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Provenance of the lower Tertiary mudrocks in the Jammu Sub-Himalayan Zone, Jammu and Kashmir State (India), NW Himalaya and its tectonic implications

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ABSTRACT: The lower Tertiary mudrocks are rich in clay minerals, which together form 48–60% whereas quartz forms 30–41% of the bulk minerals. Clay minerals of the Subathu shales are composed of illite, chlorite, and sepiolite. In the mudstones of the Murree Group, illite and chlorite are associated with kaolinite and sepiolite. The illite- and chlorite-bearing suites are indicative of their derivation from metamorphic and magmatic sources. The presence of smectite in the calcrete indicates weathering and soil-forming processes. In SiO_2 vs. K_2O/Na_2O diagram, the mudrocks occupy active continetal margin (ACM) field with a few exceptions, suggesting that they originated from an active continental margin, orogenic belt or strike-slip basin. On the other hand in mudrock maturity index vs. log K_2O/Na_2O plot, the points occupy an area in and above/around phyllo-tectic field. The trace elements values, and Rb/Sr and Ba/Sr ratios are close to the values suggested for active continental margin.

A common presence of illite, chlorite, and sepiolite in the lower Tertiary mudrocks suggests their derivation either from the TransHimalayan schists, phyllites, and granites or from the Higher Himalayan Crystallines and the Indus Suture zone.

Key words: clay mineralogy, provenance, mudrocks, lower Tertiary, NW Himalaya

1. INTRODUCTION

Both the Subathu Formation and the Murree Group, ranging in age from Palaeocene to early Miocene, form inner Tertiary belt of the Sub-Himalayan zone. These lower Tertiary rocks are exposed along the Indian part of the northwestern Himalaya continuous to those of Pakistan (Fig. 1). In Jammu region, the Subathu Formation crops out in isolated manner, whereas the Murree Group rocks extend laterally for several kilometers. The Subathu Formation consists of shale and limestone whereas the Murree Group contains mudstone, siltstone, and sandstone. In the Subathu Formation, mudrocks are of variable colour (black, green, and yellow), texture, and fissility. In the Murree Group, mudrocks are dominated by brown and greenish-yellow colour. The study area is confined to the outcrops of Kalakot tehsil (Rajouri district) where a continuous succession is present as outlier.

Coal beds of the Subathu Formation in the Jammu region are described by Middlemiss (1929) in a mineral survey report of Jammu and Kashmir Government. Singh (1970, 1973) reported foraminifers from Kalakot and adjoining areas, and made four zones on that basis. Singh and Singh (1995) have done detailed coal petrography and suggested limno-telmatic origin of coal in a foreland basin. Singh and Andotra (2000) have done detailed facies analysis and concluded barrier-lagoon and tidal environmental setting for the whole Subathu Formation.

Wadia (1928) suggested a southerly source (Indian Craton) for the Murree rocks and considered them as brackish water deposits. In his classic book on geology of the Himalaya, Gansser (1964) also suggested their derivation from the Indian Craton. Khan et al. (1971) reported marine as well as non-marine fauna from the Murree Group. However, Ranga Rao (1971), and Mehta and Jolly (1989) concluded that non-marine/fresh-water condition started with the start of the Murree sediments deposition. Diagenetic behaviour of the Murree sandstones is described by Singh and Singh (1994) and estuarine environment is suggested by Singh and Singh (1995). Singh (1996, 1999) concluded a northerly source for the Murree sediments based on sandstones mineralogy, nature of rock fragments, and palaeocurrents pattern. The present study highlights the clay minerals distribution and the chemical composition of the lower Tertiary argillaceous rocks, and their possible provenance/tectonic setting.

2. STRATIGRAPHY SETTING

The study area comprises the Subathu Formation, the Murree Group and the Siwalik Group unconformably overlying the Precambrian Sirban Limestone. The base of the Subathu Formation is highly obscure and rarely exposed. Where exposed, the rocks rest unconformably on Pre-Tertiary formations (Bhandari and Agarwal, 1966). In Kalakot and adjoining areas, the unconformity is marked by the presence of chert breccia and bauxite/limonite deposits. The Kalakot anticline (WNW–ESE trending) is part of the regional Riasi-Kotli anticlinal feature and the Sirban Limestone is exposed in the core surrounded by a rim of Tertiary rocks (Fig. 2).

The Murree Group sequence has conformable contact with the underlying Subathu Formation. On the basis of

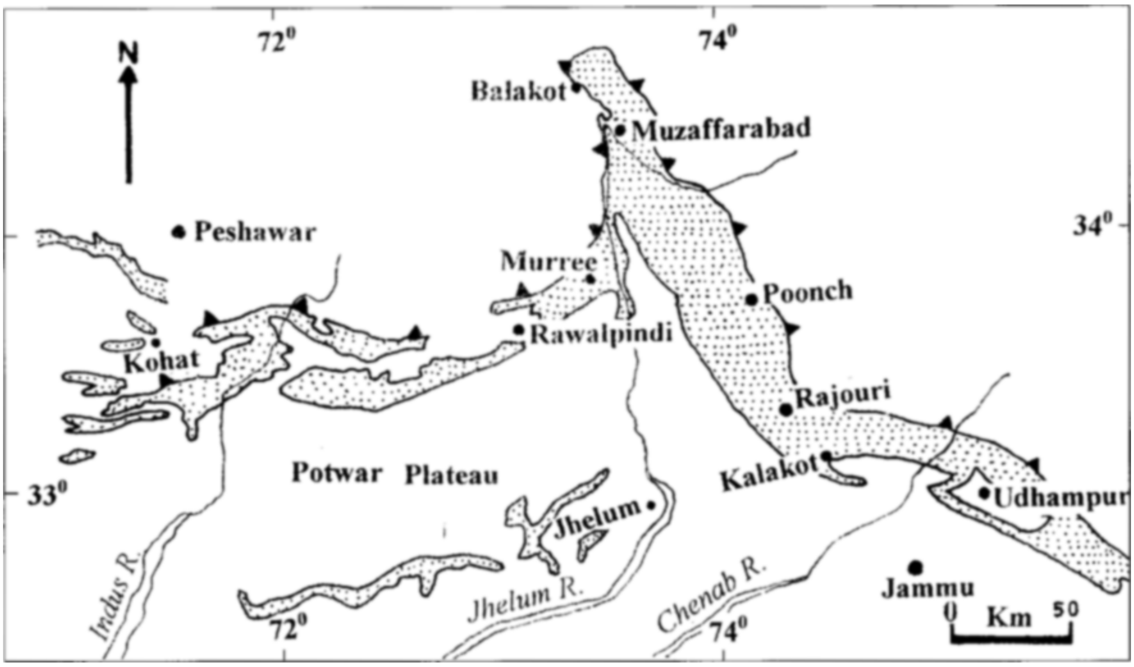

Fig. 1. Location and distribution of the lower Tertiary outcrops (filled area) in the NW Himalaya.

lithology, the Murree Group is classified into the Lower and the Upper Murree formations (Karunakarn and Ranga Rao, 1979). The equivalent rocks have been designated as the Dharamshala Group and Dagshai/Kasauli Formations in Himachal Pradesh (India). The rocks of the Murree Group are conformably overlain by the Siwalik Group. The stratigraphic succession is given in Fig. 3.

3. DESCRIPTION OF THE MUDROCKS

The lower Tertiary mudrocks are variable in colour, grain size, and fissility. The lowermost carbonaceous shale unit is hard, platy and silty, and grades upward to clay-shale with less than 5 mm thick laminae. The carbonaceous shale unit contains 2–3 workable coal seams at Kalakot, Metka, Mahogla, and other places in Jammu region. Green shale occurs in the middle part of the Subathu Formation intercalated with limestone bands in a cyclic manner. This is laminated hard and fissile with 1–2 mm thick laminae. This shale is clay rich having textural similarities with the clay-shale of Potter et al. (1980). The overlying yellow shale is platy, with individual lamina thickness of 2–4 mm. This shale contains silt and clay size minerals where clay dominates over silt, and is classified as a mud-shale.

The purple shale is again platy with lamina thickness 4–6 mm and contains silt and clay in sub-equal amount. This shale yields fresh and brackish-water micro-vertebrate fossils near Kalakot and Mahogla. The brown mudstone of the Murree Group is flaggy with 8–12 mm thick laminae. The lamina planes are darker in colour because of iron oxide staining. This mudstone contains abundant silt size quartz grains, which are intermixed in clay and iron minerals. The greenish-yellow mudstone is very thin bedded (10–20 mm thick laminae). This mudstone is soft and at times bedding planes are not intact due to bioturbation. Silt content is more than the clay in this mudstone. Calcrete forms 0.5–1.2 m thick nodular to massive horizons in the Murree Group. It shows variegated colour where upper part (in a single unit) is richer in white patches than middle and lower parts.

4. EXPERIMENTAL PROCEDURE

Sixteen mudrock and a calcrete sample from Kalakot–Sunderbani road section, and from Mahogla and Devak were subjected for the clay mineral study by a X-ray diffraction technique. The samples were freed from $CaCO_3$ and organic matter with acetic acid and H_2O_2 treatments. Clay fraction of <2 μm size was separated by cetrifugation process. Oriented slides were prepared and they (slides) were scanned using CuKα radiation of 1.5418 wavelength on a Philips Diffractometer (PW 1729). The clay slides were also analysed after glycol treatment and after heating at 550°C for one hour. The clay minerals were identified after comparison with standard d values given in the JCPDS powder data file (1975). A tentative quantification with about 80% accuracy was done by measuring the peaks area suggested by Moore and Reynold (1989). Quartz and feldspars were together estimated by fusing the mudrock samples with sodium bisulphate. Whole rock analyses of the shale and mudstone samples were carried out for determining their

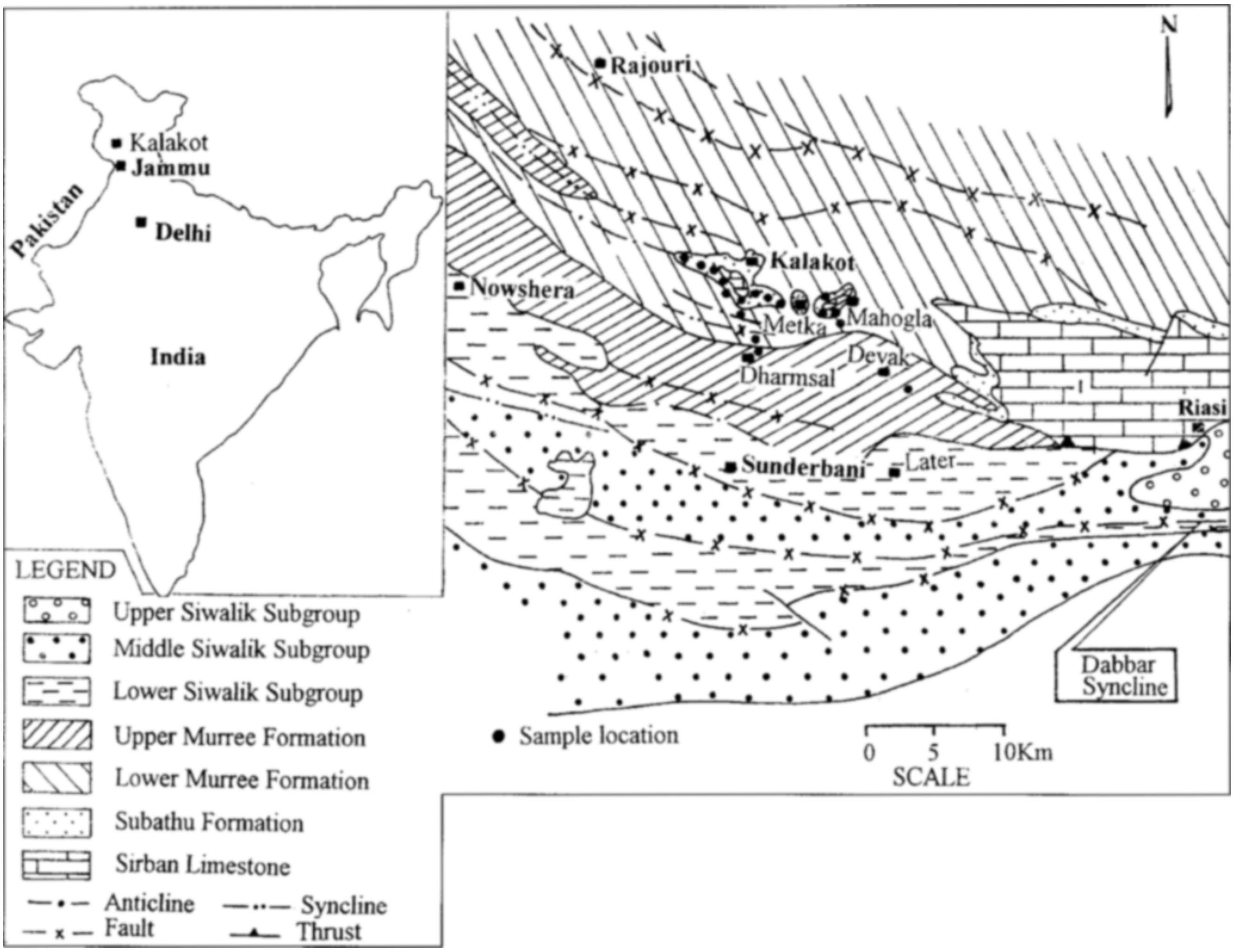

Fig. 2. Geological map of the lower Tertiary belt in part of the Jammu region with structural features and sample locations. Inset: Location of Jammu and Kalakot in the outline map of India.

GROUP	FORMATION	AGE	LITHOLOGY
Siwalik Group	Upper Siwalik Subgroup Middle Siwalik Subgroup Lower Siwalik Subgroup	Pleistocene to Middle Miocene	Conglomerates, sandstones, and claystone
Murree Group	Upper Murree Formation Lower Muree Formation	Early Miocene to Middle Eocene	Sandstone, mudstone, and mud-pebble conglomerate
	Subathu Formation	Middle Eocene to Palaeocene	Carbonaceous shale, green shale, and limestone
	~~ Unconformity ~~~~~~~~~~~~~~		
	Sirban Limestone	Precambrian	

Fig. 3. Stratigraphic succession of the lower Tertiary rocks (sources: Karunakaran and Ranga Rao, 1979; Singh and Singh, 1995; and Singh and Andotra, 2000).

chemical composition. Major oxides were determined through wet methods of rapid silicate analysis described by Shapiro and Brannock (1962). Minor and trace elements were analysed in an atomic absorption spectrophotometer (Perkin Elemer-3100). The results are ploted as SiO_2 vs. K_2O/Na_2O and mudrock maturity index vs. log K_2O/Na_2O diagrams.

5. CLAY MINERALOGY

The bulk samples of the Subathu Formation show appreciable peaks for quartz, illite, chlorite, and sepiolite (Fig. 4). The quantitative determination indicates 30% quartz, 28% illite, 20% chlorite, and 12% sepiolite in green shale; whereas 34% quartz, 23% illite, 18% chlorite, and 13% sepiolite in yellow shale. The brown mudstone of the Murree Group has comparatively more quartz (41%), and chlorite (21%), and less illite (19%), and sepiolite (8%). The greenish-yellow mudstone contains 36% quartz, 20% illite, 11% chlorite, 13% kaolinite, and 7% sepiolite. The rest is occupied by other accessary minerals.

Chlorite occurs in all argillaceous rock samples. 001, 002 003, and 004 peaks are common in air-dried, and glycol-treated samples. When heated at 550°C, the 003 peak disappears. The 2nd and 3rd order peaks of poorly crystalline chlorite disappear upon heating at 550°C (Brindley, 1972). Relative weak peaks at 001 and 003 reflection confirm the presence of Fe-chlorite (Moore and Reynold Jr., 1989). Subathu shale samples show moderate 001 and 003 peaks (Fig. 4), and the Murree mudstones show weak 001 and 003 reflections (Fig. 5) due to the presence of Mg- and Fe-chlorites, respectively.

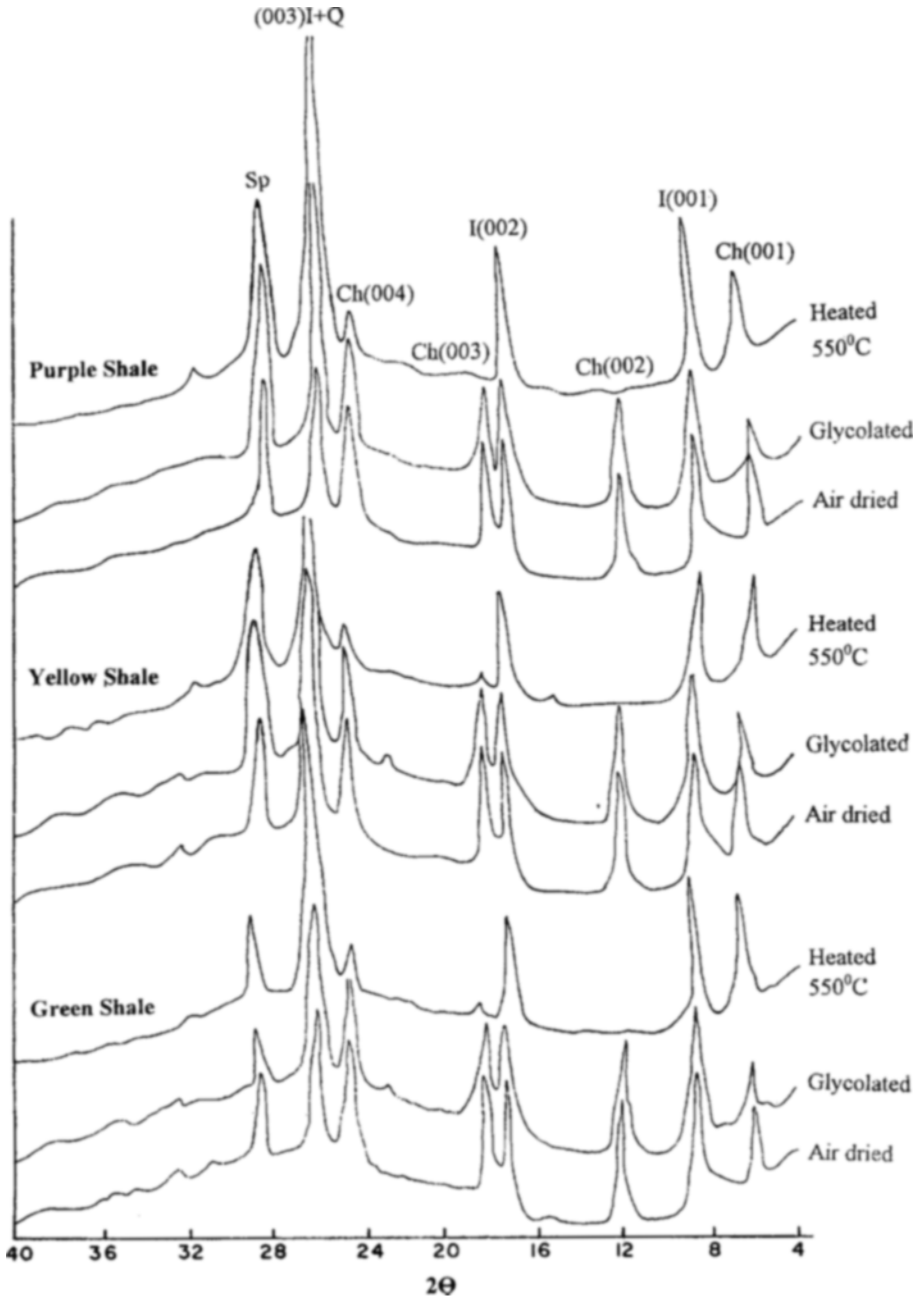

Fig. 4. X-ray diffractograms of clay minerals in Subathu shales from the Jammu region. I: Illite, Ch: Chlorite, Sp: Sepiolite, Q: Quartz.

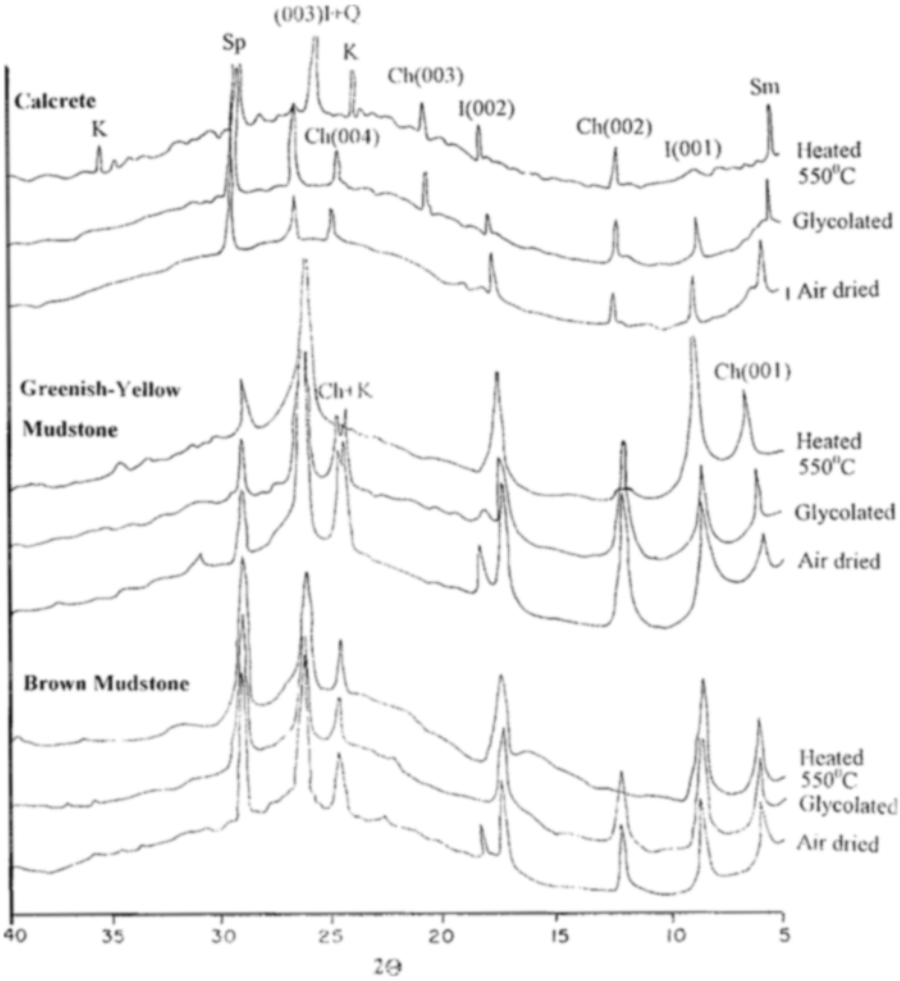

Fig. 5. X-ray diffractogram patterns of the clay fractions of the Murree mudstones and Calcrete. I: Illite, Ch: Chlorite, K: Kaolinite, Sm: Smectite, Sp: Sepiolite, Q: Quartz.

Illite peaks are persistent in the diffractograms of air-dried, glycol-treated and heated samples. The 1st and 3rd order peaks of all clay fractions are of high intensity. Illite peaks decrease in width in the glycolated samples of the Subathu shales. In some Murree mudstone samples, the 2nd and 3rd order peaks become wider after glycol treatment. Dirt et al. (1993) and Lanson et al. (1996) have concluded that increase of illite crystallinity shows a decrease in width at 10 Å band. Since the width of the 10 Å band increases upon glycolation, the illite is poorly crystalline.

The illite and the chlorite peaks of the lower Tertiary mudrocks are comparable in terms of their peak intensity and crystallinity with that of a suspended clay fraction originated from Higher Himalayan phyllite and gneiss of Himachal Pradesh described by Kumar (1999).

Although chlorite exhibits a 3rd order peak of 3.55 Å and kaolinite shows a peak of 3.75 Å (Moore and Reynolds Jr., 1989), kaolinite is poorly identified in the presence of chlorite. In some samples of Murree mudstone, both peaks are prominent and identifiable. Bagati and Kumar (1994) have suggested that kaolinite is generally identified by 2.38 Å reflection. A peak of 2.38 Å in the calcrete sample clearly reveals the presence of kaolinite (Fig. 5).

Smectite peak only appears in calcrete sample where air-dried peak at 6° (15 Å) shifts in glycol-treated and heated samples towards lower side (5° 2θ) with 16–18 Å d spacing. High intensity sepiolite peak of 3 Å is present in all clay samples of the Murree Group and the Subathu shales.

6. CHEMICAL COMPOSITION

The carbonaceous shale of the Subathu Formation has comparatively higher (up to 70.2%) SiO_2 content in comparison with other shales. Silica is present in the range of 56.2 to 63.4% in the green, yellow, and purple shales. In general, Al_2O_3 shows a range between 9.4 and 13.7% (Table 1). Fe_2O_3 and FeO exhibit variable proportions varying from 1.3 to 5.9% and from 2.0 to 6.2%, respectively. Particularly, FeO is greater than Fe_2O_3 in carbonaceous shale with one exception and the yellow shale. Fe_2O_3 is greater than FeO in purple shale. CaO with a range of 3.2–9.2% is generally greater than MgO (2.2–6.1%), except being the green shale showing a reverse order. Although K_2O content is slightly higher than Na_2O, both Na_2O and K_2O form less than 2.1%

Table 1. Chemical constituents and their relative proportion in the lower Tertiary mudrocks.

	Carbonaceous shale				Green shale			Yellow shale		Purple shale			Brown mudstone		Greenishyellow mudstone		Calc-rete
Major oxides (in wt%)																	
SiO_2	62.96	66.36	69.13	70.19	56.24	60.84	60.14	57.27	63.40	58.89	60.40	62.03	62.80	58.28	62.10	59.41	6.10
TiO_2	0.26	0.55	0.49	0.37	0.55	0.72	0.62	0.45	0.34	0.30	0.60	0.59	0.24	0.12	0.32	0.1	0.06
Al_2O_3	11.14	13.66	9.37	10.34	0.72	10.13	9.72	11.73	10.15	12.69	12.74	11.69	13.34	14.28	13.38	10.52	2.90
Fe_2O_3	2.26	4.05	2.91	2.06	5.90	4.15	5.37	1.31	1.87	5.54	4.34	4.57	0.67	1.01	1.13	0.74	0.81
FeO	3.14	3.41	2.04	3.32	6.19	2.52	4.33	3.27	5.24	4.92	3.88	3.74	1.37	1.51	1.15	1.00	0.51
MnO	0.37	0.41	0.39	0.31	0.03	0.06	0.07	0.67	0.77	0.75	0.81	0.91	0.10	0.03	0.01	0.02	0.03
MgO	2.19	3.17	3.04	2.90	5.38	5.04	6.14	4.30	3.01	3.13	3.41	3.20	0.32	0.50	0.36	0.45	10.78
CaO	8.24	3.18	5.41	3.74	7.28	6.66	6.75	7.96	9.24	6.16	7.08	7.01	4.60	7.10	8.62	11.15	32.40
Na_2O	2.10	1.10	1.13	1.34	1.13	1.25	1.34	1.24	1.21	1.37	1.19	1.23	2.60	2.20	1.30	1.28	2.00
K_2O	1.96	1.13	1.46	1.69	1.21	1.21	1.37	1.84	1.33	1.41	1.29	1.26	1.40	3.50	1.10	1.96	1.65
L.O.I.	5.14	2.71	4.03	4.74	5.27	7.78	5.17	10.84	4.13	4.80	4.23	4 .17	8.04	11.23	11.01	13.28	41.60
Trace elements (in ppm)																	
V	13	17	13	10	20	12	16	15	19	14	15	10	14	19	10	12	14
Zr	46	50	35	42	48	46	39	41	56	61	65	46	49	107	78	90	104
Cr	20	22	25	30	26	25	28	30	24	19	22	26	22	21	24	26	20
Co	03	05	03	06	08	05	05	06	03	09	08	04	04	05	02	05	02
Ni	08	07	05	06	09	07	06	05	03	06	05	05	06	05	05	05	03
Rb	135	136	128	137	130	134	142	131	130	145	138	126	134	127	131	127	131
Ba	95	86	112	89	92	106	104	102	86	98	72	94	120	123	74	86	160
Sr	37	26	45	32	35	16	30	41	42	39	34	26	45	17	19	22	37
Rb/Sr	3.64	5.23	2.84	4.28	3.71	2.12	4.73	3.19	3.09	3.71	4.05	4.80	2.97	7.40	6.89	5.70	3.52
Ba/Sr	2.56	3.30	2.48	2.78	2.62	6.62	3.46	2.48	2.04	2.51	2.11	3.60	2.66	7.23	3.89	3.90	4.32

Abbreviation: L.O.I.=Loss on ignition.

of the bulk Subathu shale samples.

In purple/dark brown and greenish-yellow mudstones of the Murree Group, SiO_2 content is in a range of 58.3–62.8% and Al_2O_3 in a range of 10.5–14.2%. FeO (1.0–1.5%) is slightly higher than that of Fe_2O_3 (0.7–1.1%) in brown as well as greenish-yellow mudstones. CaO with a range of 4.6 to 11.1% is appreciably greater than MgO (0.3–0.5%). Na_2O (1.3–2.6%) and K_2O (1.1–3.5%) show no definite trend in the Murree mudstones. The calcrete sample (Table 1) is rich in CaO (32.4%) and MgO (10.8%), but poor in SiO_2 (6.1%) and Al_2O_3 (2.9%).

Trace elements such as vanadium, cobalt, and nickel are less than 20 ppm in all varieties of the lower Tertiary mudrocks. Elemental concentration of chromium is in a range of 20–30 ppm in the Subathu shales and 21–26 ppm in the Murree mudstones. In these rocks, barium content varies from 72 to 123 ppm, strontium varies from 16 to 45 ppm and rubidium shows a range of 126 to 145 ppm (Table 1).

7. DISCUSSION

Clay mineral distribution depends on the mineral composition of the source rock, mixing of water masses and chemical modification (Chamley, 1989; Algan, 1994). Clay diagenetic modifications affecting sediments buried less than 2 kilometres are usually much less important than the modifications induced by changes in tectonic activity, climate, palaeocirculation or detrital sources (Chamley, 1989). Nature of grain contacts and minus cement porosity in the sandstones indicate that Murree sediments were buried below 2000 m in the Jammu region (Singh and Singh, 1994). The underlying Subathu sediments in the study area have a maximum thickness of about 140 m. Lower depth of burial for the lower Tertiary rocks suggests that chemical modification during diagenesis might be of lesser extent.

Clay fractions of the Subathu shales contain illite and chlorite, and subordinate sepiolite whereas the Murree mudstones contain illite, chlorite, sepiolite, kaolinite, and smectite (only in calcrete). Irion and Zolmer (1990) have suggested that illite and chlorite primarily originate from various metamorphic and magmatic rocks whereas kaolinite is the product of weathering on earth surface. The presence of poorly crystalline chlorite in all mudrocks indicates that the provenance had been chlorite-rich schists and phyllites. Intense physical weathering has been responsible for the abundance of this mineral as a detrital constituent in the lower Tertiary argillaceous rocks. Detrital illite of poor crystallinity suggests its derivation from an illite-rich source.

Phyllite, schists, gneisses, and granites of the Kohistan–Ladakh arc and Himalayan arc probably acted as the source for the lower Tertiary mudrocks. The presence of kaolinite in the Murree mudstones indicates surface weathering. Smectite commonly results from weathering of volcanic rocks (Millot, 1970) and sepiolite is an alteration product of smectite under low salinity of water (Moore and Reynolds Jr., 1989). Although smectite is absent in the Subathu shales, sepiolite is present suggesting the presence of volcanic rocks in the source area and alteration of smectite into sepiolite under low salinity condition which persisted during the sedimentation of the Murree rocks. The presence of smectite in the calcrete sample is noteworthy, which indicates soil forming processes and surface weathering.

Chemical composition of detrital sediments is controlled by variable sources, weathering, transportation, and diagenesis. Immobile chemical constituents have little variation in their concentration in sedimentation having greater imprints of their provenance, (e.g. Middleton, 1960; Bhatia, 1983; Roser and Korch, 1986). Similar to sandstones, recycled mudrocks are also poor in quartz and feldspar but rich in phyllosilicates (Bhatia, 1985). As proposed by Bhatia (1985) mudrock maturity index can be calculated on the basis of phyllosilisates and relative quartz/feldspar content. He suggested that juvenile (immature) mudrocks are significantly higher in feldspar compared to mature or recycled mudrocks, which are low in feldspar and enrich in phyllosilicates. The Subathu shales have a range of 34–39% quartz+feldspar as against 54–60% phyllosilicate whereas the Murree mudstones have a range of 41–47% and 48–51%, respectively. High phyllosilicate contents indicate a dominantly sedimentary and metamorphic source terrain. In a maturity index vs log K_2O/Na_2O plot (after Bhatia, 1985), only one point of the lower Tertiary mudrocks falls in the phyllo-tectic field and others are above/around it due to high K_2O/Na_2O ratio (Fig. 6). This suggests that the values are nearer to active/passive continental margin, although, the mudrock maturity index is in an intermediate range. Associated Murree sandstones are rich in quartz and rock fragments, and poor in feldspars on the basis of which, Singh (1996) has interpreted a recycled orogenic provenance for them.

Chemical composition of mudrocks is modified during diagenesis. Land et al. (1997) have interpreted that approximately 18 wt% of the Mexico Gulf mudrock has been lost during burial, mostly as $CaCO_3$, H_2O, and SiO_2 along with additional Ca, Sr, Fe, and Li. In the same depth interval, K_2O, Rb, Cr, and V have been added. Addition of K_2O, and $CaCO_3$ can be accounted for the imbalance of these oxides between sandstones and mudstones (Milliken et al., 1994; Land et al., 1997). Although the Murree mudstones are interbedded with sandstones and there are chances of gain/loss of some of the elements, there is no abnormality in elemental composition except for CaO and MgO (e.g. Singh, 1996) which occur in the form of pore-filling cement as calcite and dolomite.

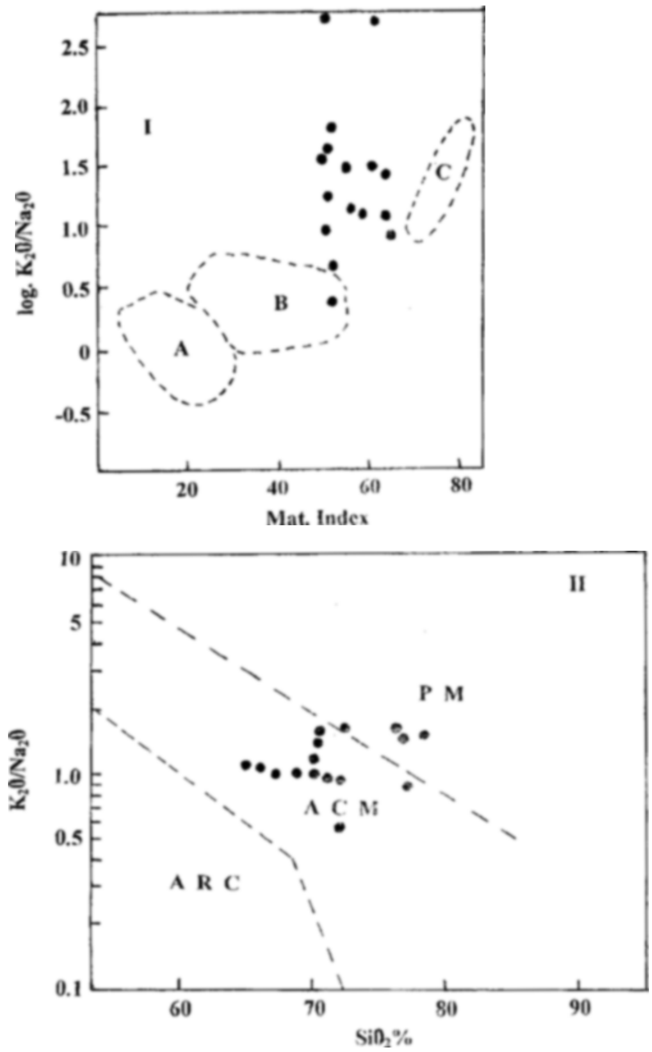

Fig. 6. I. Mudrock maturity index vs. log K_2O/Na_2O plot (after Bhatia, 1985). A: Tectic Field, B: Phyllo-tectic field, C: Phyllic field. II. SiO_2 vs. K_2O/Na_2O diagram for the lower Tertiary mudrocks (after Roser and Korsch, 1986). ARC: Arc, ACM: Active continental margin, PM: Passive continental margin.

Bhatia (1985) has suggested that mudrocks of both active, and passive continental margins can be distinguished by high Rb/Sr, Ba/Sr ratios, and abudant Cr and Ni contents. In the lower Tertiary mudrocks, both Rb/Sr, Ba/Sr ratio, and Cr and Ni contents are close to the values (Bhatia, 1985) for the active continental margin and much lower than the passive margin. In SiO_2 vs. K_2O/Na_2O diagram (after Roser and Korsch, 1986), most of the points in the plot occupy the active continental margin (ACM) field (Fig. 6) with an intermediate K_2O/Na_2O ratio and low SiO_2 values. Roser and Korsch (1986) have included fold-thrust and pull-apart basins in their active continental margin field. On this basis, we can suggest that lower Tertiary mudrocks were originated from an orogenic belt in a peripheral foreland basin whose ele-

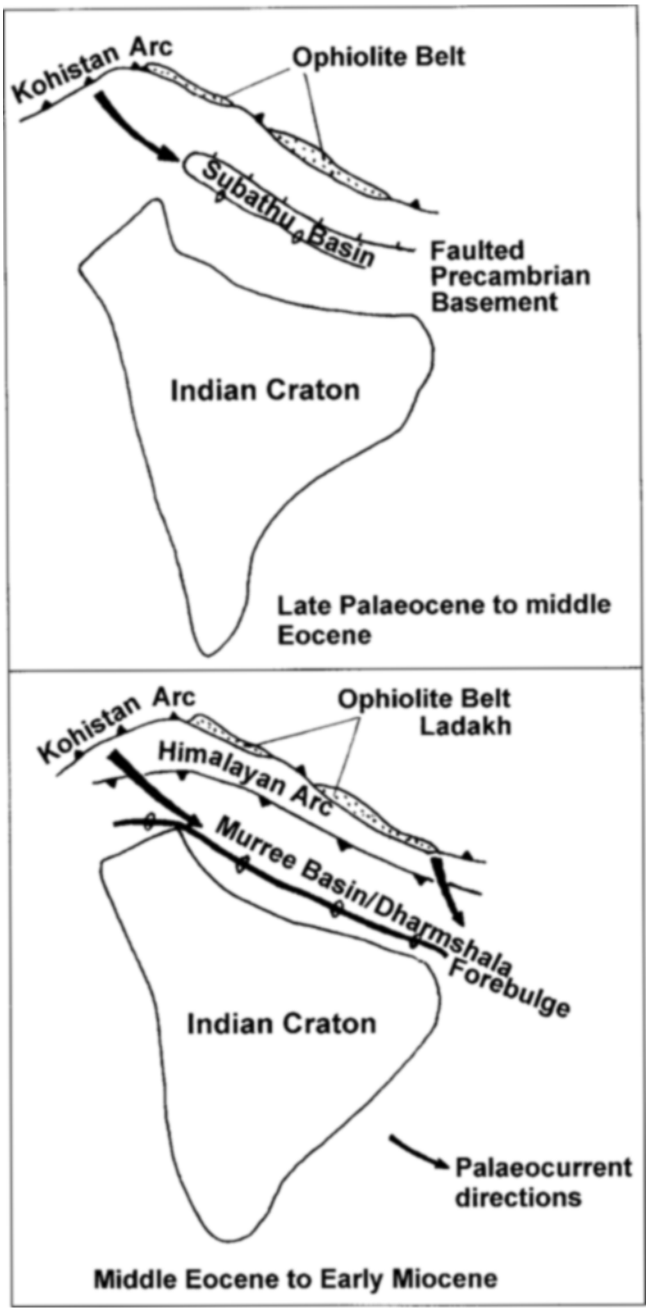

Fig. 7. Cartoon showing provenance, palaeocurrent directions, and palaeogeography during the deposition of the lower Tertiary sediments.

mental concentrations are not in full agreement with the values given by Bhatia (1985) for the phyllo-tectic mudrocks. Appreciable concentration of zirconium, which only comes from the mineral zircon, indicates the presence of plutonic rocks in the source terrain or recycled origin due to its higher stability index. Phyllo-tectic mudrocks are derived from felsic volcanic or granite-gneissic rocks and phyllic mudrocks are of recycled nature with derivation from older sedimentary-metasedimentary rocks (Bhatia, 1985).

Battacharya (1970) has indicated that the lower Tertiary sediments of the Himachal Pradesh containing illite and chlorite were deposited in epicontinental sea. The uniformity in the clay mineral compositions in the Subathu shales is suggestive of uniformity in the provenance. The addition of kaolinite in the Murree mudrocks suggests chemical weathering under warm climatic condition. The magmatic and metamorphic evolution of the Kohistan arc is related to magmatic emplacement (120–80 Ma), very high pressure granulite facies development (80–65 Ma), and conversion of granulite facies into amphibolites and greenschist facies (Ringuette et al., 1998). The rocks of the Kohistan arc comprised of amphibolites, chlorite schists and granites were probable source for the Subathu shales (Fig. 7). Singh (1996) has indicated a S–SE dominant palaeocurrent direction for the Murree Group. During the Murree sedimentation stage, with the uplift in the source terrain, detrital products of the Higher Himalaya including the ophiolite belt were added in the basin from the north (Fig. 7).

8. CONCLUSIONS

The lower Tertiary mudrocks are rich in phyllosilicates and poor in quartz and feldspar. The shales of the Subathu Formation containing illite, chlorite, and sepiolite were derived from metamorphic and granitic provenance of the Kohistan–Ladakh arc. The clay suites in the mudstones of the Murree Group indicate derivation largely from meta-sedimentary and volcanic source. In mudrock maturity index against log K_2O/Na_2O plot, a few mudrocks occupy phyllo-tectic field indicating deposition along a continental margin. The composition of trace elements is close to that of an active continental margin and much lower than that of the passive margin. These mudrocks occupy ACM field in SiO_2 vs. K_2O/Na_2O diagram suggesting their deposition along an active continental margin or in an orogenic belt. The Himalayan orogen has been active with collision of the Indian and Asian continents. At the initial stage of uplift only argillaceous rocks and associated limestones were accumulated. With a substantial uplift, the Murree sandstones and mudstones were deposited in a foreland basin.

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