.582	31.0234	22.231	49.429					
Eu/Lu	3.922	2.376	4.116	3.692					

other oxides are shown in Figure 9. The plot of SiO_2 versus Na_2O, CaO, Al_2O_3, MgO and MnO shows regression of more than 0.5. In general, phyllites having Al_2O_3 values of more than 15% show higher trace elements contents. The plot of SiO_2 versus trace elements is shown in Figure 10. The enrichment of Zr and depleted Y, Nb values indicate the preferential survival of zircon in extreme weathering conditions due to the decoupled behaviour of Y and Nb as compared to Zr. Ni and Cr show higher values as compared to PAAS. Co values are ranging from 45 to 343 ppm. The Ni/Co ratio ranges from 0.8 to 6.5 Ni shows a wide range of values with respect to Co whose values are clustered. In terms of ratios of trace elements, variability has been observed as Co/Th is on higher side due to higher values of Co as compared to Th while Sc/Th is on the lower side as the Sc is consistently low as compared to Th. HFSE ratios have shown quite a variability as the Zr/Nb ratio ranges from 3.5 to 33.2 while the Zr/Y ratio shows 1.4 to 18.2. This is due to decoupling of the HFSE in the major oxides.

The REE data of phyllites shows enrichment of LREE and depletion of HREE. The LREE ranges from 58.4 to 419.5 while the HREE ranges from 8.2–39.2. The rare earth data for the selected phyllitic assemblage were normalized to chondrites [30]. Their values are plotted in Figure 11, and it shows slightly steeper to almost flatter light rare earth element (LREE) pattern with La/Eu ratio of 30.06, a relatively flat to a slightly enriched heavy rare earth element (HREE) pattern with Eu/Lu ratio of 3.05.

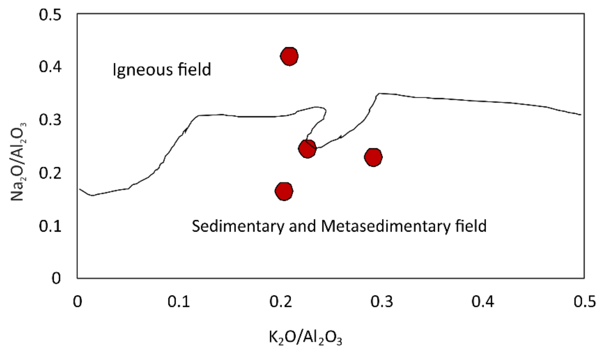

Figure 7. K_2O/Al_2O_3 versus Na_2O/Al_2O_3 after Garrels and Mackenzie (1971) [28].

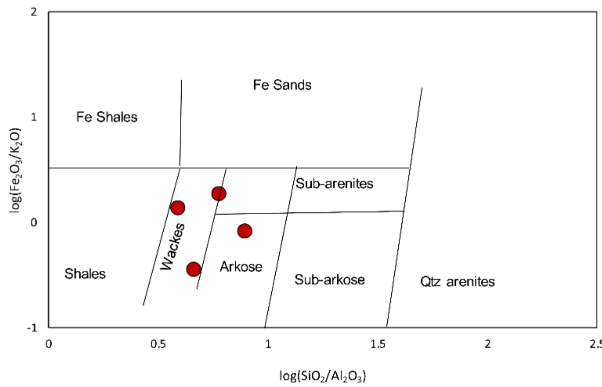

Figure 8. Log (SiO_2/Al_2O_3) versus log (Fe_2O_3/K_2O) after Herron (1988) [29] for classification of terrigenous sediments and shales.

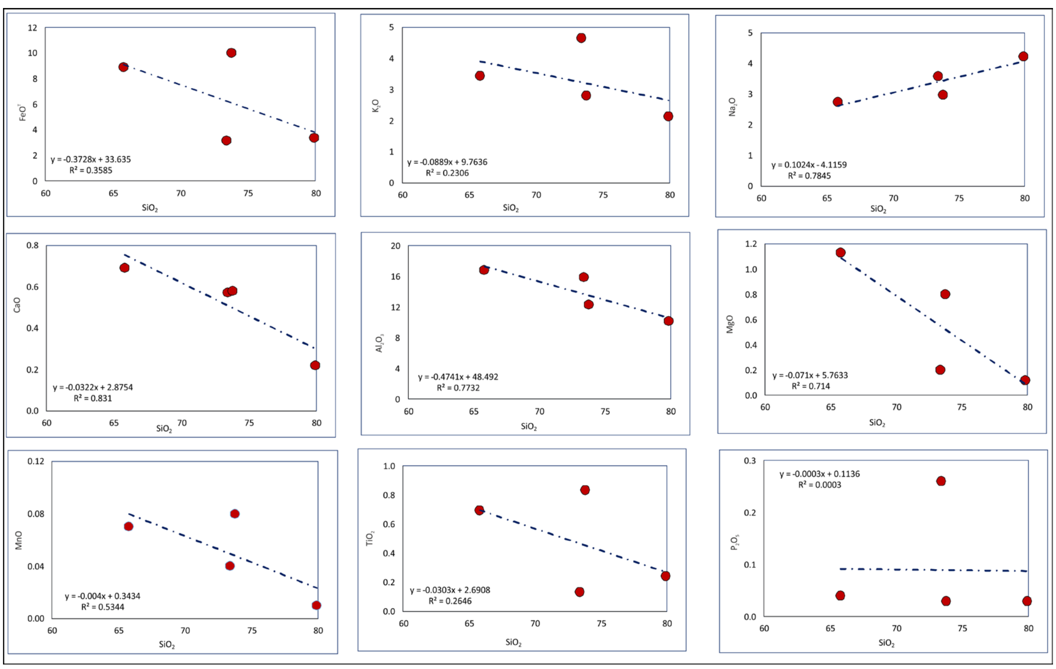

Figure 9. Harker variation diagram of Silica versus major oxides.

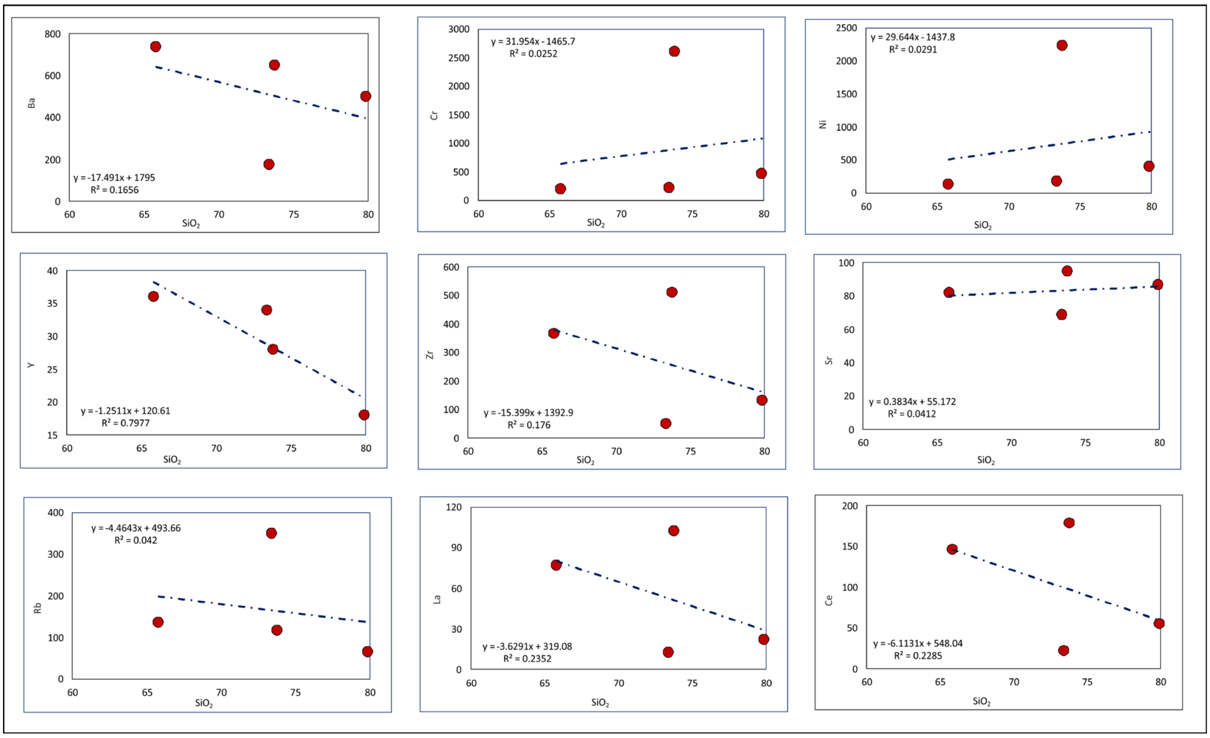

Figure 10. Harker variation diagram of Silica versus trace elements.

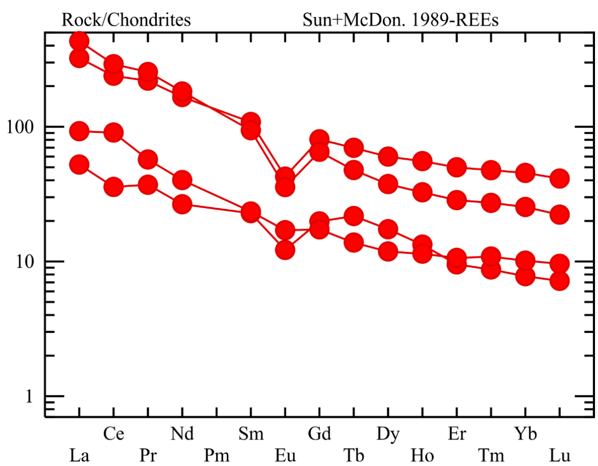

Figure 11. Chondrite normalised plot for Phyllites, Patharkhola, Sun and McDonough, 1989 [30].

5. Tectonic Implications

Studies have traditionally shown that geochemistry plays a crucial role as a sensitive indicator in determining the provenance of sedimentary and metasedimentary rocks and also to constrain the tectonic setting in which they were deposited [31-34]. Trace elements such as Co, Sc, Ni, Zr, Th, La and others are used for tectonic environment discrimination due to their fractionation and low mobility in sedimentary environments. Bhatia [31] proposed ternary plots of Sc-Th-Zr/10 and Sc-La-Th. The process of collisional tectonics and deformation is formed during the mechanism of orogeny or plate convergence leading to the formation of continental arc or active continental margin settings. These depositional environments forming in these regions are usually underlain by thick and elevated continental crust [32]. Geochemical composition of phyllites is plotted in these ternary plots. Figures 12 and 13 falls in the active continental margin and passive margin continental settings. The plot of SiO_2 versus K_2O/Na_2O (Figure 14) shows that phyllites of Patharkhola have been formed in the active continental margin.

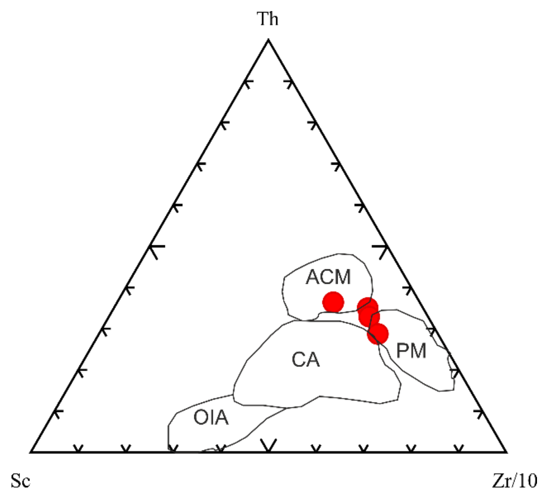

Figure 12. Th-Sc-Zr/10 tectonic setting discrimination ternary diagrams (after Bhatia & Crook 1986) [32].

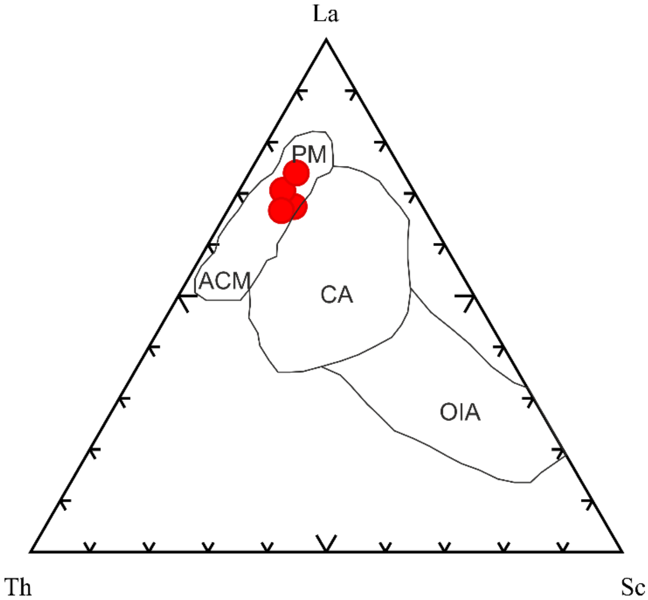

Figure 13. La-Th-Sc tectonic setting discrimination ternary diagram after Bhatia & Crook (1986) [32].

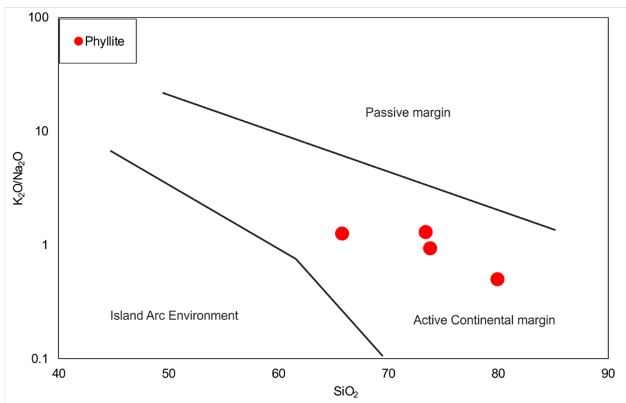

Figure 14. SiO_2 versus K_2O/Na_2O for Patharkhola rocks after Roger and Korsch 1986 [33].

6. Discussion & Conclusions

Phyllites exposed in the western part of the Patharkhola area of District Almora exposed in the NW, S to SW. They are grey, greenish grey, brownish and greyish green in colour, fine-grained and thinly foliated. Phyllites of the area are highly folded showing gentle folds, asymmetrical folds and chevron folds. Along with all these, ptygmatic folds are also found associated with the quartz vein intruded in phyllites. Based on the mineral paragenesis, phyllites have been containing Chlorite-biotite-sericite-quartz-muscovite. Geochemically, the phyllites have high SiO_2 and Al_2O_3 values along with higher ratios of K_2O/Al_2O_3 and SiO_2/Al_2O_3. Phyllites with higher Al_2O_3 values have a strong association with trace elements indicating their preponderance of K-feldspars and micas. The enrichment of Zr and depletion of Y and Nb indicate preferential survival of zircon in extreme weathering conditions. The HFSE has shown variation in the ratios due to decoupling with the major oxides. Fluids at magmatic arcs are usually marked by enrichment of LREE and LILE along with relative depletion of HFSE. The enrichment of LREE and depletion of HREE suggest mixing of the terrigenous sediments with the magma [33]. Discrimination plots to classify the tectonic settings suggested that the phyllites of Patharkhola have formed in active continental margins. The reliability of such diagrams is supported by the rock minerology as it is dominated by biotite along with a subordinate amount of feldspar. Such minerology guarantee that the K and Na were immobile at low grade metamorphism. This can be considered that the Lesser Himalayan rocks have subducted during the collisional processes leading to the formation of tholeiitic magma followed by a mixing of melt and crustal contamination. Afterwards, the exhumation of the asthenosphere is associated with arc magmatism.

Author Contributions

Author Haritabh Rana carried out the field work along with Aman Soni and Satyam Shukla as a part of his Ph.D. work under the supervision of Harel Thomas who conceptualized the work. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data used for writing this manuscript have been attached in Table 1.

Conflict of Interest

All authors disclosed no any conflict of interest.

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