Petrology and geochemistry of pyrophyllite schist from Rathamara, Keonjhar district, Odisha, India

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ABSTRACT *Mineralo-chemical analyses of three texturally distinct pyrophyllites, namely lamellar, granular and schistose were considered and sampled for the present study. It forms a large lensoidal massif sandwiched unconformably between overlying Koira quartzite and underlying parental, second phase of Singhbhum granite. These pyrophyllites consist chiefly of pyrophyllite, quartz and altered feldspar with sub-ordinate amount of muscovite, chloritoid, tourmaline, zircon, sphene and rutile as accessories. Major oxides analyses of these pyrophyllites revealed depletion of* SiO_2 *and enrichment of* Al_2O_3*.*

Keywords: *Pyrophyllite, Hydrothermal alteration, Geochemical data*

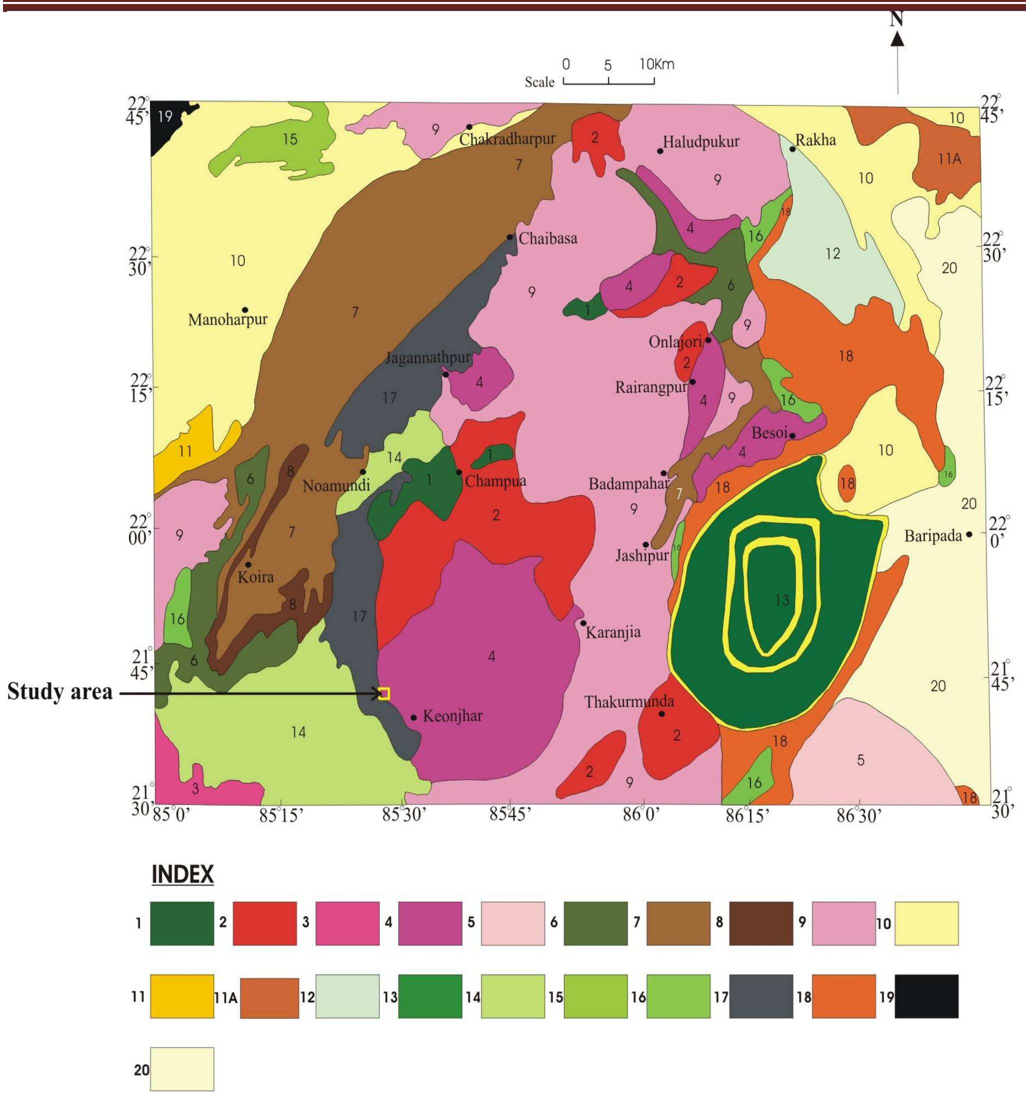
Introduction

Pyrophyllite is a secondary mineral mainly derived from alteration of feldspar which consists of SiO_2 and Al_2O_3 as major constituents and consists of FeO, CaO, MgO, TiO_2 and alkalis as impurities. It occurs in almost all colour shades, mostly white, light grey, greenish pink, brown, buff and green depending upon the proportion of coloured minerals. Pyrophyllite is considered as the one of the most important industrial minerals and is physically similar to the talc. It is mostly used in porcelain, building materials, fire-resistant material, insecticide, ceramic, refractory, paper, rubber, textiles, detergents, plastic and cosmetics industries. It usually occurs in the form of quartz-pyrophyllite schist containing pockets of massive granular pyrophyllite. Saha and Basak (1965) have been worked on pyrophyllitisation of granites of Keonjhar district and observed that the soda plagioclases of granitic rocks (Singhbhum granite phase-II) are more prone to alteration. It mostly occurs as small to large discontinuous lensoidal pockets spatially associated with the Singhbhum granite phase-II.

The present paper discusses field occurrence, petrographic and whole-rock geochemical data of pyrophyllite schist from the Rathamara (21º40′32.8″ N: 85º33′12.3″ E) area and their relationship with Singhbhum granite and the Koira quartzite.

Geological setting

The study area forms a part of the Eastern Indian Shield and is located at the contact of Bonai-Kendujhar belt and Singhbhum Craton (Fig.1). The supracrustals of the Older Metamorphic Group (OMG) are considered to be the oldest rocks (3.5 - 3.6 Ga) in the Singhbhum craton (Saha, 1994; Misra et al., 1999; Misra, 2006). The OMG rocks are intruded by the TTG gneisses which are termed the Older Metamorphic Tonalite Gneiss (OMTG) and dated at 3.44 Ga (Goswami et al., 1995). Both the OMG and OMTG are surrounded by the 3.2 - 3.3 Ga old Singhbhum Granite Complex (SGC) of nearly 10,000 km^2 (Fig. 1) covering major part of Archaean nucleus of this craton. The Iron Ore Group (IOG) is low-grade volcano-sedimentary successions comprising Banded Iron Formation (BIF), bimodal volcanic rocks, ultramafic rocks, chert, shale and minor carbonates. IOG rocks flank the Singhbhum granitoid plutons as three detached belts along the periphery viz. Noamundi- Jamda-Koira, the western IOG; Tomka-Daitari, the southern IOG and Badampahar- Gorumahisani, the eastern IOG. A new occurrence of pyrophyllite schist has been recorded at the contact of Singhbhum granite and Koira quartzite near Rathamara, Keonjhar district, Odisha (Fig.1).



1- Older Metamorphic Group; 2- Older Metamorphic Tonalite Gneiss; 3- Pala Lahara Gneiss; 4- Singhbhum Granite Phase-A (includes phase I and II); 5- Nilgiri Granite; 6- Iron Ore Group lavas; ultramafics; 7- Iron Ore Group shales, tuffs, phyllites; 8- BHJ, BHQ and sandstone-conglomerate of Iron Ore Group; 9- Singhbhum Granite Phase B; Bonai Granite: Chakradharpur Granite; 10- Singhbhum Group pelites, psammipelites; 11- Singhbhum Group quartzite; 11A- Quartzites-pelites; 12- Quartzite - conglomerate-pelite of Dhanjori Group; 13- Simlipal lavas; 14- Jagannathpur lavas; 15- Dalma Lavas; 16- Proterozoic Gabbro-anothosite-ultramafics; 17- Kolhan Group and equivalents; 18- Mayurbhanj Granite; 19- Chhotanagpur granite gneiss (CGG) 20- Alluvium; Tertiaries

Fig. 1: Geological map (modified after Saha, 1994) of the Central Singhbhum Craton, North Odisha showing location of the study area.

Geology of the study area

Pyrophyllite schist is exposed in NW-SE trending hillock underlain by granodiorite belonging to Singhbhum granite phase-II (Fig.2). The pyrophyllite bodies are mostly confined to hill top which is capped by Koira quartzite of variable thickness. It is a leucocratic, coarse to medium grained, massive and foliated rock at places schistose which is mainly composed of quartz and pyrophyllite along with minor muscovite and sericite. In this rock, anhedral coarse grains of quartz and subhedral grains of altered feldspars are embedded in a matrix consisting of pyrophyllite and muscovite which is prominently foliated. The pyrophyllite flakes are coarse grained which can split into individuals flakes or lamellae (Fig.3a). At places, schistose variety of pyrophyllite schist has also been observed (Fig.3b). Granulose variety occurs as small pockets within pyrophyllite. It lacks in schistosity and comprises of a mosaic of fine granular pyrophyllite and quartz exhibiting a granulose texture (Fig.3c). Later quartz veins intrusions are also noticed within it (Fig.3d). Pyrophyllites schist show angular unconformity with overlying Koira quartzite (Fig.3e). Varying thickness of palaeosol is immediately noticed at the contact between Koira quartzite and pyrophyllite schist (Fig.3f).

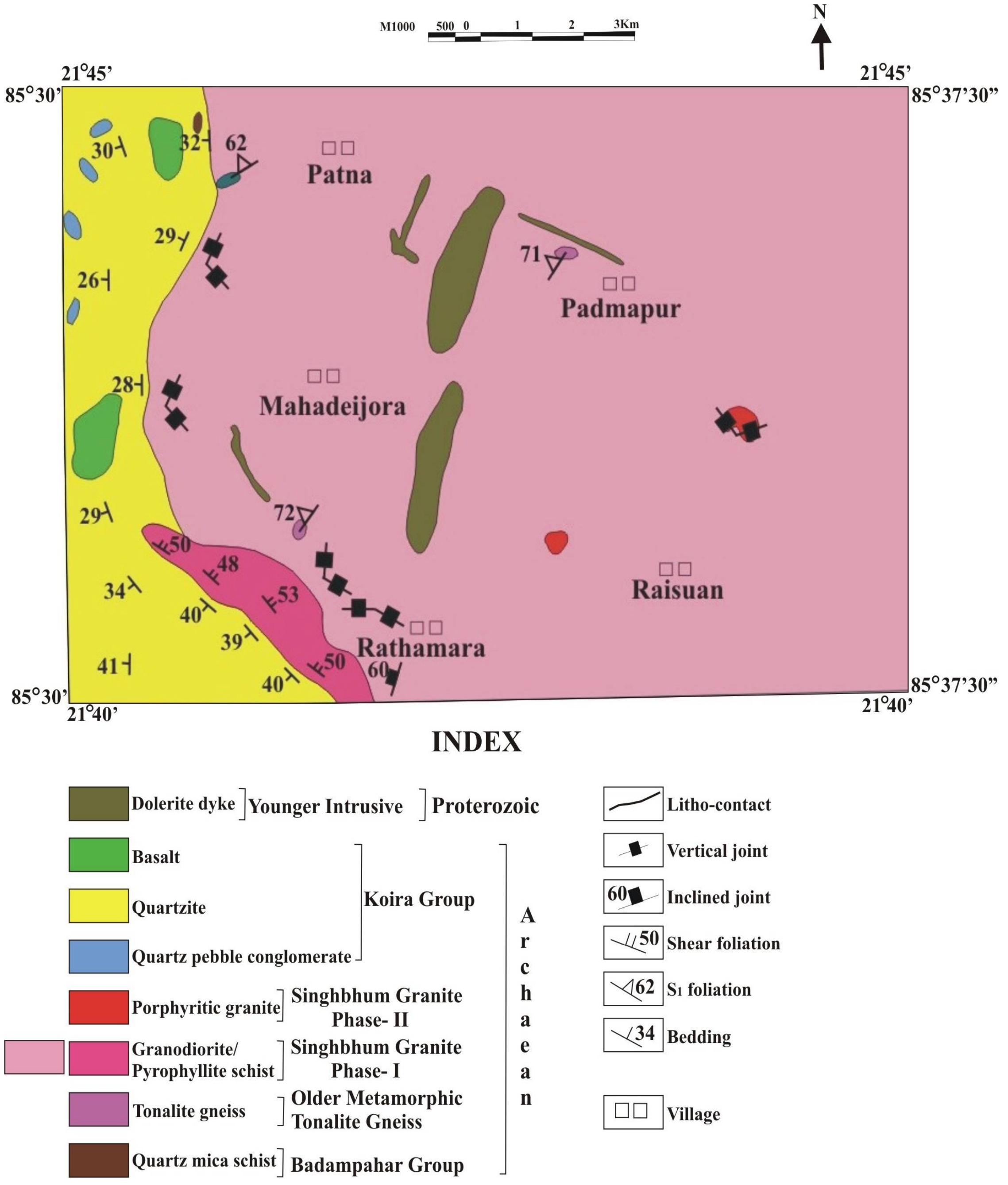


Fig.2: Geological map of the study area showing the occurrence of pyrophyllite schist.

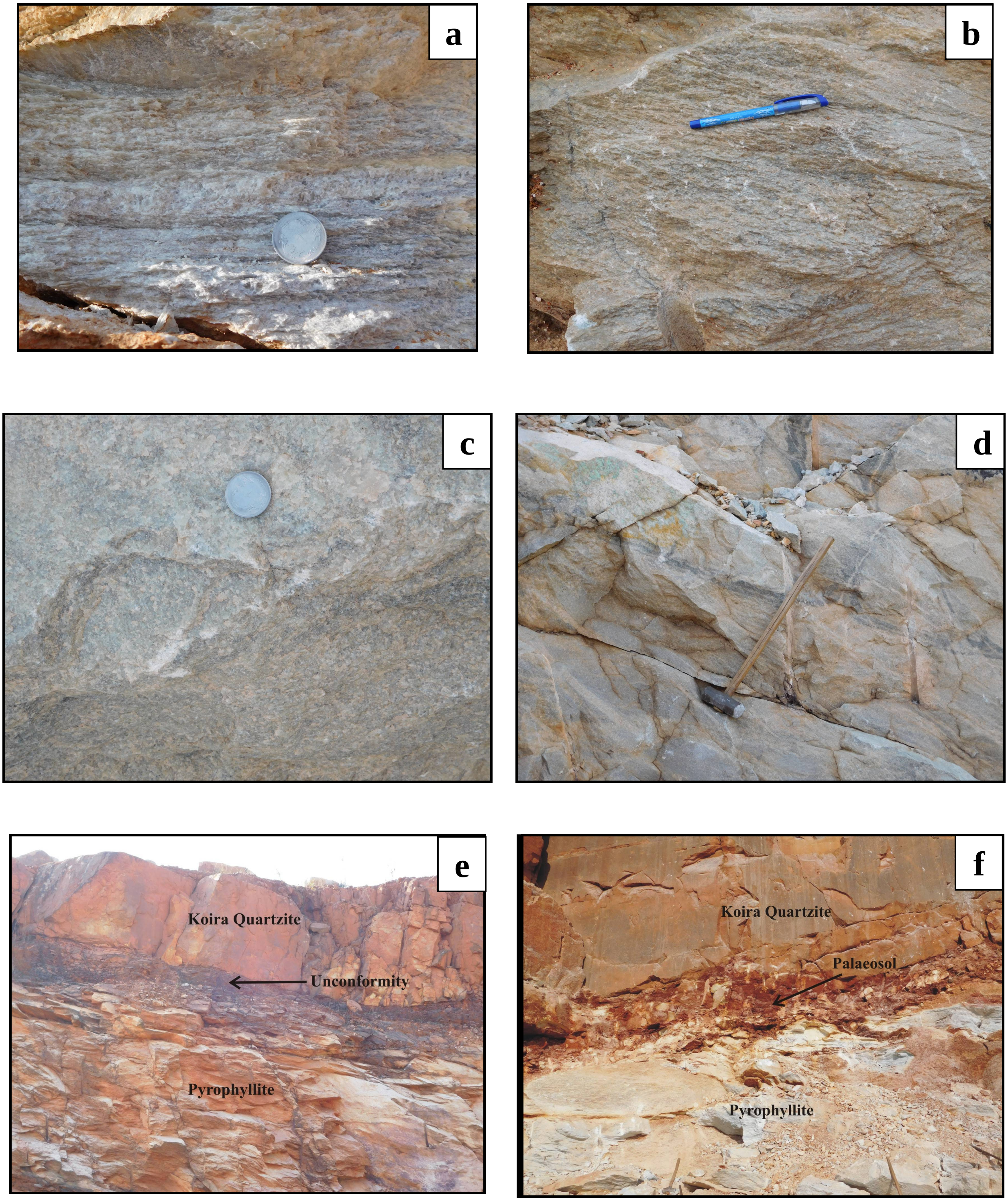


Fig.3: (a) Pyrophyllite as coarse to medium flakes along with flaky muscovite. **(b)** Fine to medium grained schistose variety of pyrophyllite. **(c)** Lack of schistosity in the granulose pyrophyllite. **(d)** Quartz vein intrusion in granulose pyrophyllite. **(e)** Moderately dipping pyrophyllite unconformably overlain by Koira quartzite. **(g)** Palaeosol is noticed between Koira quartzite and pyrophyllite.

Petrography

Ten samples of pyrophyllite schist were selected for petrographic and EPMA studies. Based on structure and texture, three varieties of pyrophyllites have been identified as;

(i) Schistose variety: Schistose variety is containing the mineral assemblages of pyrophyllite (Table-1), quartz and muscovite as dominant minerals. Pyrophyllite as an acicular forms exhibits colourless to greenish colours along with flaky muscovite, which imparts pronounced schistosity (Fig.4a). Accessory mineral phases include rutile, zircon, sphene, apatite, tourmaline, muscovite and chloritoid. Aggregates of tourmaline have been noticed at the contact of the foliation plane. At places, porphyroclast of quartz grains show undulose extinction and subgrains formation (Fig.4b) confirming plastic deformation. Porphyroclast of quartz shows well developed sigma (σ) structure with dextral sense of movement (Fig.4b).

(ii) Flaky variety: The pyrophyllite flakes are coarse grained which can split into individual flakes or lamellae. The essential minerals are pyrophyllite and quartz (Fig.4c). Secondary biotite, muscovite, rutile (Fig.4d), zircon (Fig. 4d) and chloritoid are present in minor proportions.

(iii) Granulose variety: This variety exhibits a granular texture. Irregular and anhedral coarse grains of quartz and subhedral grains of altered feldspars are embedded in the matrix of pyrophyllite. The mineral assemblages are pyrophyllite and quartz as dominant minerals along with muscovite, tourmaline, chloritoid and zircon as accessories.

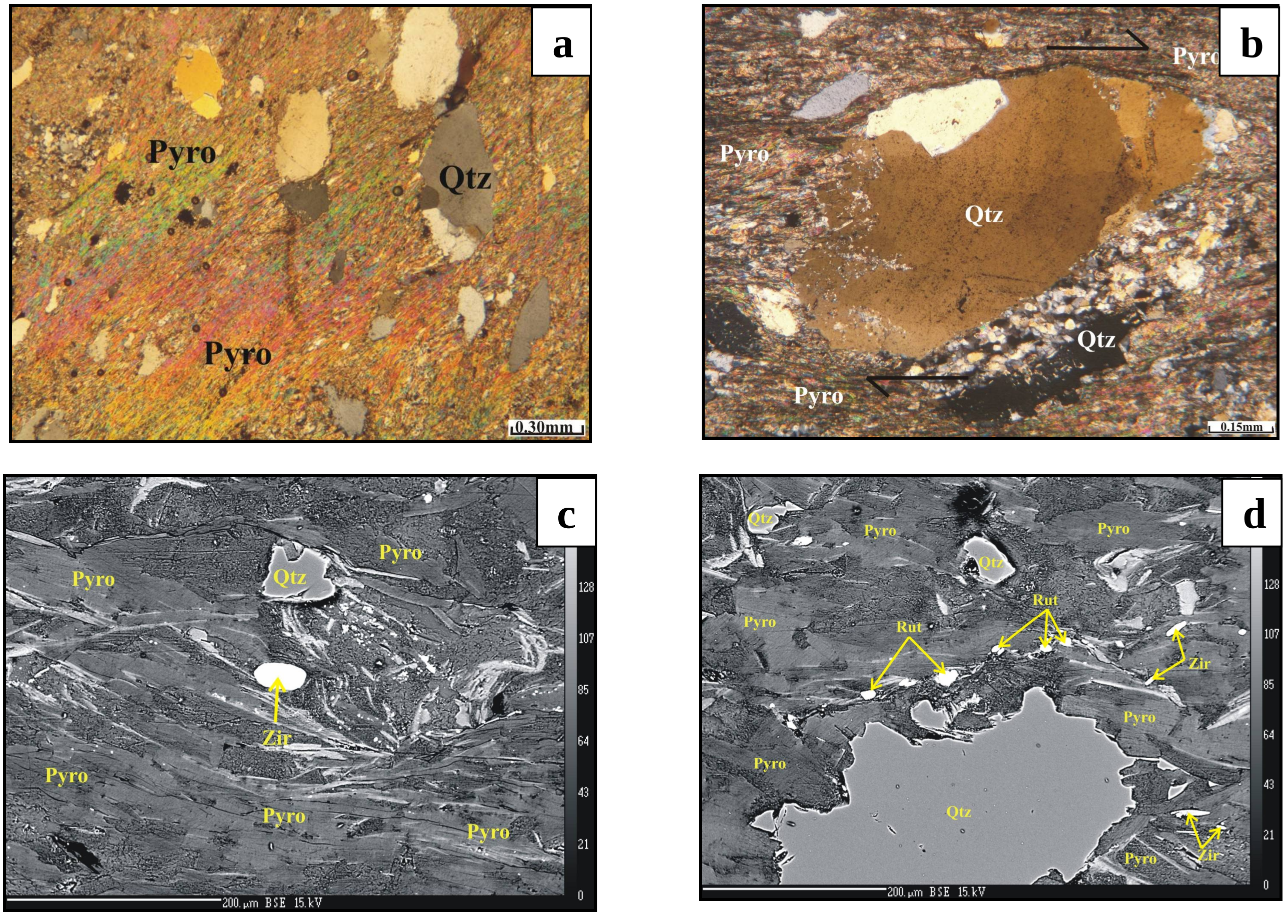


Fig.4: **(a)** Photomicrographs display essential minerals of pyrophyllite schist. **(b)** Quartz porphyroclast shows dextral sense of movement. **(c)** BSE image shows dominant minerals of pyrophyllite schist. **(d)** BSE image display trails of rutile in pyrophyllite schist.

Abbreviations: Pyro; Pyrophyllite, Qtz; Quartz, Zir; Zircon, Rut; Rutile.

Table 1. EPMA data of pyrophyllite schist around Rathamara.

Sample	**KL-570/1**	**KL-570/2**	**KL-570/3**	**KL-570/4**	**KL-570/5**	**KL-570/6**	**KL-570/7**	**KL-570/8**	**KL-570/9**	**KL-570/10**
Na2O	0.03	0.05	0.05	0.02	0.05	0.01	0.05	0.05	0.06	0.02
MgO	0	0	0.01	0	0.02	0.02	0	0	0	0
Al2O3	28.67	28.66	29.77	29.57	29.33	28.79	29.23	29.45	29.28	29.19
SiO2	67.27	67.1	68.6	68.46	68.5	66.87	66.97	67.5	68	67.54
P2O5	0	0	0	0	0.05	0.04	0	0.03	0.01	0
K2O	0.01	0.01	0.05	0.01	0.02	0	0	0	0.05	0.02
CaO	0.01	0.07	0.02	0	0	0	0	0	0	0.02
TiO2	0	0	0.05	0	0.03	0	0	0.01	0.04	0.01
Cr2O3	0.04	0	0	0.04	0	0	0.08	0.05	0	0
MnO	0	0	0.04	0.07	0	0.05	0	0	0	0.03
FeO	0.02	0.06	0.04	0.01	0.04	0.06	0.01	0.05	0.05	0.04
NiO	0	0.01	0	0	0	0	0.04	0	0	0.02
Total	**96.05**	**95.95**	**98.63**	**98.18**	**98.04**	**95.83**	**96.38**	**97.14**	**97.51**	**96.9**

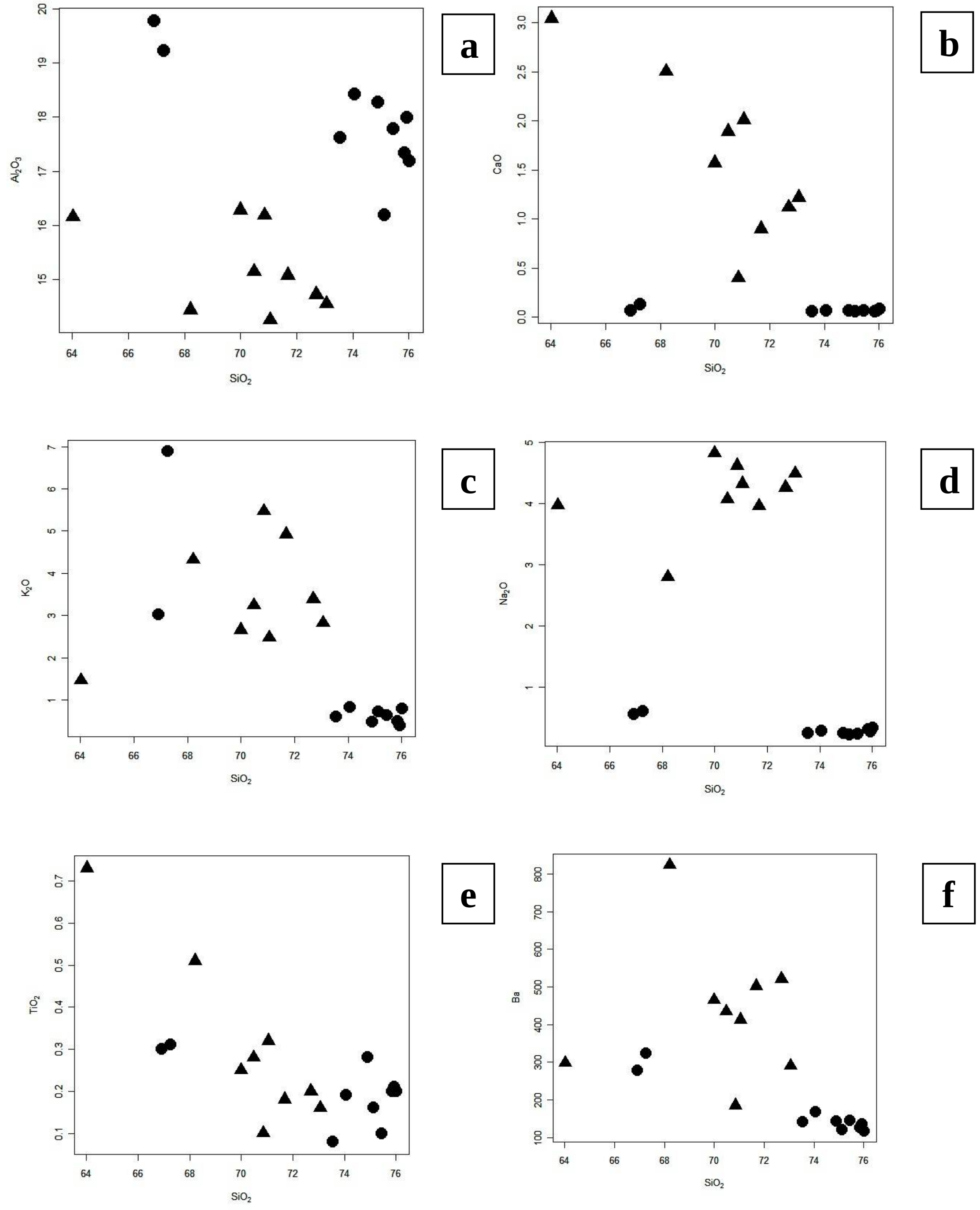
Geochemistry of pyrophyllite schist

Ten representative samples of pyrophyllite schist were analysed for major oxides and trace elements by X-Ray Fluorescene (XRF) and REE by Inductively Coupled Plasma Mass Spectrometer (ICPMS) at Geological Survey of India, Eastern Region Laboratory, Kolkata, India. The analytical results of pyrophyllite schist and granodiorite are presented in the Table-2 and plotted in Harker diagrams.

From the chemical analysis revealed that silica and alumina are the major elements of the pyrophyllite schist with minor to trace amounts of iron, calcium, magnesium, sodium, potassium and titanium elements. These elements are originally presented in the granodiorite which is presumed to be the parent rock of pyrophyllite schist. Analytical results of the pyrophyllite schist shows the intermediate to high contents of SiO_2 (66.9-76.02 wt%), Al_2O_3 (16.19-19.79 wt%), CaO (0.06-0.13 wt%), Na_2O (0.23-0.61

wt%), K_2O (0.39-6.89 wt%) and TiO_2 (0.1-0.31 wt%). Major oxides and trace elements diagrams (Fig.5) are used to interpret the geochemical processes in operation during development of pyrophyllite rock.

Harker diagram of major oxides shows strong negative correlation between SiO_2 and Al_2O_3 (Fig.5a). It is typical of granodiorite weathering in which silica is leached out and the alumina content relatively enriched (Sykes and Moody, 1978). Presence of relatively pure quartz in pyrophyllite schist is an evidenced for high silica activity in the fluid phase during pyrophyllitistion (Sykes and Moody, 1978). Systematic removal of K_2O than Na_2O along with SiO_2 from the parent rock is clearly noticed in Fig.5c & 5d (Goldich, 1938). Ca_2O and TiO_2 display almost identical behaviour during the alteration and their rate of removal from the parent rock is almost same in the order (Fig.5b & 5e). Ba, Rb, Sc, V and Zr (Fig.5f, g, h, j & l) display negative correlation against SiO_2 whereas, Th and Y (Fig.5i & k) reveals positive correlation with SiO_2.



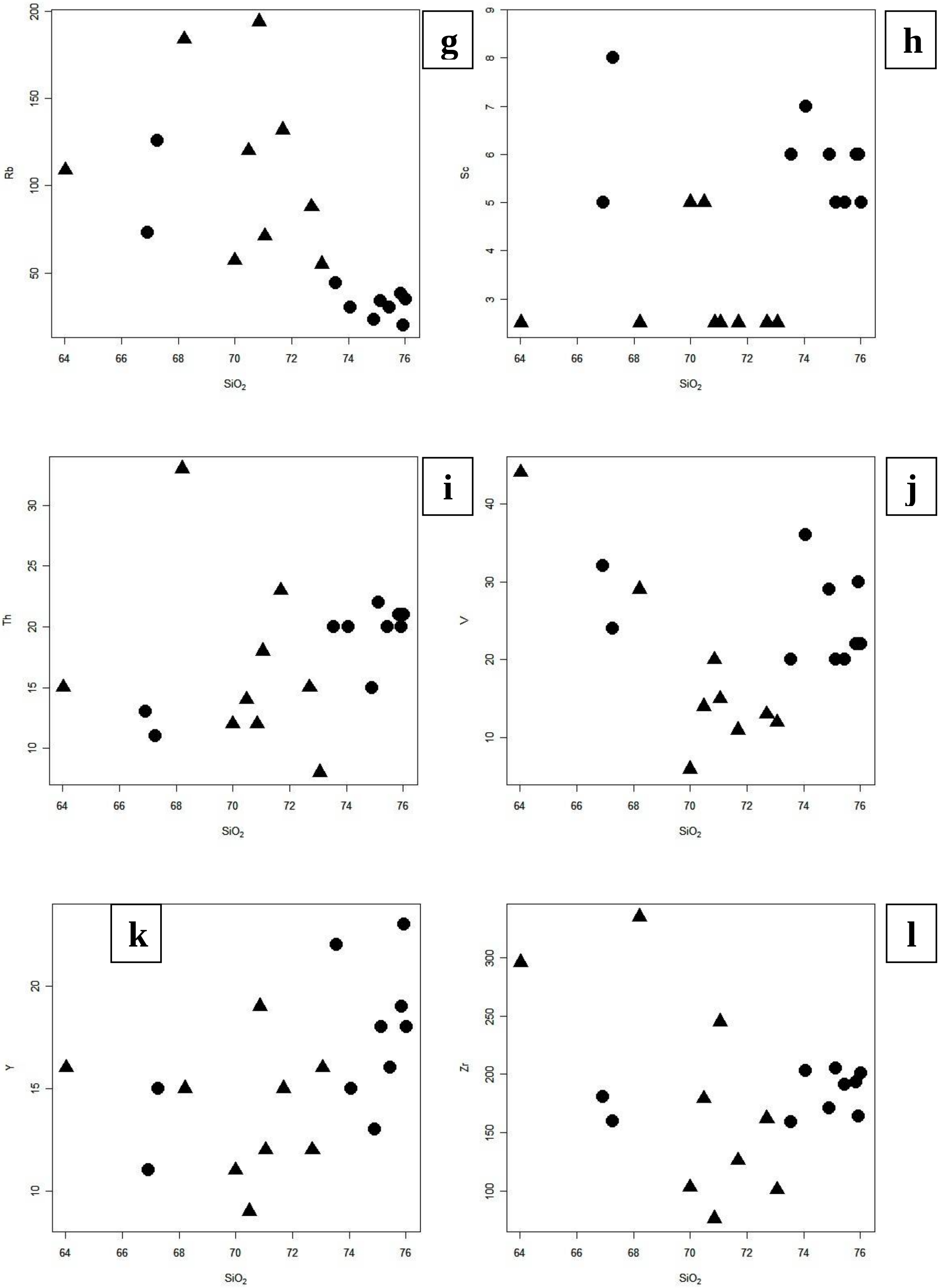


Fig.5. Plots of pyrophyllite schist and granodiorite in binary variation diagrams for selected major oxides and trace elements plotted against SiO_2 (● Pyrophyllite schist; ▲ Granodiorite).

The analysed samples show large variation in total REE contents which varies from 78.13 to 199.33 ppm. REE plot of chondrite normalised (Fig.6) reveals the enrichment of LREE and relatively less enriched HREE contents. They are characterised with moderately steep LREE and almost flat HREE patterns. Strongly negative Eu anomaly is attributed to the alteration of feldspar into pyrophyllite and sericite (Alderman et al., 1980; Ward et al., 1992; Kaur and Mehta, 2007).

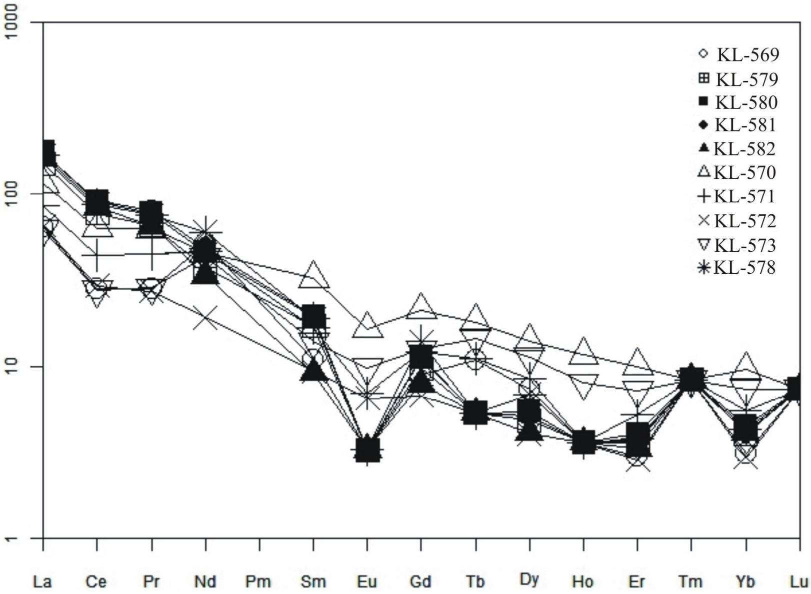


Fig.6. Chondrite normalised REE plots for pyrophyllite (Nakumura, 1974).

Table 2. Whole-rock major (in wt. %), trace element and REE (in ppm) composition of pyrophyllite schist and granodiorite around Rathamara.

Sample No.		SiO_2	Al_2O_3	Fe_2O_3 (T)	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5
KL-569	**Pyrophyllite schist**	66.9	19.8	0.32	0	0.1	0.1	0.56	3	0.3	0
KL-570		75.9	18	0.25	0	0.1	0.1	0.27	0.4	0.2	0
KL-571		74.1	18.4	0.34	0	0.1	0.1	0.29	0.8	0.2	0
KL-572		74.9	18.3	0.24	0	0.1	0.1	0.25	0.5	0.3	0
KL-573		67.3	19.2	0.51	0	0.1	0.1	0.61	6.9	0.3	0.1
KL-578		75.5	17.8	0.29	0	0.1	0.1	0.24	0.6	0.1	0
KL-579		73.5	17.6	0.29	0	0.1	0.1	0.25	0.6	0.1	0
KL-580		75.1	16.2	0.28	0	0.1	0.1	0.23	0.7	0.2	0
KL-581		76	17.2	0.32	0	0.1	0.1	0.33	0.8	0.2	0
KL-582		75.8	17.3	0.25	0	0.1	0.1	0.31	0.5	0.2	0
RG-5	**Granodiorite**	71.05	14.24	2.53	0.04	1.14	2.01	4.32	2.47	0.32	0.14
RG-6		73.06	14.54	1.50	0.03	0.53	1.22	4.49	2.82	0.16	0.04
LK-16		68.22	14.43	3.27	0.07	1.63	2.50	2.80	4.32	0.51	0.14
LK-19		71.68	15.07	1.56	0.02	0.65	0.90	3.96	4.92	0.18	0.05
LK-14		70.86	16.18	1.21	0.04	0.42	0.40	4.62	5.47	0.10	0.05
LK-47		64	16.2	5.11	0.1	2.30	3	3.97	1.5	0.7	0.3
LK-48		70.5	15.1	1.97	0	1.1	1.9	4.07	3.2	0.3	0.1
LK-1274		72.70	14.71	1.89	0.03	0.76	1.12	4.26	3.39	0.20	0.08
LK-1284		69.98	16.28	2.02	0.04	0.74	1.57	4.82	2.66	0.25	0.10

Total	**Ba**	**Sc**	**V**	**Th**	**Pb**	**Ni**	**Nb**	**Co**	**Cu**	**Cr**	**Rb**	**Sr**	**Y**	**Zr**	**La**	**Ce**	**Pr**	**Nd**	**Eu**	**Sm**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
91.1	277	5	32	13	2	11	5	3	6	15	73	59	11	181	21.41	24.25	3.15	32.70	0.25	2.20	2.44	0.51	2.53	0.25	0.66	0.25	0.68	0.25
95.2	135	6	30	20	2	7	5	2	3	15	20	61	23	164	38.12	54.76	7.07	28.69	1.27	6.59	5.86	0.85	4.75	0.81	2.25	0.25	2.09	0.25
94.3	168	7	36	20	2	8	5	1	5	15	30	52	15	203	28.10	38.15	5.02	29.09	0.54	3.40	3.35	0.52	2.89	0.25	1.16	0.25	1.21	0.25
94.6	142	6	29	15	2	10	5	2	3	15	23	42	13	171	21.62	25.34	3.05	12.07	0.50	1.89	1.84	0.25	1.38	0.25	0.64	0.25	0.65	0.25
95.2	324	8	24	11	2	44	9	3	23	15	126	94	15	160	20.49	24.09	3.19	27.14	0.75	2.82	3.43	0.69	3.88	0.56	1.62	0.25	1.61	0.25
94.7	144	5	20	20	2	8	5	1	5	15	30	46	16	191	55.79	75.97	8.40	37.79	0.25	3.84	3.83	0.25	2.34	0.25	0.85	0.25	0.94	0.25
92.5	141	6	20	20	10	6	5	1	1	15	44	60	22	159	50.22	67.11	7.34	23.65	0.25	3.47	2.68	0.25	1.65	0.25	0.81	0.25	0.88	0.25
92.9	120	5	20	22	2	7	5	1	6	15	34	50	18	205	58.53	78.93	8.64	29.01	0.25	3.94	3.12	0.25	1.86	0.25	0.91	0.25	0.99	0.25
95.1	117	5	22	21	5	10	5	1	1	15	35	53	18	201	58.43	80.03	8.95	30.48	0.25	3.95	3.07	0.25	1.76	0.25	0.81	0.25	0.91	0.25
94.6	125	6	22	21	5	6	5	1	5	15	38	46	19	193	53.62	72.47	7.33	21.20	0.25	1.85	2.16	0.25	1.39	0.25	0.74	0.25	0.90	0.25
98.26	413	3	15	18	19	10	9	3	2.5	3	71	349	12	245														
98.39	290	3	12	8	15	5	6	5	2.5	3	55	518	16	101														
97.89	824	3	29	33	39	11	15	9	16	3	184	244	15	335														
98.99	502	3	11	23	27	9	5	3	9	3	132	266	15	126														
99.35	185	3	20	12	38	5	8	3	8	3	194	64	19	76														
97.1	298	3	44	15	19	17	14	9	128	66	109	337	16	296														
98.3	435	5	14	14	25	11	7	3	2.5	62	120	299	9	179														
99.14	521	3	13	15	18	6	5	3	2.5	26	88	244	12	162														
98.46	465	5	6	12	16	20	3	3	11	17	57	455	11	103														

Sn	Hf	Ta	Total
3.81	5.76	1.39	**102.50**
2.73	10.57	2.58	**169.49**
28.83	6.79	3.10	**152.90**
2.32	4.90	0.93	**78.13**
2.72	5.73	1.87	**101.08**
1.63	6.04	0.59	**199.28**
1.45	5.74	0.50	**166.76**
1.99	7.39	0.50	**197.06**
1.98	7.09	0.63	**199.33**
2.10	7.19	0.87	**173.07**

Petrogenesis of pyrophyllite schist

Pyrophyllite schist of the all over world is associated with diverse precursor rocks in varying geological setting. Pyrophyllites have been reported from various precursor rocks viz. high alumina tuffs and breccias of dacitic and rhyolitic composition (Zen, 1961), shale (Henderson, 1970; Bucher and Frey, 1994), Precambrian metavolcanics (Sykes and Moody, 1978; Sahoo, 2006), high alumina tuffs (Bryndzia, 1988; Uygun and Solkoglu, 2002) and Archaean Singhbhum granite phase-II (Das et al., 2012). Pyrophyllite deposits are also developed due to hydrothermal activity and low to medium grade of metamorphism (Hilderbrand, 1961; Zen, 1961; Sharma, 1979; Cornish, 1983; Evans and Guggenheim, 1988; Brown et al., 2006). Experimental research revealed that pyrophyllite is a stable phase within a temperature range of 375 to 420ºC under varying P_{H2O} in an acidic environment (Roy and Osborn, 1954).

The mineralogy and petrography of the pyrophyllite schist indicate leaching mechanism like alteration (feldspar replaced by pyrophyllite). The linear trend between silica and alumina (Fig.5a) is marked a classical weathering profiles as observed at the Carolina schist belt (Sykes and Moody, 1978). At this time, silica is leached out and the alumina content is comparatively enriched. Zen (1961) proposed that weathering produced the protolith for the pyrophyllite deposits. The incidence of pure quartz in pyrophyllite mineralized zones is the confirmation for high silica activity in the fluid phase through pyrophyllitisation. Zen (1961) proposed the reactions for albite and orthoclase of the parent rock for alteration to form pyrophyllite and is furnished below:

$$2KAlSi_3O_8 + 9H_2O + 2H^+ = Al_2Si_2O_5(OH)_4 + 2K^+ + 4H_4SiO_4$$

$$2NAlSi_3O_8 + 9H_2O + 2H^+ = Al_2Si_2O_5(OH)_4 + 2Na^+ + 4H_4SiO_4$$

Both Ba and Rb are mobile elements and can be lost during alteration (Fig. 5f & 5g). Considerable scatter in the geochemical data of pyrophyllite schist may be due to alteration and followed by low grade metamorphism of parent granitic rock (Smith and Smith, 1976).

Conclusion

Pyrophyllite schist of the study area is characterized by a range of textural varieties viz. schistose, flaky and granulose. It is mostly used in ceramics, refractory, fiberglass, fillings, paper and plastic industry. The mode of occurrence and mineral assemblage of the pyrophyllite schist at Rathamara indicated the formation of this rock is a low to medium temperature from the parent granite rock (Singhbhum granite phase- II) through hydrothermal alteration.

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