Journal of Nepal Geological Society, 2000, Vol. 21, pp. 123-128

Geochemical characteristics and provenance studies of metasedimentary rocks: Kullu-Rohtang Pass-Sissu section of NW Himalaya, India

D. Rameshwar Rao and S. A. Rashid

Wadia Institute of Himalayan Geology, 33 General Mahadeo Singh Road, Dehradun - 248 001, India

ABSTRACT

The metasedimentary rocks along the Kullu-Rohtang Pass-Sissu section, NW Himalaya, have been analysed geochemically to characterise the composition of their provenance. The studies carried out suggest that, the source for these rocks is mainly of felsic nature, remarkably similar in composition to average Phanerozoic upper continental crust. The deposition of the sediments took place in an oxidising environment, and in a tectonic setting that spans from active to passive continental margins.

INTRODUCTION

In the last three decades, the examination of trace element abundance along with some major elements in sedimentary rocks has added greatly to the understanding of crustal evolution (Wildeman and Haskin 1973; Nance and Taylor 1976). The use of sedimentary geochemistry is also now becoming more prominent to assign sedimentary units to plate-tectonic settings (Bhatia 1983; Roser and Korsch 1986; and Roser and Korsch 1988).

In this paper, we examine the geochemistry of post-Archaean, clastic metasedimentary rocks from Kullu-Rohtang Pass-Sissu region of the NW Himalaya, in order to characterise the chemical composition of the upper crust. The area under investigation comprises dominantly of granitoids, metapelites, and metapsammites. The results of present investigation are also compared with those of other sedimentary sequences and discussed in terms of provenance, tectonic setting, and evolutionary changes of the upper continental crust in the Himalayas.

GENERAL GEOLOGY

The area under study includes the inverted metasedimentary sequence of the Lesser and Higher Himalayan Crystallines of the Kullu-Rohtang Pass-Sissu section of Himachal Pradesh. The principal lithologies comprising the Lesser and Higher Himalayan Crystallines are the monotonous series of metapelites and metapsammites. They are intercalated with augen gneisses and metagranites with rare calc-silicate rocks. These rock sequences are intruded by early Palaeozoic Rohtang granodiorite (612±100 Ma, Bhanot et al. 1975) and Jispa granodiorite (495±16 Ma, Frank et al. 1977); also to the east and southeast of the study region by Proterozoic Wangtu granitic gneisses (1895±64 Ma, Rameshwar Rao et al. 1995) and Palaeozoic Chor granite (526±46 Ma), respectively. The felsic intrusions in the metasedimentary rocks of the NW Himalayas indicate that the country rocks are as old as 2000 Ma.

The metasedimentary rocks of the crystalline nappe consist mainly of quartz-rich schists with varying contents of chlorite, muscovite, and biotite, and in the higher metamorphic area by staurolite, kyanite, and sillimanite. The staurolite- and kyanite/sillimanite-bearing layers are intercalated in the monotonous series of quartzitic schists and gneisses. The lithological variation sometimes is so small that it is difficult to make subdivision of the metapsammites and metapelites on the map. The regional geology of the area was described by Misra and Tewari (1988), who mark seven lithological units in the Jutogh and Vaikrita Groups. Fig. 1 describes these seven units along with locations of samples collected mainly from the interbanded sequence of metapelites and metapsammites in the Katrain, Kalath, Palchan, Khoksar, and Sissu regions. Thöni (1977), describing the depositional history of the rocks suggested that the arenaceous and argillaceous parts were derived from a thick series of marine clayey sand, while minor components of calc-silicates of the region were derived from sandy-clayey marls or partly from carbonate concentrations. Frank et al. (1977), Thöni (1977), Kumar (1981), Misra and Tewari (1988), and Epard et al. (1995) have given further structural details.

GEOCHEMISTRY

The major, trace, and rare earth elements of the metasedimentary rocks were analysed using XRF and ICP-AES at Wadia Institute of Himalayan Geology, Dehradun. The analytical data are provided in Tables 1 and 2. The major and trace elements against SiO_2 wt % show linear trends from metapelites to metapsammites. The similar behaviour of major and trace elements indicates a common source for the two sequences. Table 1 shows that the less-sorted metapsammites are enriched in SiO_2, CaO, Na_2O, Sr, Cu, while well sorted metapelites are enriched in TiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Ni, Zr, Rb, Y, and Ga (Table 1). The significantly higher contents of K_2O and Al_2O_3 in the metapelites are due to the enrichment of clay minerals.

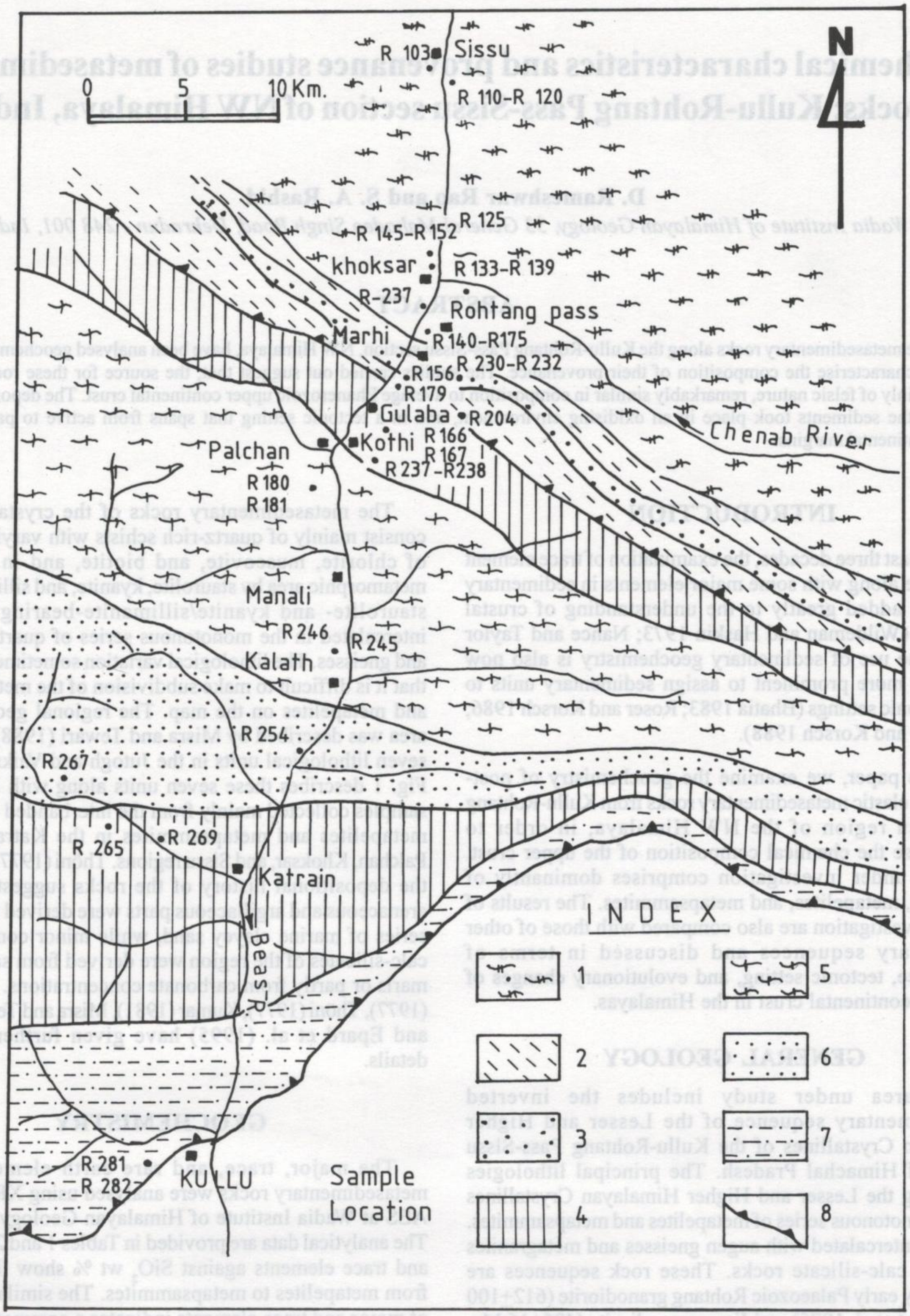

Fig. 1: Geological map of Kullu-Sissu section of Himachal Pradesh, the NW Himalayas (after Misra and Tewari 1988). The figure also gives sample locations. Index: (1) coarse-grained, quartzo-feldspathic, biotite-rich banded gneiss with tourmaline, (2) kyanite-sillimanite schists and gneisses, (3) quartz-biotite garnetiferous schist interbedded with foliated micaceous quartzite, (4) biotite schist with foliated micaceous quartzite, (5) fine-grained banded gneiss, (6) foliated micaceous quartzite, (7) garnetiferous-biotite phyllonite and schist, and (8) thrust.

Table 1: Chemical composition of post-Archaean metasedimentary rocks from NW Himalaya

	Pelites													
Attributes/Sp. No.	R112	R120	R138	R140	R167	R175	R179	R204	R230	R231	R232	R238	R280	R281
SiO_2	57.93	45.19	55.58	59.32	47.59	58.22	62.24	62.93	52	65.33	62.08	47.51	50.77	44.31
Al_2O_3	18.97	14.69	20.58	17.35	23.07	19.95	16.32	17.55	19.8	15.66	16.52	19.73	20.4	23.95
Fe_2O_3	8.09	16.24	9.05	8.89	9.25	7.92	7.54	5.63	8.99	6.48	7.28	9.85	9.35	10.68
MgO	4.94	8.2	4.9	5.11	5.37	4.2	4.32	8.68	5.99	4.73	6.58	6.84	6.97	7.77
CaO	1.07	1.93	0.95	1.07	1.58	1.01	1.32	0.03	1.06	0.96	0.68	1.12	0.49	1.14
Na_2O	1.63	1.47	1.72	1.42	0.98	1.29	1.74	0.27	1.85	1.95	1.23	1.16	1.06	1.32
K_2O	4.86	6.49	5.51	4.55	5.53	4.67	4.25	3.34	5.46	3.46	2.54	6.09	5.29	6.16
TiO_2	1.02	2.27	1.1	0.92	1.03	0.9	0.91	0.84	1.22	0.76	0.96	1.13	0.87	1.13
P_2O_5	0.07	0.28	0.1	0.06	0.04	0.04	0.08	nd	0.06	0.03	0.22	0.06	0.04	0.09
MnO	0.1	0.44	0.05	0.1	0.1	0.1	0.11	0.05	0.13	0.04	0.06	0.13	0.12	0.18
Sum	98.68	97.2	99.54	98.79	94.54	98.3	98.83	99.32	96.56	99.4	98.15	93.62	95.36	96.73
Ni	98	215	91	154	230	63	81	64	91	85	88	96	nd	118
Cu	51	nd	35	135	nd	27	17	44	13	52	18	28	nd	23
Zn	126	335	121	113	190	118	134	47	144	69	151	135	nd	177
Ga	21	27	22	21	22	20	20	22	23	19	23	21	nd	24
Pb	17	6	15	18	17	18	19	nd	19	17	25	12	nd	18
Th	6	8	7	6	6	6	6	24	6	5	5	7	nd	7
U	1	nd	0.8	0.9	0.7	1	1	10	0.8	2	2	0.3	nd	0.6
Rb	197	1161	209	172	219	200	166	153	206	124	108	233	nd	186
Sr	152	224	147	147	151	150	148	19	168	123	120	151	nd	145
Y	48	180	58	49	64	55	52	27	61	34	65	60	nd	69
Zr	222	156	228	186	160	182	220	204	312	175	391	197	nd	242
Nb	20	90	18	18	22	19	19	19	20	23	38	17	nd	21
SiO_2/Al_2O_3	3.05	3.08	2.70	3.42	2.06	2.92	3.81	3.59	2.63	4.17	3.76	2.41	2.49	1.85
K_2O/Na_2O	2.98	4.41	3.20	3.20	5.64	3.62	2.44	12.37	2.95	1.77	2.07	5.25	4.99	4.67
Th/U	6.0	-	8.8	6.7	8.6	6.0	6.0	2.4	7.5	2.5	2.5	23.3	-	11.7
Ni/Zr	0.44	1.38	0.40	0.83	1.44	0.35	0.37	0.31	0.29	0.49	0.23	0.49	-	0.49

	Psammites										
Attributes/Sp. No.	R103	R110	R115	R117	R142	R156	R181	R237	R245	R246	R268
SiO_2	75.05	73.07	68.67	74.17	73.25	70.10	67.75	70.70	68.46	65.01	65.62
Al_2O_3	11.07	12.67	13.68	12.06	11.32	13.49	15.72	15.65	14.34	15.80	16.16
Fe_2O_3	4.90	5.61	6.74	5.81	6.22	6.24	5.24	1.76	6.85	6.05	4.56
MgO	1.46	1.90	3.27	2.02	2.18	3.27	2.54	1.61	3.03	3.49	2.74
CaO	1.16	1.03	1.40	0.82	1.27	1.57	2.93	1.82	1.62	3.44	3.29
Na_2O	2.82	2.47	2.94	1.61	2.57	3.13	2.48	3.14	2.26	2.92	2.99
K_2O	1.75	2.76	2.47	0.82	1.84	2.50	3.93	5.36	3.21	2.98	3.65
TiO_2	0.67	0.69	0.65	0.76	0.75	0.68	0.52	0.23	0.80	0.64	0.55
P_2O_5	0.19	0.18	0.21	0.19	0.02	0.11	0.12	0.05	0.10	0.13	0.09
MnO	0.07	0.11	0.08	0.09	0.07	0.09	0.09	0.06	0.10	0.10	0.08
Sum	99.14	100.49	100.11	98.35	99.49	101.18	101.32	100.38	100.77	100.56	99.73
Ni	38	41	17	43	48	68	48	46	52	49	23
Cu	62	50	38	62	48	51	57	94	56	60	52
Zn	55	64	42	68	77	110	58	4	98	91	70
Ga	11	11	5	12	13	16	8	13	15	12	17
Pb	3	4	19	11	11	20	25	24	2	7	18
Th	17	18	9	22	26	20	4	2	22	15	5
U	1	5	28	5	2	4	11	2	8	153	2
Rb	62	98	355	105	83	99	157	300	134	12	197
Sr	144	159	41	110	141	153	156	90	133	14	179
Y	29	25	22	28	26	22	20	17	22	151	33
Zr	277	223	103	305	306	141	128	76	230	12	196
Nb	14	14	23	15	16	16	23	nd	16	-	11
SiO_2/Al_2O_3	6.78	5.77	5.02	6.15	6.47	5.20	4.31	4.52	4.77	4.11	4.06
K_2O/Na_2O	0.62	1.12	0.84	0.51	0.72	0.80	1.58	1.71	1.42	1.02	1.22
Th/U	17.0	3.6	0.3	4.4	13.0	5.0	0.4	1.0	2.8	0.1	2.5
Ni/Zr	0.14	0.18	0.17	0.14	0.16	0.48	0.38	0.61	0.23	4.08	0.12

Major oxides in wt.%; trace elements in ppm; total iron as Fe_2O_3; nd = not determined

Table 2: REE composition of the post-Archaean NW Himalayan sedimentary rocks

	Pelites				Psammites		
Attributes/Sp.No.	R140	R175	R179	R281	R155	R165	R268
La	36.42	47.4	42.16	44.21	16.09	12.38	33.89
Ce	72.61	84.54	87.05	91.87	33.06	21.85	66.39
Nd	31.51	39.78	37.12	38.81	14.64	10.86	28.53
Sm	6.42	7.38	7.36	9.23	3.94	2.71	6.24
Eu	1.19	1.28	1.33	1.66	0.34	0.29	0.7
Gd	5.48	5.9	6.48	8.48	3.28	2.47	5.11
Dy	4.18	5.21	4.64	7.1	3.31	3.18	3.2
Er	3.73	2.97	2.18	17.22	2.08	2.02	1.47
Yb	2.25	2.87	1.79	3.08	1.92	2.03	1.27
Lu	0.31	0.37	0.24	0.38	0.17	0.3	0.15
∑ REE	164	198	190	222	79	58	147
$(Ce/Yb)_N$	8.96	8.18	13.51	8.29	4.78	2.99	14.52
Eu/Eu *	0.61	0.59	0.59	8.29	0.29	0.34	0.38

REE concentration in ppm, $Eu/Eu^* = Eu_N/(Sm_N{*}Gd_N)^{1/2}$

The plotting of samples on the binary diagram using the ratios SiO_2/Al_2O_3 and K_2O/Na_2O (Fig. 2a) show that they plot well within the field of Phanerozoic to Proterozoic shales. On the K_2O-Fe_2O_3-Al_2O_3 ternary diagram the metapelites and metapsammites occupy the North American Shale Composite (NASC) field (Fig. 2b). The major elemental data of metapelites and metapsammites compare well with NASC data. As far as trace elemental data are concerned, the overall concentrations of Zr, Y, Ti, and Nb are more-or-less similar to those of NASC. Nb and Y contents of the metapelites are relatively higher than those in the metapsammitic rocks. Their Ti/Zr and Zr/Nb ratios are similar to and Zr/Y ratios greater than those of NASC. The metapelitic samples of the region have highly variable Ni content (63-230 ppm) that is generally higher than that of the metapsammites and NASC. This may be related to the Mg-bearing phases present in the metapelitic rocks, e.g., biotite, chlorite, and garnet which are rare or absent in the metapsammitic rocks. Ni concentration of the metapsammitic rocks (~ 43 ppm) is equal to or less than that of the post-Archaean metasedimentary rocks.

The rare earth elements (REE) are generally considered to be immobile, exhibiting only minor changes during sedimentary processes, and their abundance in source rocks and weathering conditions in the provenance region have been considered as the major factors controlling the REE in sediments (Taylor and McLennan 1985). The REE patterns of the analysed samples are shown in Fig. 3 and the data are given in Table 2. The metapelites show the light rare earth elements (LREE) enriched and the heavy rare earth elements (HREE) depleted patterns (La_N/Yb_N = 10.3-16.81) with higher total REE abundance (~222 ppm). They have significant negative Eu anomalies (~0.60), which are similar to mean values of NASC (~0.66) and post-Archaean rocks (0.62 – 0.72; McLennan et al., 1983). Metapsammitic rocks also exhibit similar patterns as that of metapelites but have low total REE abundance (~58 ppm) and a large negative Eu anomaly (~0.33). The REE contents of metapelites are higher than those of metapsammites. This variation may be due to the increase in the quartzose content in the metapsammites.

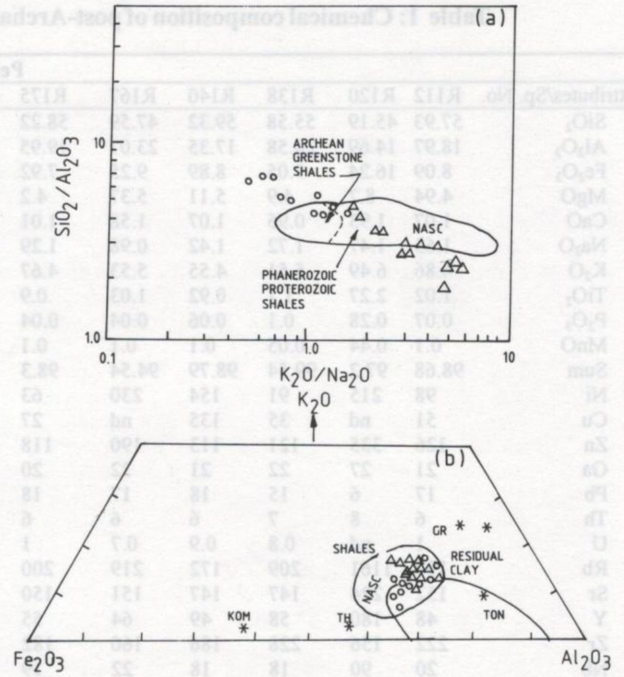

Fig. 2a: K_2O / Na_2O vs SiO_2 /Al_2O_3; Fig. 2b: Fe_2O_3 – K_2O – Al_2O_3 distributions in metasedimentary rocks. Details about fields given in Wronkiewicz and Condie (1989). Symbols: filled triangles are metapelites and filled circles are metapsammites. Index: Gr - granite, Ton - tonalite; Th - tholeiite, and Kom - komatiite

DISCUSSIONS

To characterise the provenance composition of the rocks under study, it is important to rely on the elements that are least mobile under the expected range of geological conditions. In this respect, REE, HFSE, Th, and Sc are envisaged to be the most suitable elements for provenance studies (Taylor and McLennan 1985). The major and trace elemental data of metapelites and metapsammites indicate that, their compositions (Table 1, 2; Fig. 2, 3) are almost similar to that of Phanerozoic NASC. The metapelites have K ~ 4.9 %, Rb ~ 256 ppm, Th ~ 8 ppm, and U < 2 ppm; and metapsammites are characterised by K ~ 2.8 %, Rb ~ 145 ppm, Th ~14 ppm, and U ~20 ppm. A significant proportion of K_2O in the samples indicates that the felsic rocks like granites were probably present in the source area. The REE patterns of the sediments with moderate to large Eu anomalies (Fig. 3) suggest that the felsic rocks have been derived from intra-crustal melting involving fractionation of feldspars. These geochemical features of metasediments compare favourably to the estimated values for post-Archaean exposed upper continental crust (cf. McLennan and Taylor 1980), which is significantly more felsic (granodioritic). The Th/U ratio of the sedimentary rocks is variable (2.4 to 21.2 for metapelites and 0.3 to 17.0 for metapsammites) and is higher than the NASC ratio (Th/U is ~4.4). The high Th/U ratio for metapelites also supports the derivation of the metasediments from a felsic source. The metasediments of the region have mean Ni/Zr ratio less than 1 (metapelites ~0.5 and metapsammites ~0.23), which implies a greater contribution from a granitic source rather than from a mafic source, although high Mg and Ni contents in some of the metapelite samples point towards the presence of minor mafic-komatiitic sources.

Two possibilities appear to stand equally good for the felsic nature of the rocks under study. Firstly, there could have been the intrusion of K-rich granites at the end of Archaean time. Though we do not have any evidence for the granitic intrusion in the Himalayas older than 1900 Ma (Rashid 1996), based on palaeocurrent studies, it is generally agreed that the source rocks of these sediments might have been the Arvalli-Delhi mountain chain and Bundelkhand Massif (Valdiya 1995). Secondly, the sedimentary REE pattern from the present study area could also result because of sedimentary environment prevailing during the post-Archaean times. Yanding and Yongchao (1997) based on REE studies of the Early Proterozoic sediments from the North China Craton, have convincingly argued that the REE patterns (including Eu-anomalies) though mostly depend on their provenance, can also be controlled by sedimentary environment. They observed that, the sediments with low ΣREE and positive Eu-anomaly were deposited in a reducing environment (i.e., under low fo_2 conditions), while the sediments with high ΣREE and negative Eu-anomaly in an oxidising environment (i.e., under high fo_2 conditions). From this, it appears that the post-Archaean clastic sedimentary rocks from the Himachal Himalayas, characterised by high ΣREE and strong negative Eu-anomaly were deposited in the oxidising environment.

Further, in the samples it can be noted that the U content in metapelites and metapsammites is generally less than Th, which resulted in the higher ratios of Th/U (> 6). This can be argued as an evidence of sedimentary recycling and the presence of oxygen-rich atmosphere during the deposition of the post-Archaean Himalayan sediments (cf. McLennan and Taylor 1980). The sedimentary recycling is also evident on the discriminant function diagram (after Roser and Korsch 1988) of the provenance signatures using major elements. The metapelites and metapsammites of the region on this diagram (Fig. 4) spread over from felsic to recycled quartzose sedimentary provenance.

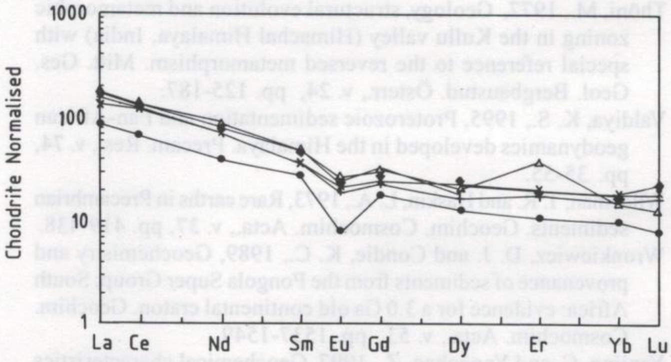

Fig. 3: Chondrite - normalised average REE plots of metasedimentary rocks. Symbols: filled triangles and filled circles as in Fig. 2. The trends are compared with those of Average European Shales Composite (filled diamonds); average PASC (plus symbols); and average NASC (cross symbols). Normalising values after Sun and McDonough (1989).

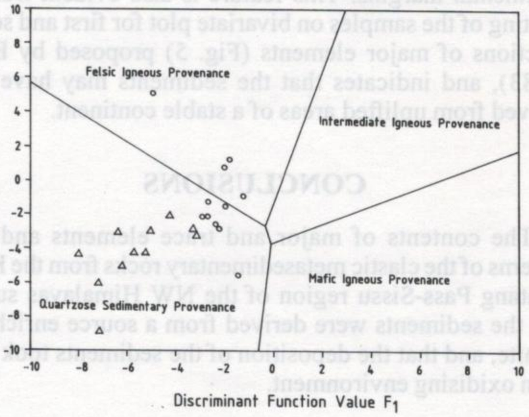

Fig. 4: Discriminant Function 1 against discriminant function 2 variation diagram. Fields after Roser and Korsch (1988), wherein F1 = - 1.733TiO_2 + 0.607Al_2O_3 + 0.76Fe_2O_3(total) - 1.5MgO + 0.616CaO + 0.509Na_2O - 1.224K_2O - 9.09, and F2 = 0.445TiO_2 + 0.07Al_2O_3 - 0.25Fe_2O_3(T) - 1.142MgO + 0.438CaO + 1.475Na_2O + 1.426K_2O - 6.861. Symbols as in Fig. 2.

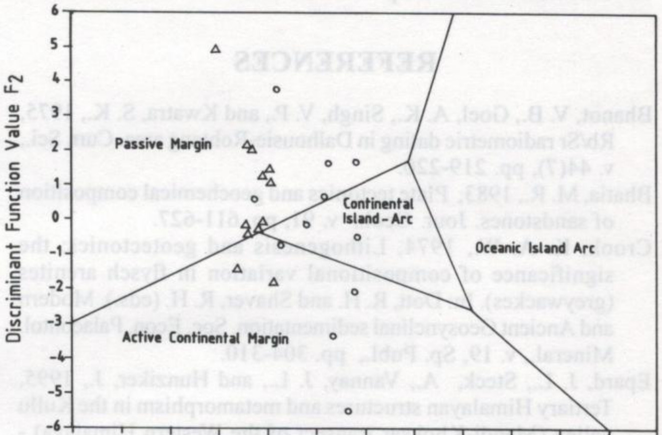

Fig. 5: Discriminant Function 1 against discriminant function 2 variation diagram. Fields after Bhatia (1983), wherein F1 = - 0.0447SiO_2 - 0.972TiO_2 + 0.008Al_2O_3 - 0.267Fe_2O_3 + 0.208FeO - 3.082MnO + 0.14MgO + 0.195CaO + 0.719Na_2O - 0.032K_2O + 7.510P_2O_5 + 0.303, and F2 = - 0.421SiO_2 + 1.988TiO_2 - 0.526Al_2O_3 - 0.551Fe_2O_3 - 1.61FeO + 2.72MnO + 0.881MgO - 0.907CaO - 0.177Na_2O - 1.84K_2O + 7.244P_2O_5 + 43.57. Symbols as in Fig. 2.

Several samples of metapelites and metapsammites show K_2O/Na_2O ratio >1, and have not been greatly affected by post-depositional processes, as they show a progressive decline with increasing SiO_2, despite being subjected to relatively intense regional metamorphism. They occupy the quartz-rich field and a few occupy quartz-intermediate field of Crook (1974) classification scheme. This suggests that, the metapelites and metapsammites were deposited in an environment of transitional phase, from active to passive continental margins. This feature is also evident from the plotting of the samples on bivariate plot for first and second functions of major elements (Fig. 5) proposed by Bhatia (1983), and indicates that the sediments may have been derived from uplifted areas of a stable continent.

CONCLUSIONS

The contents of major and trace elements and REE patterns of the clastic metasedimentary rocks from the Kullu-Rohtang Pass-Sissu region of the NW Himalayas suggest that the sediments were derived from a source enriched in granite, and that the deposition of the sediments took place in an oxidising environment.

ACKNOWLEDGEMENTS

We are grateful to the Director, Wadia Institute of Himalayan Geology, Dehradun, for providing facilities and giving permission to publish this work. Thanks are due to Drs P. P. Khanna and N. K. Saini for their help during the analytical work. We are also thankful to Professor K. K. Sharma for his help in the field.

REFERENCES

Bhanot, V. B., Goel, A. K., Singh, V. P., and Kwatra, S. K., 1975, Rb/Sr radiometric dating in Dalhousie-Rohtang area. Curr. Sci., v. 44(7), pp. 219-220.

Bhatia, M. R., 1983, Plate tectonics and geochemical composition of sandstones. Jour. Geol., v. 91, pp. 611-627.

Crook, K. A. W., 1974, Lithogenesis and geotectonics: the significance of compositional variation in flysch arenites (greywackes). In: Dott, R. H. and Shaver, R. H. (eds.), Modern and Ancient Geosynclinal sedimentation. Soc. Econ. Palaeontol. Mineral., v. 19, Sp. Publ., pp. 304-310.

Epard, J. L., Steck, A., Vannay, J. L., and Hunziker, J., 1995, Tertiary Himalayan structures and metamorphism in the Kullu valley (Mandi-Khoksar transect of the Western Himalaya) - Shiker Beh Nappe and Crystalline Nappe. Schweiz. Mineral. Petrogr. Mitt., v. 75, pp. 59-84.

Frank, W., Purtscheller, F., and Thöni, M., 1977, Geology and Petrography of Kulu-South Lahaul area. Collq. Int. Ecolo-Geol. de la Himalayas, *CNRS*, v. 268(2), pp. 147-172.

Kumar, S., 1981, Metamorphism in Mandi-Rohtang Pass area northwest Himalaya. In: Saklani, P. S. (ed.), *Metamorphic tectonics of the Himalaya.* Today and Tomorrow Publication, Delhi, pp. 155-174.

McLennan, S. M., Nance, W. B., and Taylor, S. R., 1980, Rare earth element-thorium correlations in sedimentary rocks, and the composition of the continental crust. Geochim. Cosmochim. Acta., v. 44, pp. 1833-1839.

McLennan, S. M. and Taylors, S. R., 1980, Th and U in sedimentary rocks: crustal evolution and sedimentary recycling. Nature, v. 285, pp. 621-624.

McLennan, S. M., Taylor, S. R., and Kroner, A., 1983, Geochemical evolution of Archean shales from South Africa. I. The Swaziland and Pongola Supergroups. Precamb. Res., v. 22, pp. 93-124.

Misra, D. K. and Tewari, V. C., 1988, Tectonics and sedimentation of the rocks between Mandi and Rohtang, Beas Valley, Himachal Pradesh, India. Geoscience Jour., v. 9, pp. 153-172.

Nance, W. B. and Taylor, S. R., 1976, Rare earth patterns and crustal evolution 1: Australian post-Archean sedimentary rocks. Geochim. Cosmochim. Acta., v. 40, pp. 1539-1551.

Rameshwor Rao, D., Sharma, K. K., and Gopalan, K., 1995, Granitoid rocks of Wangtu Gneissic Complex. Himachal Pradesh: An example of in-situ fractional crystallization and volatile action. Jour. Geol. Soc. India, v. 46, pp. 5-14.

Rashid, S. A., 1996, *Petrology and geochemical studies of granitiods and associated rocks occurring in Kulu-Larji-Rampur window, Himachal Pradesh, India.* Ph.D. Thesis, Aligarh Muslim University, Aligarh, 184 p.

Roser, B. P. and Korsch, R. J., 1986, Determination of tectonic setting of Sandstone-Mudstone suites using SiO_2 content and K_2O/Na_2O ratio. Jour. Geol., v. 94, pp. 635-650.

Roser, B. P. and Korsch, R. J., 1988, Provenance signatures of sandstone-mudstone suites determined using discriminant function analysis of major-element data. Chem. Geol., v. 67, pp. 119-139.

Sun S. S., and McDonough, W. F., 1989, Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and process. In: Saunder, A. D. and Norry, M. J. (eds.), Magmatism in the Ocean Basins. Geol. Soc. Lond., No. 42, Sp. Publ., pp. 313-345.

Taylor, S. R. and McLennan, S. M., 1985, *The Continental Crust: Its composition and evolution*. Blackwell, Oxford, 312 p.

Thöni, M., 1977, Geology, structural evolution and metamorphic zoning in the Kullu valley (Himachal Himalaya, India) with special reference to the reversed metamorphism. Mitt. Ges. Geol. Bergbaustud. Österr., v. 24, pp. 125-187.

Valdiya, K. S., 1995, Proterozoic sedimentation and Pan-African geodynamics developed in the Himalaya. Precam. Res., v. 74, pp. 35-55.

Wildeman, T. R. and Haskin, L. A., 1973, Rare earths in Precambrian sediments. Geochim. Cosmochim. Acta., v. 37, pp. 419-438.

Wronkiewicz, D. J. and Condie, K. C., 1989, Geochemistry and provenance of sediments from the Pongola Super Group; South Africa: evidence for a 3.0 Ga old continental craton. Geochim. Cosmochim. Acta., v. 53, pp. 1537-1549.

Yanjing, C. and Yongchao, Z., 1997, Geochemical characteristics and evolution of REE in the Early Precambrian sediments evidence from the southern margin of the North China Craton. Episodes, v. 20(2), pp. 109-116.