Shamshad Ahmad, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 12, Issue 10, October 2022, pp. 100-113

RESEARCH ARTICLE OPEN ACCESS

Major and trace elements geochemistry of metasedimentary rocks from Bomdila Group, Arunachal Pradesh, NE Lesser Himalaya : Paleo-weathering, provenance and tectonic setting

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Abstract
Major, trace, and rare-earth element data of the Paleoproterozoic metasedimentary rocks (quartzites and pelites) of Bomdila Group were analyzed to evaluate their provenance, tectonic setting and paleoweathering conditions. In general, the metasedimentary rocks show high SiO_2, Al_2O_3, K_2O contents and depleted MgO, TiO_2, Fe_2O_3 and CaO concentrations. The transition trace elements like Co, Ni, and V are lower in the Bomdila metasedimentary rocks than upper continental crust (UCC) values. However, the metasedimentary samples are lower in Cr content than average UCC value (~ 35). The poor correlation between Cr and Ni imply that these rock samples were derived from felsic source rocks. Geochemical analyses indicate that the Bomdila metasedimentary rocks are characterized by moderate to intense Chemical Index of Alteration (CIA) values. REE element distributions, Eu/Eu* values, and high Zr/Sc and Th/Sc ratios indicate that the samples were likely derived from predominantly felsic sources. Tectonic discrimination diagrams based on immobile trace elements (e.g. Th-La-Sc, Sc-Th-Zr/10), multi-element patterns, REE characteristics, and diagnostic trace element ratios (i.e. Th/Sc, Zr/Hf, La/Th, La/Sc) imply that the tectonic setting of the source area was a passive continental margin. Moreover, the Chondrite-normalized REE patterns with light rare earth elements (LREE) enrichment, a flat heavy rare earth elements (HREE) and negative Eu anomalies can also be attributed to a felsic source for the Bomdila basin sediments.

Keywords: Geochemistry, Weathering, Provenance, Bomdila Group, NE Lesser Himalaya.

Date of Submission: 07-10-2022 Date of Acceptance: 18-10-2022

I. INTRODUCTION

The Himalayan orogenic belt is the result of Cenozoic Indo-Eurasian plate collision (Gansser 1974, Yin and Harrison, 2000; Aitchison et al., 2007) and represents one of the youngest and the highest mountain range in the world. Mountain belts created by continent-continent collision are perhaps the most dominant geologic features of the surface of the Earth. The youngest and perhaps most spectacular of all the continent-continent collisional belts on Earth is the Himalayan-Tibetan orogen, occupying the east-west trending, high-altitude Himalaya and Karakorum ranges in the south and the vast Tibetan plateau to the north. The use of sedimentary geochemistry is also now becoming more prominent to assign sedimentary units to plate tectonics (Bhatia 1983; Roser and Korsch 1986,1988). Sedimentary rocks also provide valuable evidence of crustal evolution during early Precambrian time, where the source rock has been destroyed by erosion (e.g., Feng and Kerrich, 1990; McLennan et al., 1983; Nesbitt et al., 1996; Taylor and McLennan, 1985). The combination of petrography and geochemistry data of sedimentary rocks can reveal the nature of source regions, the tectonic setting of sedimentary basins, and paleoclimate conditions (e.g., Dickinson and Suczek, 1979; Valloni and Mezzardi, 1984; Bhatia and Crook, 1986; McLennan et al., 1993; Armstrong-Altrin et al., 2004). Chemical weathering strongly affects the major-element geochemistry and mineralogy of siliciclastic sediments (e.g., Nesbitt and Young, 1982; McLennan, 1993). Chemical composition of a clastic sedimentary rock is largely controlled by its provenance; although several sedimentary processes such as weathering, erosion, diagenesis, etc. tend to modify its original composition. Samples have been collected from various outcrops of the Rupa section, Bomdila section and Dedza section. They have been investigated for their petrography and geochemistry to evaluate and restrain its provenance, paleoweathering and paleoclimatic conditions.

II. GEOLOGICAL SETTING

Das et al., (1975) coined the term 'Bomdila Group' which consist of a thick succession of low to medium grade metamorphic and associated magmatic rocks exposed around Bomdila town in the West Kameng Valley, Arunachal Pradesh, NE India. The Bomdila succession occupies a wide area throughout the Lesser Himalaya of Arunachal Pradesh from Siang Valley in the east to Kameng Valley and Bhutan in the west. The Bomdila Group mainly consists of mylonitic augen gneisses, garnet-biotite schists, carbonaceous schists, and foliated micaceous quartzites. Occurrences of tourmaline bearing pegmatite bodies with sharp contacts and minor feldspathization of the country rocks indicate its intrusive nature. Previous studies by many geoscientists have established general stratigraphy and tectonic framework of this region (Thakur,1986; Singh and Chowdhary,1990; Acharyya,1994,1998; Kumar,1997). In this paper we deal with the geochemical analysis of these metasedimentary rocks to infer the provenance, weathering condition and tectonic setting. The Bomdila Group of rocks are bounded by many thrust faults on either side (Fig. 1). In general, two major tectono-stratigraphic units of mostly Proterozoic age can be identified in the study area; 1) Sela Group belonging to Higher Himalaya consisting of gneisses, granites and migmatites, and 2) Bomdila Group belonging to the Lesser Himalaya. The gneisses that occur at the base of the Bomdila Group has a well developed mylonitic foliation, shown by the alignment of biotite and muscovite. Main Crystalline Thrust (MCT) separates the Sela Group from Bomdila Group of rocks and thus the former group belongs to the Higher Himalayas. The present study is confined to Bomdila Group of rocks, which is tectonically underlying Sela Group. The Bomdila orthogneiss is a batholithic dimension body occupying ~500km² area in the western Arunachal Pradesh. Based on Rb/Sr geochronology, the Bomdila orthogneiss of the Bomdila Group is assigned as 1914 ± 23 Ma by Dikshitulu et al. (1995). They are medium to coarse-grained well-defined porphyritic augen gneisses wherein the quartz/albite augens are wrapped with biotite and muscovite. Amphibolitic sills and dykes occur within the gneisses. On the way from Bomdila to Rupa village, a weakly foliated leucogranite is found, which is intruding into the augen gneisses. This intrusive relationship indicates that the leucogranite is essentially represents a younger episode of magmatism in the Bomdila area. Since these orthogneisses intrude the associated metasedimentary rocks, the Bomdila Group metasedimentary rocks are assigned as Paleoproterozoic in age. Efforts were made to collect fresh and unweathered samples of the metasedimentary rocks mainly from road cuttings along different traverses (Bomdila-Rupa-Shergaon; Bomdila-Dedza; Bomdila-Munna) in the study area.

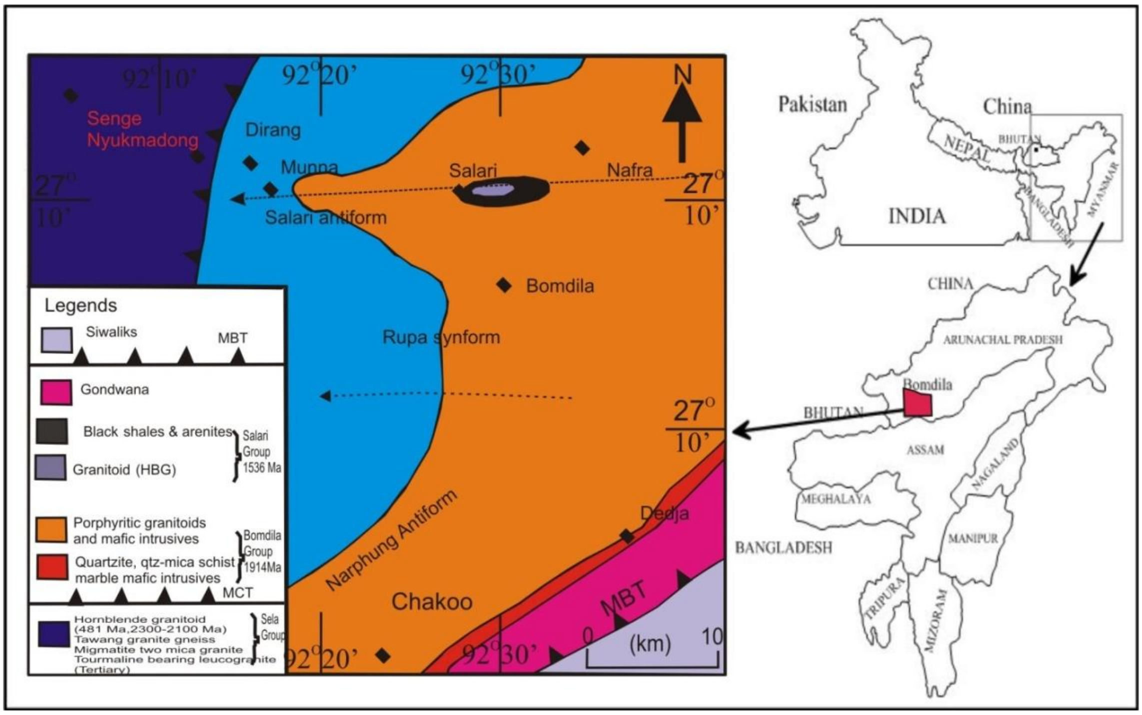

Fig.1 Simplified geological map of the Bomdila area, western Arunachal Himalaya (after Srinivasan, 2001).

III. Sampling and Analytical techniques

Twenty-nine samples of metasedimentary rocks were collected from outcrops after scraping out the surface for few centimeter to avoid weathering. Care has been taken to select fresh and unweathered samples. The bulk samples were reduced to small and fresh chips, then crushed and pulverized to -200 mesh using agate mortar for maintaining the homogeneity and true representativeness of the sample. Major elements have been analyzed by X-ray Fluorescence (XRF) Spectrometer. Pressed pellets were prepared for major element analysis. The rock powder and the binding agent were gently grinded with the help of an agate ball mill and pestle so that mixture will be thoroughly mixed. This homogenized material was pressed in a hydraulic press to produce a circular 40 mm disk marked with the representative sample number, which was utilized for chemical analysis for major element oxides. The precision of the analytical data is better than 5% for most of the major oxides while trace elements, including REEs and high field strength elements, were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) at the National Geophysical Research Institute (NGRI), Hyderabad, India. For trace element analysis, 50 mg of the homogenized sample powder was digested using strong mineral acids [perchloric acid ($HClO_4$) + nitric acid (HNO_3) and hydrofluoric acid (HF)]. The analytical precision for trace elements is well within 5-10%.

IV. Results

4.1 Major elements geochemistry

Sedimentary rocks contain a wealth of information about the composition, tectonic setting and evolutionary growth of the early continental crust. The composition of sedimentary rocks have been used to constrain the potential source areas (Taylor and McLennan, 1985; Gibbs et al., 1986; McLennan et al., 1995). Geochemistry can be used to constrain the provenance and tectonic setting of sedimentary and metasedimentary rocks if their original whole-rock composition was not significantly altered during diagenesis, weathering, and/or metamorphism, (McLennan et al., 1993). However, major element geochemistry can give important information about weathering profile of rocks (e.g. Nesbitt & Young 1984; Nesbitt et al., 1996; Bahlburg 1998; Zimmermann & Bahlburg, 2003). Among the major elements the SiO_2 content of the quartzite (62−89%), Al_2O_3 (8.1-22.6%), TiO_2 (0.08−0.8%), CaO(0.02−0.6%), MgO(0.03−2.8%), K_2O(0.8− 6.2%) Na_2O(0.03−2.3%) (Fig. 2.1). Slightly higher values of K_2O/Na_2O ratio indicate the presence of K-bearing minerals such as K-feldspar, muscovite and biotite (McLennan et al., 1983; Nath et al., 2000; Osae et al., 2006). Low content of TiO_2 (average = 0.5wt%) indicates the presence of phyllosilicates in minor amount (Dabard, 1990; Condie et al., 1992). Conversely, among the major elements, SiO_2 (61−80%), Al_2O_3 (12- 27 wt%). Most of the pelite samples have lower concentration of CaO and Na_2O (up to 0.6 wt% and 1wt%, respectively) probably indicating the breakdown of plagioclase in the source region (Fig. 2.2). As Na is leached preferentially to K during subaerial weathering, depletion of Na and high K_2O/Na_2O ratios (avg. 7.7 for pelites) results than that of average crustal values (0.9). This might have been caused by more intense decomposition of plagioclase than K-feldspar. In comparison to Na and Ca, the pelites have relatively high values of K_2O (upto 7.9%), implying that either the source contains K-rich minerals or these higher values may have resulted from post-depositional K-metasomatism, which is a common feature of clastic sediments.

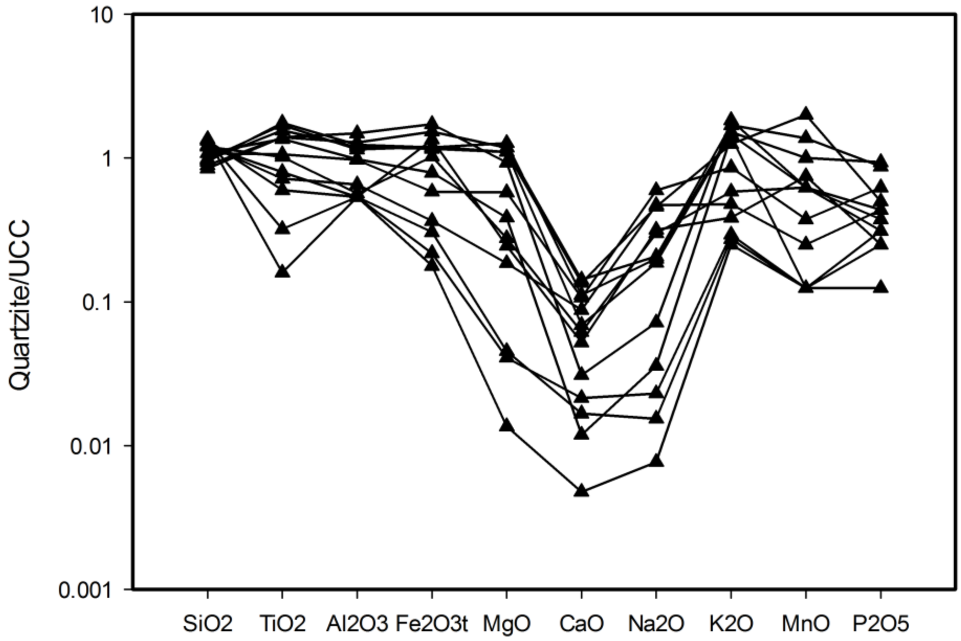

Fig.2.1 UCC-normalized major element patterns of Bomdila quartzites (UCC values after Taylor and McLennan, 1985).

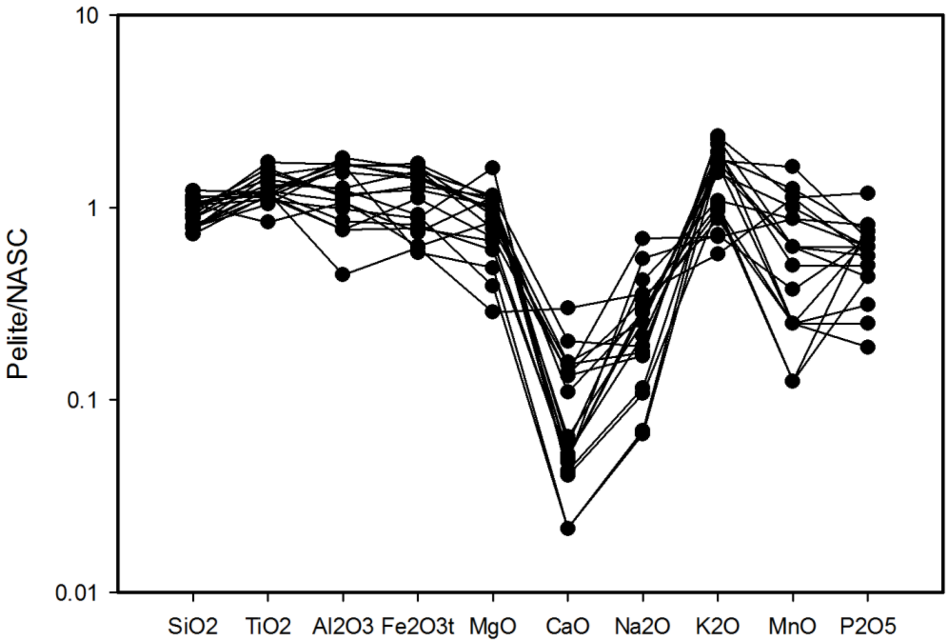

Fig.2.2 NASC normalized major element patterns of Bomdila pelites (NASC values after Taylor and McLennan, 1985).

4.2 **Trace elements geochemistry**

The trace elements exhibit wide range of variation when compared to UCC. Th/Sc ratios of the quartzite ranges (1.2 -6.1) and many ratios are above the average of the UCC (0.79; McLennan et al., 1990) and are possibly derived from felsic sources. Zr/Hf ratios (26-42) of these studied rocks are higher when compared with UCC (32.8, Taylor and McLennan, 1985), possibly indicating that they are the result of sediment recycling during transport. Transition trace elements (TTE; Cr, V, Co, Ni, and Sc) show depletion as compared to UCC (Fig. 3.1) suggesting the depletion of mafic component. The high values of (La_N/Sm_N = 4.5-5.8), almost flat

HREE (Gd_N/Yb_N= 0.8-4) with negative Eu anomaly (Eu/Eu^* = 0.4-0.7, average 0.5) are uniform and similar to UCC implying that they have been derived from similar source (Fig. 3.2). Conversely, the trace element concentrations of Bomdila pelites are variable and with the exception of Sr, all the other elements are similar to that of NASC (Fig. 3.3). Zr concentration is more or less similar to NASC. The transition trace elements (TTE; Cr, Co, V, Ni) of the pelite samples are enriched when compared to NASC (Cr=83ppm), probably shows minor contribution from the nearby mafic/ultramafic source. The pelite samples show enriched light rare earth elements (LREE) whereby the $(La/Sm)_N$ ratios varies from (4.3-5.5) and the distinctive negative Eu anomalies (Eu/Eu^*= 0.3-0.7) and flat HREE pattern (Fig. 3.4) of these Proterozoic Lesser Himalayan pelites suggest derivation from an old continental crust composed chiefly of felsic components.

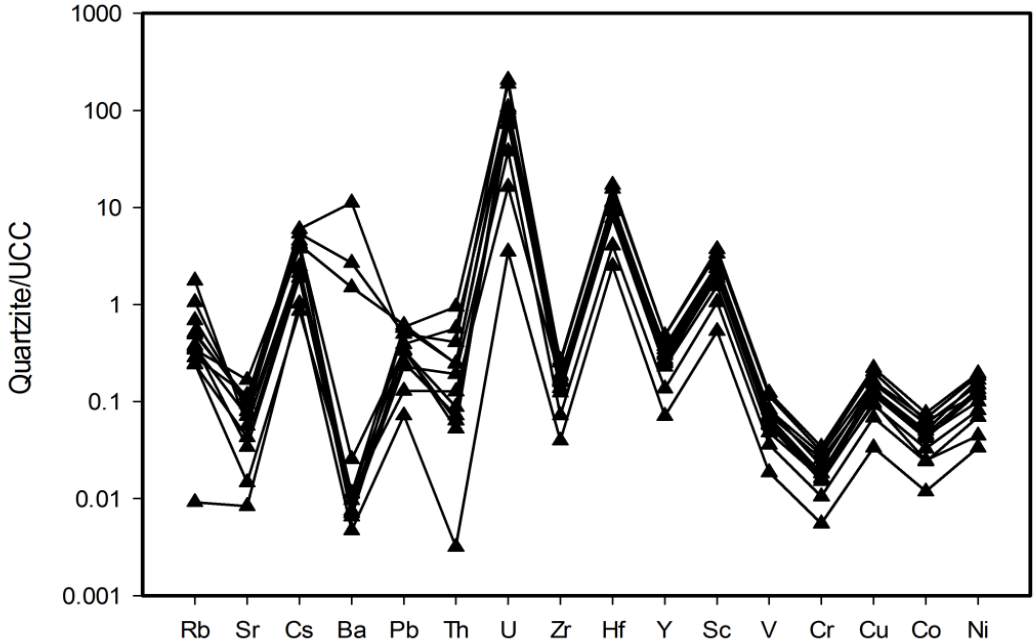

Fig.3.1 UCC normalized trace element patterns of the Bomdila quartzites (UCC values after Taylor and McLennan, 1985).

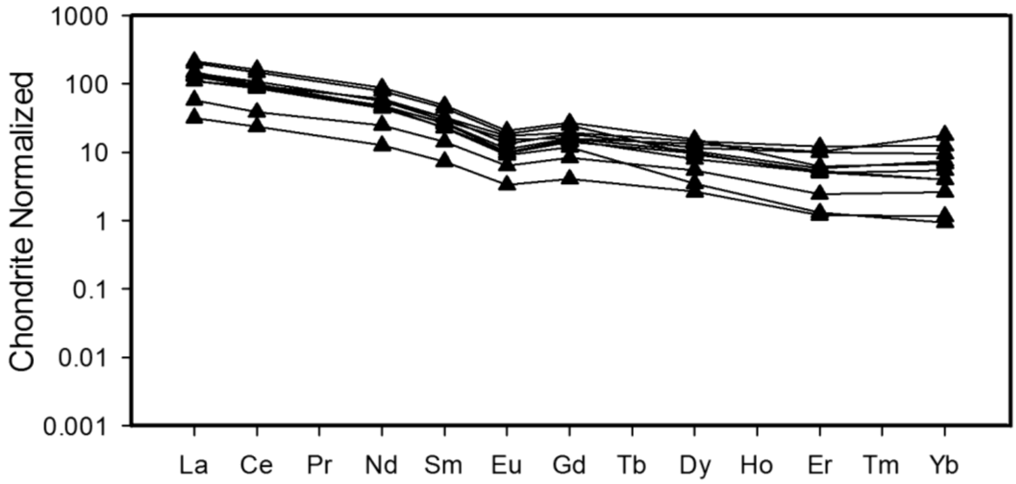

Fig.3.2 Chondrite-normalized REE distribution pattern of Bomdila quartzites (Chondrite normalizing values after McDonough and Sun, 1995).

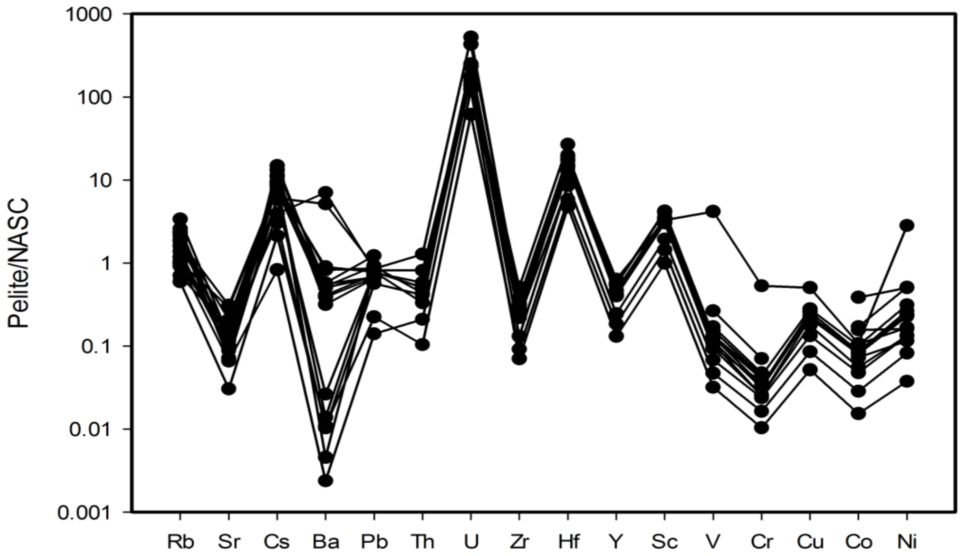

Fig.3.3 NASC normalized trace element patterns of the Bomdila pelites (UCC values after Taylor and McLennan, 1985).

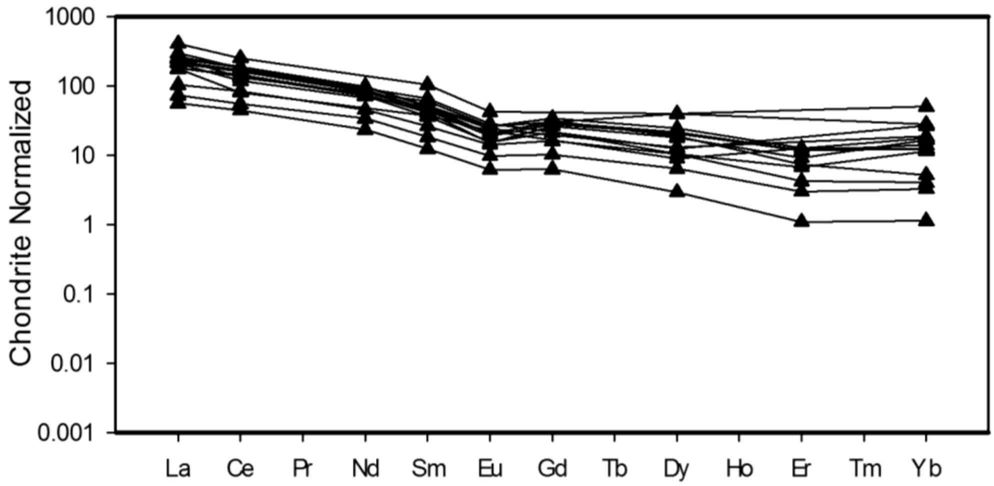

Fig.3.4 Chondrite-normalized REE distribution pattern of the Bomdila pelites (Chondrite normalizing values after McDonough and Sun, 1995).

V. Discussion

5.1 Paleoweathering

Sedimentary rocks sensu stricto are composed merely of weathering products and reflect the composition of weathering profiles, rather than bedrock (e.g. Nesbitt et al., 1996). The extent of weathering is determined primarily by the amount of rainfall (acids) on the weathering profile (Singer, 1980) where as the climatic effect on weathering trends is probably insignificant (Nesbitt and Young, 1989). Alteration of rocks during weathering results in depletion of alkalis and alkaline earth elements and preferential enrichment of Al_2O_3 (e.g., Cingolani et al., 2003). Therefore, weathering effects can be evaluated in terms of the molecular percentage of the oxide components, using the formulae of chemical index of weathering (CIW = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O] \times 100$; Harnois, 1988) and chemical index of alteration (CIA= $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O] \times 100$); Nesbitt and Young, 1982). All the samples from the study area plot around typical shale values and close to the Al_2O_3-K_2O (Fig.4) boundary implying that the rocks had undergone moderate to intensive weathering conditions. It can also be noticed in the diagram that sedimentary rock samples plot on granite to granodiorite weathering trend lines, thus favouring a felsic source for the sedimentary rocks.

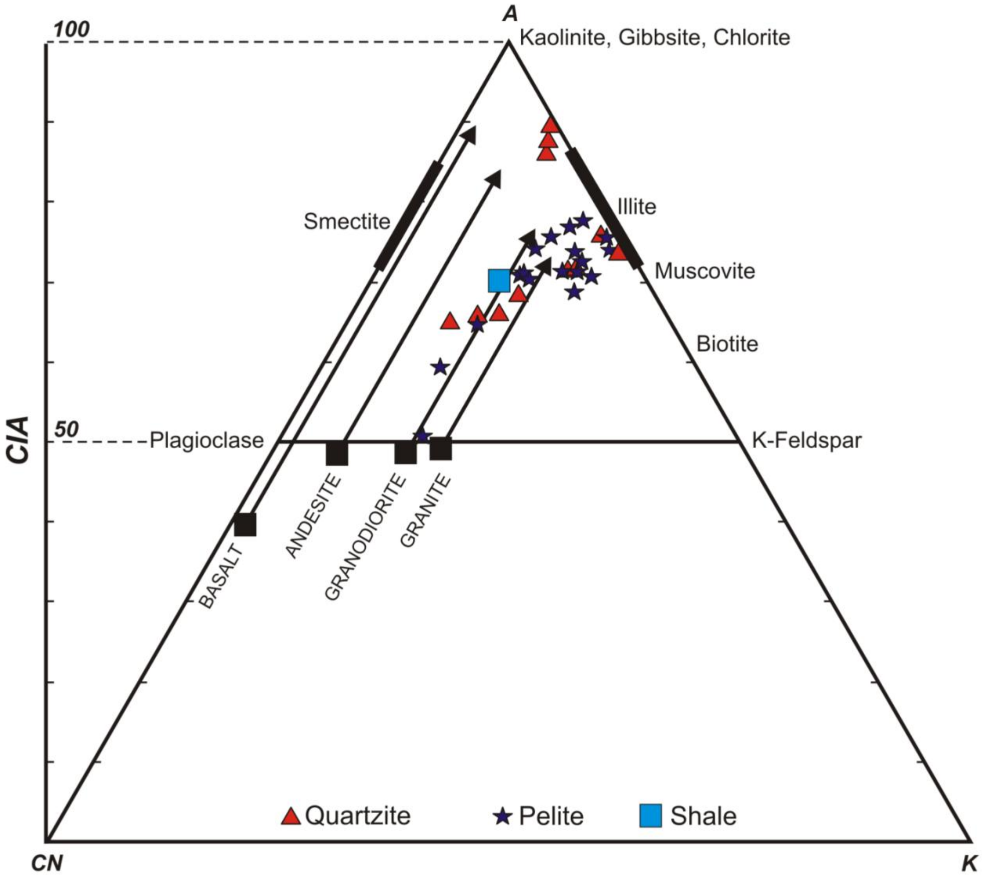

Fig 4 A–CN–K diagram (after Nesbitt and Young, 1984) of Bomdila metasedimentary rocks, using molar proportions of Al_2O_3, CaO, Na_2O and K_2O.

5.2 Provenance

Geochemistry of sedimentary rocks is considerable consequence to understand the provenance of the sediments (McLennan, 1989). The high field strength elements (HFSE) such as Zr, Nb, Hf, Y, Th and U are preferentially partitioned into melts during crystallization (Feng and Kerrich, 1990) and as a result these elements are enriched in felsic sources rather than the mafic sources. Zr, Hf, and Y are thought to reflect provenance compositions as a consequence of their immobile behaviors (Taylor and McLennan, 1985).The ferromagnesian trace elements Cr, Ni, Co and V generally show similarity with the behavior of magmatic processes, but they may be fractionated during weathering (Feng and Kerrich, 1990). Sc, Th, Zr, REE, and high field strength trace elements (HFSE) are reliable chemical elements in provenance analysis of sediments and metasedimentary rocks due to their insolubility and immobile character during transport, diagenesis, weathering, and metamorphism (McLennan and Taylor, 1991; McLennan et al., 1995). Element ratios, such as Cr/V, La/Sc, Th/Co, Th/Sc, Cr/Th, and Eu/Eu*, are particularly useful in the study of the chemical composition of the source rocks (Taylor and McLennan, 1985; McLennan et al., 1990; Cullers, 1994; Girty et al., 1994). Additionally, incompatible and compatible element ratios are diagnostic in the identification of felsic and mafic source components (Cullers, 1994; Cox et al., 1995; Fedo et al., 1996). The Th/Sc ratio is a reliable marker for source composition and the identification of mafic source components (McLennan et al., 1990; McLennan and Taylor, 1991). Th is highly incompatible, and more abundant in crustal sources. Thus, the Th/Sc ratio will be high in rocks derived from the crust and low in rocks with a mantle origin. Our samples show Th/Sc ratios between 0.69 and 1.2 (average 0.95), consistent with upper crustal compositions (average Th/Sc ratio for UCC = 0.79, McLennan, 2001). It can be noticed from the diagram (Fig.5) that quartzose sedimentary rocks and felsic igneous rocks with minor amount of intermediate igneous source form the source rocks for the Bomdila metasedimentary rocks.

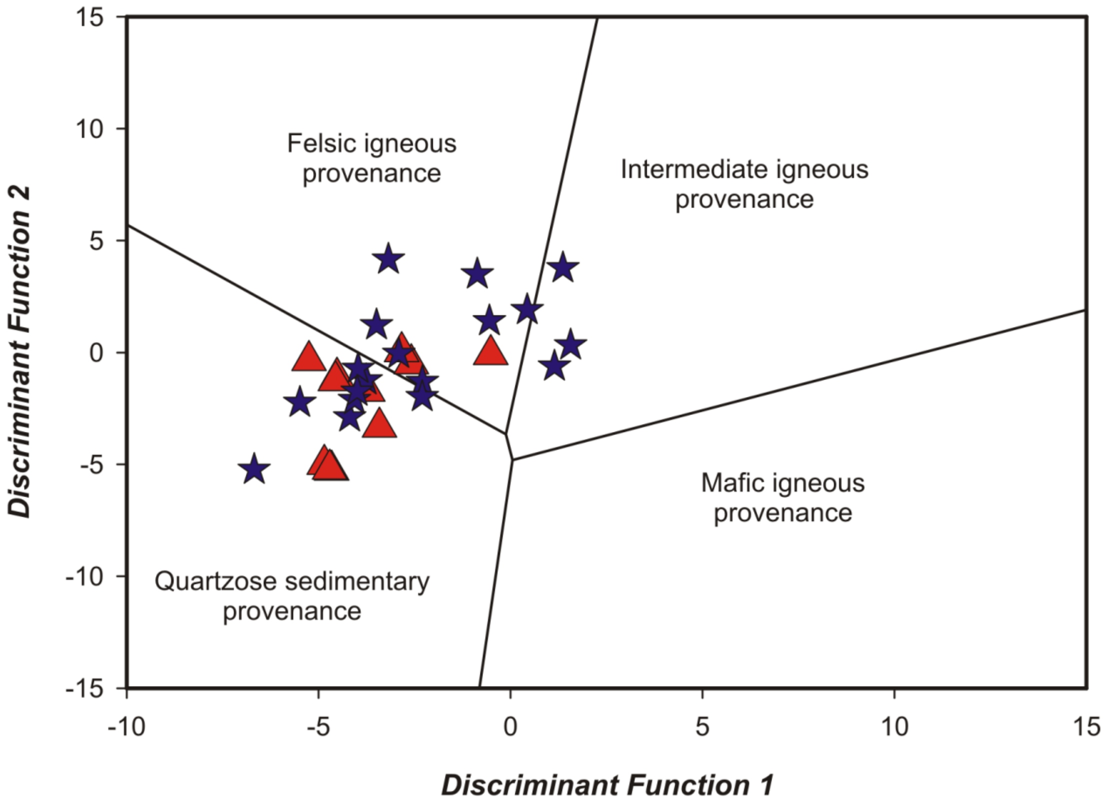

Fig.5 Discriminant function diagram for the provenance signatures of the Bomdila metasedimentary rocks using major elements. Boundaries between different fields are taken from Roser and Korsch (1988).

5.3 Tectonic Setting

It has been shown that the geochemical compositions of the sediments can be related to plate tectonic processes, making geochemistry a powerful tool in the recognition of ancient tectonic settings (Maynard et al.1982; Bhatia 1983, 1985; Bhatia and Crook, 1986; Taylor and McLennan 1985; Roser and Korsch 1986; McLennnan et al., 1990; McLennan and Taylor 1991; Chen and Jahn 2002). Therefore, the geochemistry of sediments and metasedimentary rocks can be directly related to plate tectonic processes and has been traditionally used to identify their tectonic setting (Taylor and McLennan, 1985; Roser and Korsch, 1986; McLennan and Taylor, 1991). Trace elements, particularly those that are relatively immobile, with low residence times in seawater (*i.e*. La, Nd, Th, Zr, Hf, Nb, Ti) are reliable fingerprints for tectonic setting discrimination (McLennan et al., 1990). On La–Th–Sc, Th–Co– Zr/10, and Th–Sc–Zr/10 plots (Bhatia and Crook, 1986;). Roser and Korsch (1986) demonstrate three different tectonic setting of sedimentary basin (i.e. active continental margin, passive continental margin or intracratonic and Island arc) based on bivariate plot between SiO_2 and K_2O/Na_2O. Thus, the geochemical data of Bomdila metasediments, suggest a stable craton interior platformal setting of deposition for the sediments of Bomdila Group (Fig.6). Similarly, La-Th-Sc triangular diagram is also used to considered to be strong discriminant of tectonic setting indicators (Bhatia and Crook, 1986). In this triangular diagram (Fig.6.1) Bomdila metasedimentary samples plotted near La vertex in the field of passive margin.

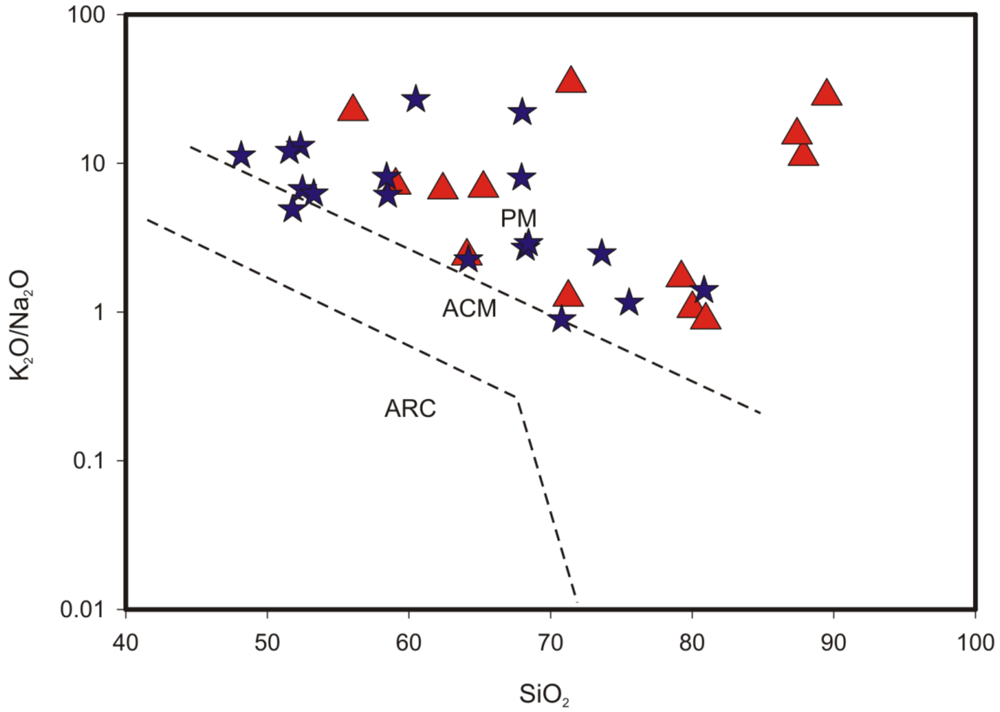

Fig.6 Tectonic discrimination diagram (after Roser and Korsch,1986) of Bomdila metasedimentary rocks indicating passive margin tectonic setting. ARC-Island Arc; ACM-Active Continental margin; PM-Passive margin.

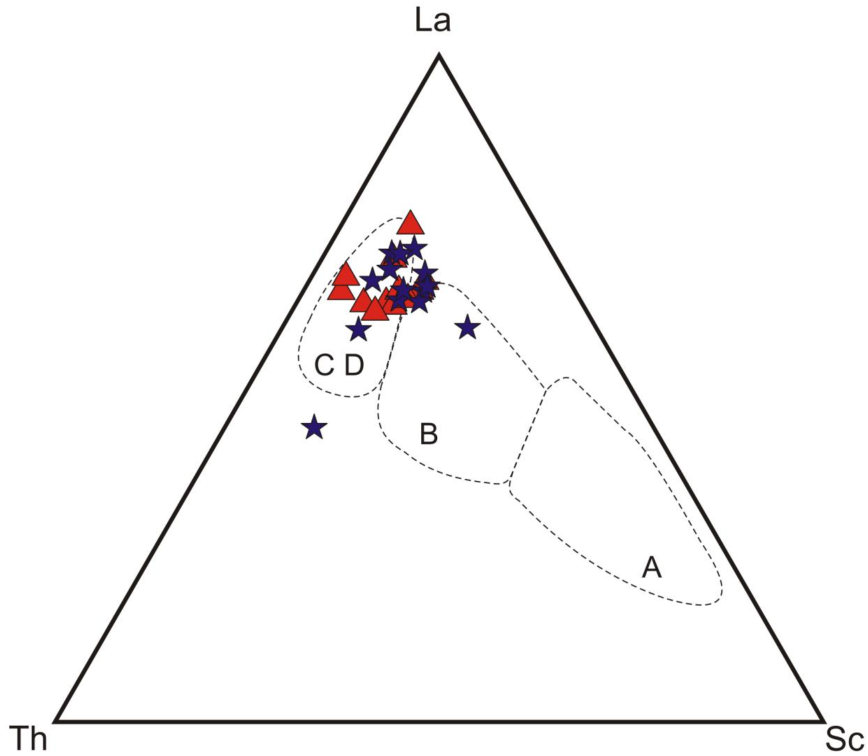

Fig.6.1 Trace element La-Th-Sc ternary plot for Bomdila metasedimentary rocks. Tectonic discrimination boundaries after Bhatia and Crook (1986). A-Ocenic island arc; B-Continental island arc; C-Active continental margin; D-Passive continental margin.

Table. 1 Major and trace element concentrations of metasedimentary rocks from Bomdila Group, NE Lesser Himalaya. Major element in wt% and trace elements in ppm.

QUARTZITE									
Element	**BG10**	**BG12**	**BG37**	**BG-64**	**BG-70A**	**BG-71**	**RG-29**	**RG-32**	**RG-43**
SiO_2	62.4	56.05	64.09	87.86	79.23	71.45	89.5	87.4	71.25
TiO_2	0.88	0.7	0.78	0.16	0.51	0.68	0.08	0.3	0.53
Al_2O_3	18.81	22.6	18.17	8.15	8.65	14.95	8.15	8.15	14.77
Fe_2O_3t	5.92	8.6	5.8	1.09	5.13	3.96	0.89	1.53	2.93
MgO	2.8	2.05	2.43	0.09	0.61	0.85	0.03	0.1	1.27
CaO	0.47	0.13	0.57	0.09	0.26	0.05	0.02	0.07	0.45
Na_2O	0.78	0.28	1.79	0.09	1.17	0.14	0.03	0.06	2.33
K_2O	5.17	6.24	4.26	1	1.99	4.83	0.85	0.93	2.93
MnO	0.08	0.05	0.16	0.01	0.05	0.01	0.01	0.01	0.03
P_2O_5	0.15	0.07	0.08	0.05	0.05	0.05	0.02	0.04	0.1
TOTAL	97.46	96.77	98.13	98.58	97.65	96.96	99.54	98.58	96.59
Sc	6.76	2.004	1.054	nd	6.374	9.824	5.982	3.768	8.035
V	53.266	13.186	5.967	nd	65.735	45.267	34.306	7.909	57.299
Cr	9.912	3.258	3.107	nd	114.102	247.717	116.317	204.038	230.165
Co	17.99	39.94	37.452	nd	25.904	10.921	72.333	23.193	20.517
Ni	10.653	6.356	6.532	nd	24.478	28.309	13.662	9.248	41.192
Cu	1.131	0.43	0.445	nd	25.241	24.602	0.948	0.874	27.533
Zn	52.643	11.422	9.719	nd	56.53	42.471	31.137	25.362	55.237
Ga	14.493	5.704	0.881	nd	15.643	12.986	22.094	4.963	16.793
Rb	118.188	31.89	1.029	nd	57.898	197.306	54.904	27.317	77.26
Sr	27.688	40.781	2.926	nd	35.223	19.73	37.638	5.137	33.016
Y	16.73	13.986	3.798	nd	19.868	8.712	22.047	3.181	15.181
Zr	3.879	5.289	2.59	nd	1479.487	6.211	6148.4	6.293	822.841
Nb	11.434	5.061	1.434	nd	9.979	11.723	7.845	2.57	12.347
Cs	2.639	0.772	0.034	nd	4.397	10.145	6.08	1.357	2.623
Ba	297.608	232.499	9.804	nd	577.152	523.539	281.737	45.597	261.949
La	50.439	25.989	7.501	nd	34.286	47.727	26.158	30.96	35.793
Ce	98.93	52.787	14.48	nd	64.941	89.897	55.622	59.992	57.979
Pr	10.598	5.48	1.562	nd	7.554	10.517	5.714	6.002	8.166
Nd	40.929	20.702	5.862	nd	26.122	36.717	21.978	22.169	28.205
Sm	7.4	3.528	1.117	nd	4.899	6.828	4.141	3.431	4.952
Eu	1.19	0.566	0.193	nd	1	1.065	0.637	0.529	0.762
Gd	5.537	2.917	0.841	nd	4.01	5.056	3.275	2.421	3.813
Tb	0.758	0.419	0.118	nd	0.674	0.633	0.497	0.247	0.588
Tm	0.118	0.095	0.021	nd	0.331	0.109	0.248	0.017	0.264
Yb	1.158	0.93	0.196	nd	2.118	0.677	3.031	0.16	1.609
Lu	0.183	0.133	0.029	nd	0.359	0.114	0.633	0.023	0.242
Hf	0.144	0.175	0.075	nd	34.55	0.17	143.645	0.193	19.969
Ta	1.972	1.002	1.066	nd	2.427	1.777	7.704	1.811	2.252

Pb	72.849	41.348	9.891	nd	2.276	2.208	24.33	11.518	2.073
Th	15.442	12.253	3.397	nd	13.895	18.947	7.432	6.874	12.625
U	2.658	1.28	0.41	nd	5.085	2.126	12.32	1.133	1.709
K2O/Na2O	6.628205	22.28571	2.379888	11.11111	1.700855	34.5	28.33333	15.5	1.257511
SiO2/Al2O3	3.317384	2.480088	3.527243	10.78037	9.159538	4.779264	10.9816	10.72393	4.823968
Na2O/K2O	0.15087	0.044872	0.420188	0.09	0.58794	0.028986	0.035294	0.064516	0.795222
CIA	71.13569	75.516	68.10523	85.71162	65.71558	73.27257	89.17914	87.30075	65.5396
CIW	89.78821	97.0064	82.0203	96.49391	78.29181	97.89545	98.95841	97.63497	76.04438
Zr/Sc	0.573817	2.639222	2.457306	nd	232.1128	0.632227	1027.817	1.670117	102.4071
Th/Sc	2.28432	6.114271	3.22296	nd	2.17995	1.928644	1.242394	1.82431	1.571251
Cr/Th	0.641886	0.265894	0.914631	nd	8.211731	13.07421	15.65083	29.68257	18.23089
Co/Th	1.165005	3.25961	11.02502	nd	1.864268	0.576397	9.732643	3.374018	1.625109
La/Th	3.266352	2.121032	2.208125	nd	2.467506	2.518974	3.519645	4.503928	2.835089
Ti/Zr	1359.812	793.3055	1805.14	nd	2.066213	656.2411	0.077991	285.7456	3.860788
Ti/Nb	461.3181	829.0443	3260.329	nd	306.3368	347.6852	61.12418	699.6875	257.2945
Eu/Eu*	0.568352	0.539396	0.608774	nd	0.68976	0.554144	0.528816	0.56114	0.536111
(Gd/Yb)N	3.955515	2.59472	3.54958	nd	1.56623	6.178108	0.893846	12.51734	1.960414
(La/Sm)N	4.400255	4.755586	4.335199	nd	4.518065	4.512464	4.077955	5.825367	4.66617

Continued

PELITES										
Element	**BG-60A**	**BG-61**	**BG-65**	**DG5**	**DG-6**	**DG-7**	**DG8**	**DG-9**	**DG-10**	**DG-11**
SiO_2	68.23	52.48	67.95	51.56	64.2	73.62	58.43	75.55	53.28	80.84
TiO_2	0.61	0.52	0.55	0.73	0.8	0.61	0.66	0.57	0.62	0.6
Al_2O_3	16.51	25.54	15.01	25.26	17.3	12.95	19.21	11.72	23.17	6.8
Fe_2O_3t	3.15	7.33	4.4	8.18	6.52	4.06	7.76	3.9	7.09	3.1
MgO	1.86	2.15	3.54	2	2.5	1.32	2.54	1.47	2.13	0.63
CaO	0.57	0.27	0.17	0.56	0.25	0.21	0.85	0.2	0.66	1.26
Na_2O	1.29	0.99	0.42	0.66	1.64	1.2	0.74	2.12	0.99	1.39
K_2O	3.48	6.63	3.36	7.98	3.7	2.97	6	2.45	6.19	1.95
MnO	0.01	0.04	0.02	0.09	0.07	0.02	0.13	0.03	0.1	0.09
P_2O_5	0.13	0.08	0.05	0.09	0.13	0.11	0.11	0.11	0.12	0.19
TOTAL	96.2	96.03	95.47	97.11	101.68	100.1	96.43	101.08	94.89	98.86
Sc	7.299	nd	10.12	1.891	22	8	2.158	8	12.768	9.9
V	19.198	nd	47.425	11.329	95	62	16.058	61	34.569	34
Cr	185.863	nd	121.831	2.436	108	405	3.286	238	208.244	211
Co	25.678	nd	19.24	24.734	17	14	45.694	14	23.718	11
Ni	8.373	nd	25.552	5.325	60	107	8.11	45	10.152	29.9
Cu	0.685	nd	1.148	1.564	16	16	0.499	16	0.638	11
Zn	31.706	nd	64.083	13.615	132	65	10.732	61	51.931	28
Ga	13.644	nd	31.171	5.272	22.3	16	6.082	13.6	24.273	10.8
Rb	102.86	nd	154.267	110.129	180	130	66.644	117	213.266	79
Sr	48.48	nd	33.084	22.922	52	31	10.651	48	72.459	57
Y	11.236	nd	14.535	3.066	40.6	32.7	7.871	31	30.679	34.2
Zr	5.663	nd	3867.46	1.307	227	306	6.002	279	7.618	456
Nb	11.294	nd	16.363	2.796	14.5	13.5	4.467	13.5	15.234	17.2
Cs	4.425	nd	8.686	2.239	nd	nd	1.106	nd	6.228	nd
Ba	475.011	nd	490.39	339.765	496	380	171.384	353	694.673	1202
La	42.521	nd	24.819	13.301	nd	nd	17.364	50.5	50.634	70.8
Ce	84.824	nd	51.792	27.398	nd	nd	33.713	72.5	98.565	109.6
Pr	8.826	nd	5.375	2.875	nd	nd	4.054	nd	10.272	nd
Nd	33.556	nd	21.333	10.922	nd	nd	15.831	nd	38.66	nd
Sm	5.589	nd	4.063	1.906	nd	nd	2.823	7.72	6.777	10.2
Eu	0.896	nd	0.832	0.361	nd	nd	0.571	1.4	1.1	1.66
Tm	0.07	nd	0.156	0.022	nd	nd	0.053	nd	0.242	nd
Yb	0.693	nd	1.949	0.193	nd	nd	0.559	3.21	2.416	4.56
Lu	0.115	nd	0.407	0.034	nd	nd	0.077	0.62	0.403	0.69

Hf	0.167	nd	91.616	0.061	nd	nd	0.195	nd	0.241	nd
Ta	2.164	nd	3.923	1.087	nd	nd	1.773	nd	1.756	nd
Pb	20.032	nd	27.386	61.381	12	9.6	49.378	11.9	26.455	11.1
Th	22.451	nd	7.018	4.403	16.5	13.3	6.7	12.6	16.884	20.1
U	3.434	nd	8.243	0.823	3.6	4.5	1.163	4.8	3.026	4.1
K2O/Na2O	2.697674	6.69697	8	12.09091	2.256098	2.475	8.108108	1.15566	6.252525	1.402878
SiO2/Al2O3	4.132647	2.054816	4.526982	2.041172	3.710983	5.684942	3.041645	6.446246	2.299525	11.88824
Na2O/K2O	0.37069	0.149321	0.125	0.082707	0.443243	0.40404	0.123333	0.865306	0.159935	0.712821
CIA	70.65226	73.59198	76.65747	70.47095	70.94621	70.14287	68.55857	64.48364	71.12221	50.57483
CIW	83.93291	92.33385	93.75033	92.30497	84.58242	84.60351	88.75095	75.26316	89.11246	59.78785
Zr/Sc	0.77586	nd	382.1601	0.691169	10.31818	38.25	2.781279	34.875	0.596648	46.06061
Th/Sc	3.075901	nd	0.693478	2.328398	0.75	1.6625	3.104727	1.575	1.322368	2.030303
Cr/Th	8.278607	nd	17.35979	0.553259	6.545455	30.45113	0.490448	18.88889	12.33381	10.49751
Co/Th	1.143735	nd	2.741522	5.617533	1.030303	1.052632	6.82	1.111111	1.404762	0.547264
La/Th	1.893947	nd	3.536478	3.020895	nd	nd	2.591642	4.007937	2.998934	3.522388
Ti/Zr	645.6532	nd	0.852419	3347.829	21.12419	11.9488	659.1192	12.24579	487.828	7.886829
Ti/Nb	323.7413	nd	201.4725	1564.954	330.7029	270.8395	885.613	253.0796	243.946	209.0927
Eu/Eu*	0.549577	nd	0.694335	0.703296	nd	nd	0.713233	nd	0.536255	nd
(Gd/Yb)N	5.306102	nd	1.401954	5.537864	nd	nd	3.140297	nd	1.986977	nd
(La/Sm)N	4.911481	nd	3.943488	4.5051	nd	nd	3.970836	4.222962	4.82334	4.481013

VI. Conclusions

This study comprising major and trace element geochemistry of Paleo-Proterozoic Bomdila metasedimentary rocks exposed in the Arunachal Pradesh, NE Lesser Himalaya. Lower concentrations of immobile trace elements like Cr, Co, V, and Sc suggest the felsic source rock provenance, which is also supported by the Th/Sc, Th/Co, Th/Cr, Cr/Th, and La/Sc ratios. Moderate to high degree chemical weathering of the source rock is concluded from the range of CIA values and A-CN-K compositional trend of the samples. Geochemical data based on major and trace element (La-Th-Sc ternary plot) geochemistry indicates that the tectonic setting of the deposition of Bomdila Group of rocks was passive margin and intracratonic in nature. Chondrite-normalized REE patterns for most of the samples display the significant enrichment of LREEs, the distinctive negative Eu-anomolies and flat HREE patterns and in general correlate well with the UCC and NASC average composition suggest derivation from an old upper continental crust composed chiefly of felsic components. Various studies on Lesser Himalayan rocks (Rashid, 2009) indicate that Proterozoic granites and the associated mafic rocks occurring in Peninsular India (for e.g. Bundelkhand Massif, Aravalli Craton) may have supplied detritus to the Lesser Himalayan sedimentary basins (Valdiya, 1998). It can therefore be concluded that the Bomdila Group sediments appear to have been derived from these terrains, which needs further confirmation from more rigorous studies based on trace elements and isotopes.

Acknowledgment

We thank the Chairman, Department of Geology, AMU, Aligarh for providing necessary facilities. We also thank Prof. A.K. Gupta, Director WIHG, Dehradun, for providing the required facilities to carry out this work. We are also grateful to Dr. N.K.Saini (WIHG) for their help in geochemical analysis.

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