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RESEARCH ARTICLE

Petrological and Geochemical Characteristics of Al-rich Pelitic Granulites/Paragneiss from Thana, District-Bhilwara Rajasthan: Implication for Its Origin

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ARTICLE INFO

Article history
Received: 23 June 2022
Revised: 25 July 2022
Accepted: 29 July 2022
Published Online: 10 August 2022

Keywords:
Petrogeochemistry
Protolith
Al-rich pelitic granulites/paragneiss
Tectonic settings and origin

ABSTRACT

Al-rich pelitic granulites/paragneiss are frequently observed in the medium- to high-grade metamorphic rocks of Thana. It is dominantly composed of sillimanite-kyanite-garnet-biotite-plagioclase-k-feldspar and a subordinate amount of quartz. Garnet both xenoblastic as well as idioblastic is wrapped around by flaky minerals. These Al-rich pelitic granulites are the result of the metamorphism of pre-existing sedimentary rocks under medium to high grade P-T conditions and consist essentially of sillimanite-kyanite-staurolite-garnet-biotite bearing Al-rich pelitic granulites/paragneiss. The geochemical data reflect that Thana pelitic granulite is of S-type and peraluminous in nature. Geochemically, the protolith for these Al-rich pelitic granulites/paragneiss is shale or greywacke. Paper records the petrography, geochemical characters and probable origin of these Al-rich pelitic granulites/paragneiss.

1. Introduction

The granulites of Rajasthan occur as enclaves in the Banded Gneissic Complex (BGC), Heron (1917, 1935 and 1953) [1-3] and Gupta (1934) [4]. It is dominantly composed of sillimanite-kyanite-garnet-biotite-plagioclase-k-feldspar and a subordinate amount of quartz. Garnet both xenoblastic as well as idioblastic is wrapped round by flaky minerals. Geochronological studies indicate that the granulites evolved during the late-Paleoproterozoic between ca. 1725 and ca. 1622 Ma Sarkar et al. (1989) [5]; Joshi et al., (1993) [6]; Fareeduddin et al., (1994) [7] and Roy et al., (2005) [8]; Buick et al., (2006) [9]; Rao et al., (2011) [10] The granulite facies rocks include charnockite/enderbite, mafic granulites, khondalites, leptynites and Al-Mg riched metapelites, reported by Sharma, R.S., (1977, 1988 and 1999) [11-13]; Joshi et al., (1993) [14] and Thomas (1995 and 2005) [15,16]; Thomas and Sujata (2008) [17], Thomas and Neeraj, (2011a and b) [18,19]; Thomas and Lalu, (2014) [20]; Kavita and Thomas, (2018) [21], Neeraj and Thomas, (2015) [22] and Thomas, H., and Rana, H. (2020) [23]. Al-rich pelitic granulites/paragneiss are the special type of mixed meta-

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DOI: https://doi.org/10.30564/eps.v1i2.564

morphic of Bhilwara Complex Gupta (1934) [4]. These rocks developed in the SW of Thana area (Figure 1). They are predominantly kyanite-sillimanite-garnet-biotite gneiss. Between Thana and Shivpura village the paragneiss is embedded in hornblende-biotite gneiss. In the NE of Thana and near Shivpura the paragneiss banding becomes thin and small and the rocks contain sillimanite-garnet and staurolite-kyanite-garnet. Small lensoid bodies containing enderbite and metanorite were found in paragneiss in NE of Thana and Shivpura villages. The main rock types exposed in the area are pelitic granulite/paragneiss, charnockite/enderbite, metanorite, gneisses. The main aim of the present paper is to: (i) provide petrographic and geochemical characteristics of pelitic granulite/paragneiss; (ii) find out the petrogenesis of pelitic granulite/paragneiss; (iii) placement of these rocks in the tectonic history of the banded gneissic complex of central Rajasthan.

2. Geological Setting

Heron (1917, 1935 and 1953) [1-3] and Gupta (1934, Figure 1) [4] have classified the Precambrian metamorphic rocks of Rajasthan into four stratigraphic units. They introduced the term "Banded Gneissic Complex" to designate the Archaean Basement rocks of the Central Mewar region. The different geological formations of Central Mewar (which includes the present Udaipur and Bhilwara districts) are summarized after Gupta (1934) [4] in Tables 1 and 2.

The Sand Mata rocks mapped by Gupta (1934) [4] have been designated by him as Sand Mata paragneiss complex of Pre-Aravalli age. However, in the accompanying map of his Memoir, these paragneisses have been erroneously shown under the Aravalli System, the rocks which unconformably overlie the BGC rocks in Rajasthan. Gupta (1934, Figure 1) [4] called these rocks as "special type of mixed rocks of metamorphic origin" and recognized them as undoubtedly meta-sedimentary rocks of the Pre-Aravalli age. Gupta et al., (1980 and 1997) [24,25] divided the BGC of Central Rajasthan into two tectonic-cum-metamorphic domains i.e. the Sand Mata Complex (granulite facies rocks) towards west and the Mangalwara Complex (amphibolite facies rocks) towards east, which are separated by the northsouth Delwara lineament. In the investigated area, only the Banded Gneissic Complex of Bhilwara Supergroup is exposed and the detailed sequence of the Pre-Aravalli (after Gupta, 1934, p. III) [4], from oldest to youngest is as follows (Table 2):

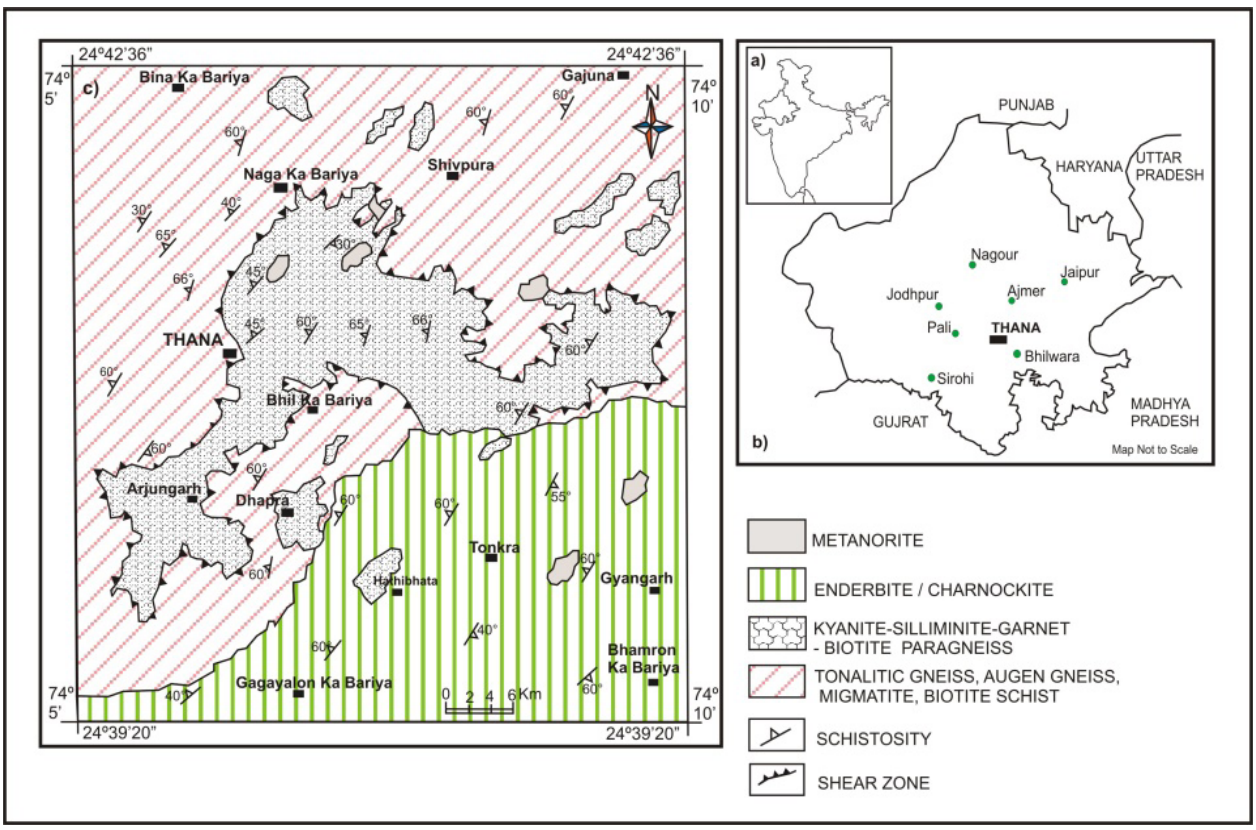


Figure 1. Geological map around Thana, Bhilwara, Rajasthan by author [1], showing different lithounits.

Table 1. The different geological formations of Central Mewar (which includes present Udaipur and Bhilwara districts) are summarized after Gupta (1934) [4] and Gupta et al., 1997 [25].

Mesozoic & Cenozoic		**Deccan Traps, Tertiary Alkaline Complex, Sedimentary and Quaternary sediments**
Palaeozoic		
Proterozoic	Marwar Supergroup	Jodhpur Group, Bilara Group, Nagaur Group
	Malani Igneous Supergroup	
	Vindhyan Supergroup	Lower Vindhyan Group, Upper Vindhyan Group
	Delhi Supergroup	Railo Group, Alwar Group, Ajabgarh Group, Gogunda Group, Khumbhalgarh Group, Sirohi, Punagarh Group, Sindreth Group
	Aravalli Supergroup	Debari Group,Udaipur Group, Bari Lake Group, Kankroli Groupv, Jharol Group, Dovda Group, Nathdwara Group, Lunavada Group
	Bhilwara Supergroup	Rajpur-Dariba Group, Pur-Banera Group, Jahazpur Group, Sawar Group, Ranthambor Group
Archaean	Bhilwara Supergroup	Sandmata Complex, Mangalwara Complex, Hindoli Group

Table 2. The different geological formations of Central Mewar (which includes present Udaipur and Bhilwara districts) are summarized after Gupta (1934) [4].

Banded Gneissic Complex (Bhilwara Supergroup)	------ Paragneiss (Sand Mata) ------ Dolerite ------ Schist ------ Quartz Veins ------- Pegmatite ------- Granite ------- Aplite --------Amphibolite (Epidiorite)

3. Petrography

Al-rich pelitic granulites/paragneiss occupy a substantial portion of the explored area. They are dark, greenish to light in colour and contain garnet, sillimanite, kyanite, staurolite, biotite, K-feldspar, plagioclase, quartz and secondary muscovite and chlorite in several assortments. On the basis of paragenesis, the Al-rich pelitic rocks can be categorized into five major groups.

i. Kyanite-staurolite-garnet-bearing paragneiss
ii. Kyanite-biotite-garnet bearing paragneiss
iii. Sillimanite-garnet-biotite bearing paragneiss
iv. Sillimanite-Kyanite-garnet-biotite bearing paragneiss
v. Andalusite-kyanite-sillimanite-garnet-bearing gneiss

Regardless of the variation in mineralogy and texture, their petrography has been described concurrently to avoid repetition.

Kyanite-Staurolite-Garnet bearing gneiss megascopic characters

The rocks are dark greenish to light, fine to coarse grained with well-developed foliations. Two sets of foliations are evident by the orientation of kyanite, sillimanite, biotite and secondary muscovite.

Microstructure/Texture

The texture is granoblastic to schistose. Garnet and andalusite occur as porphyroblasts, in a few sections, reaction rims of garnet are present around biotite and kyanite/sillimanite and hornfelsic texture is also observed.

Kyanite-Staurolite-Garnet-bearing paragneiss

Kyanite-staurolite-garnet-quartz with secondary muscovite (Sample No.R87/438).

Kyanite-Biotite-Garnet bearing paragneiss

Kyanite-garnet-biotite-kyanite needles-quartz-k-feldspar-plagioclase-sericite-magnetite (Sample No. R87/347).

Sillimanite-Garnet-Biotite bearing paragneiss

Sillimanite-biotite-garnet-quartz-k-feldspar-plagioclase (secondary muscovite-chlorite)-rutile (Sample No. R87/407).

Kyanite-Sillimanite-Biotite-Garnet bearing paragneiss

Sillimanite-kyanite-garnet-biotite-quartz-(secondary muscovite)-K-feldspar-plagioclase-ilmenite (Sample No. R87/248 & 250).

Andalusite-Kyanite-Sillimanite-Garnet bearing gneiss

Andalusite-garnet-biotite-quartz-epidote-magnetite-k-feldspar (Sample No. R87/452).

Microscopic description of minerals

Kyanite

Prisms of varying sizes are interleaved with biotite showing a significant dimensional orientation in a few sections kyanite appears to wrap around garnet porphyroblasts. Its association with garnet, biotite and staurolite suggests the following reactions:

Staurolite + quartz = kyanite + garnet

Biotite + kyanite + quartz = garnet + k-feldspar

The first generation kyanite has broad blades which are scarcely folded. The later generation kyanite is characterized by acicular form and random orientation; they may be called needle kyanite.

Sillimanite

Sillimanite occurs as rectangular to short crystals it envelopes small blades of kyanite and shows cross-cutting relationship with early generation kyanite (KY1). In a few sections sillimanite shows microscopic folding and sometimes sillimanite merges into kyanite needles, these features reveal that the sillimanite event occurred between kyanite (1) and needle kyanite (2).

Garnet

Garnet sizes ranging from 0.4 mm to 0.6 mm few grains are elongated along the fracture plane and have an inclusion of kyanite, biotite, quartz, magnetite, staurolite, rutile and sphene. Garnet is marginally altered into chlorite and, suggests the reaction

Garnet+ fluid = chlorite + quartz + magnetite

Staurolite

Crystals are short prismatic and show a prominent dimensional orientation; it shows sharp contact with garnet and kyanite and appears as inclusions in garnet, indicating the following reactions:

Staurolite + Quartz = Garnet + Kyanite

Biotite

Garnet laths are reddish brown; pleochroism varies from red brown to light brown. Pleochroic haloes around zircon grains are common and biotite shows a clear textural relation with kyanite and sillimanite and imparts an appreciable foliation to the rock. The corroded outline of the biotite and its textural relation with fresh garnet and k-feldspar indicate the following reaction.

Biotite + Sillimanite + Quartz = Garnet + K-feldspar + Water

K-feldspar

It is mostly microcline with clear cross-hatched twinning. Microcline porphyroblasts have inclusions of biotite, kyanite/sillimanite and, garnet which suggests the reaction:

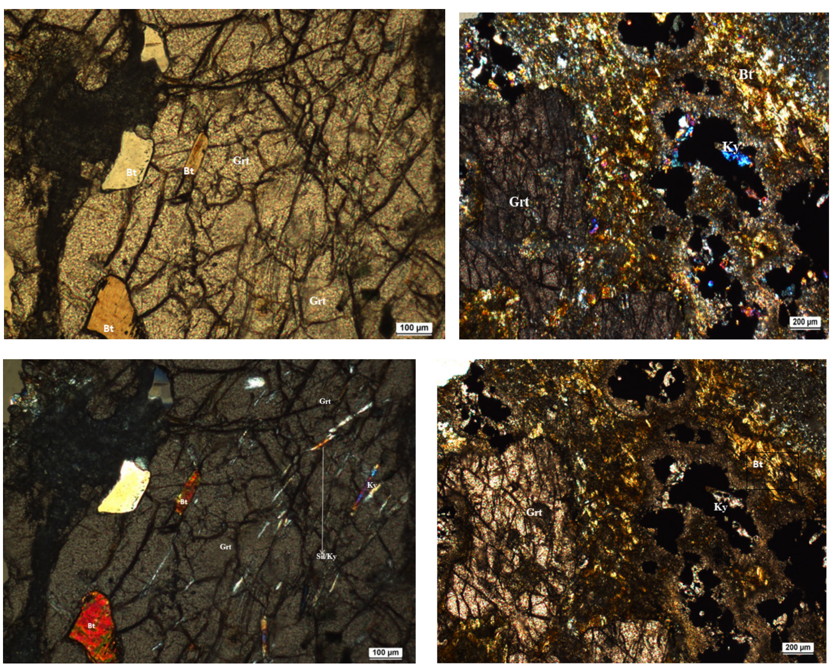
Garnet + K-feldspar + Water = Biotite + Kyanite/Sillimanite + Quartz

Plagioclase

Plagioclase is invariably present in the rocks. The grains are twinned on the albite and Carlsbad laws.

Quartz

Quartz is mainly xenoblastic in shape showing wavy extinction. Quartz is also found as an inclusion in garnet and shows sharp contact with all minerals except staurolite.



Photomicrography: (A & B) garnet porphyroblast showing irregular fractures along with inclusions of biotite and kyanite/sillimanite (sample No. R87/423); Photomicrograph (C & D) showing kyanite interleaved with biotite.

4. Geochemistry and Petrogenesis of Al-rich Pelitic Granulites/Paragneiss

Results of the fifteen selected rock samples of paragneiss/Al-rich pelitic assemblages were analyzed by Atomic absorption spectrometry (AAS) and flame photometry from the Wadia Institute of Himalayan Geology. The major elements, trace elements in (ppm) and Niggli values are shown in Tables 3, 4 and 5 respectively. The rocks of different assemblages show clear chemical differences. The calculated Niggli values are shown in Table 3.

The SiO_2 and Al_2O_3 contents fluctuate between 45.2% to 68.28% wt% and 13.10% to 25.2% wt% respectively. In all the fifteen samples the SiO_2 content is generally > 45% whereas the percentage of Al_2O_3 content is higher in R87/397, R87/293 and R87/342. The ACF and AKF diagrams (Figure 2) clearly indicate that all samples lie within the pelitic field. The rocks have an average Na_2O and K_2O concentration of 1.30% and 2.99% respectively and the average K_2O/Na_2O ratio is 2.3 and their TiO_2 content varies from 0.48% to 2.08%.

Table 3. Major element analyses (wt%) of the Al-rich pelitic granulites/paragneiss from the Thana and adjoining area, district Bhilwara, Rajasthan.

S. No.	Sample NO.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	Total
1	R87/291	50.75	22.26	2.6	10.48	4.64	2.8	0.8	2.4	0.103	0.99	0.16	97.983
2	R87/293	45.2	25.27	2.4	12	4.64	2.2	1	3.4	0.065	1.4	0.09	98.065
3	R87/299	58.13	18.07	2.47	9.92	3.63	2.8	0.8	2.1	0.131	0.723		98.774
4	R87/342	49.8	24.35	3.6	11.17	3.43	2.24	1	1.2	0.17	0.84	0.2	98
5	R87/ 368	68.28	13.1	1.42	4.34	1.41	3.36	3.04	3.1	0.048	1.015	0.27	99.743
6	R87/377	58.13	21.20	1.76	6.56	2.42	2.8	1	3.8	0.037	0.907	0.15	98.764
7	R87/392	69.2	13.9	2.48	5.59	2.02	2.8	1.2	1.7	0.04	0.853	0.13	99.913
8	R87/397	49.8	25.14	3.12	9.08	2.22	3.36	1.2	3.4	0.054	1.123	0.12	98.617
9	R87/409	65.51	14.7	1.37	6.2	1.61	5.6	2	1.4	0.076	0.713	-	99.179
10	R87/423	60.9	20.2	1.9	5.85	2.62	2.25	1.4	3.1	0.06	0.756	-	99.036
11	R87/442	57.21	20.95	1.72	7.17	2.82	3.08	1	3.6	0.078	0.89	0.095	98.613
12	R87/477	65.51	19.38	1.07	4.12	0.6	3.36	1	3.7	0.046	0.48	-	99.246
13	R87/478	58.13	17.55	2.2	12.8	3.02	2.8	0.8	2.2	0.07	1.14	0.13	100.84
14	91/518	66.08	21.28	-	4.99	3.18	0.1	0.29	3.25	-	0.83	-	100
15	91/544	52.31	21.45	-	6.45	4.78	3.03	3.06	6.61	0.14	2.08	-	99.98

Table 4. Trace element (in ppm) of the Al-rich pelitic granulites/paragneiss from the Thana and adjoining area, district Bhilwara, Rajasthan.

Ref. No.	Sample No.	Cu	Co	Li	Ni	Rb	Sr	V	Zn	Rb / Sr
1	R87/291	165	11	22	33	96	68	92	188	1.41
2	R87/293	75	14	26	39	126	31	225	240	4.06
3	R87/299	165	9	8	26	81	76	92	148	1.06
4	R87/342	86	13	9	38	68	47	200	186	1.45
5	R87/ 368	174	9	11	26	103	188	108	147	0.55
6	R87/377	156	9	38	28	183	65	120	140	2.81
7	R87/392	189	9	12	25	68	52	135	161	1.31
8	R87/397	176	12	13	32	73	298	216	204	0.24
9	R87/409	222	9	15	27	53	199	108	107	0.27
10	R87/423	290	10	4	29	161	140	90	156	1.15
11	R87/442	200	13	19	31	93	95	240	126	0.97
12	R87/477	262	7	15	20	89	129	120	136	0.69
13	R87/478	224	11	17	36	91	26	160	234	3.50
Average		183.38	10.61	15.15	30	98.84	108.77	146.62	167.15	0.91

Table 5. Niggli values of Al-rich pelitic granulites/paragneiss from Thana, Bhilwara, Rajasthan.

Sample no.	al	alk	C	mg	fm	Si	ti	p	k
R87/291	36.3	6.37	8.3	0.39	49	140.5	2.04	0.18	0.6
R87/293	38.36	6.95	5.97	0.367	47.7	114.66	2.66	0.09	0.69
R87/299	33.8	6.7	9.5	0.34	49.86	184.8	1.7	-	0.6
R87/342	40.1	4.83	6.7	0.295	48.3	139.2	1.7	0.23	0.44
R87/368	32.96	22.49	15.36	0.36	29.16	291.6	3.25	0.48	0.37
R87/377	42.5	11.56	10.22	0.345	35.6	198.2	2.32	0.21	0.71
R87/392	35.58	9.75	13.2	0.314	41.63	300.68	2.78	0.273	0.48
R87/397	42.28	9.5	10.27	0.25	37.93	142.16	2.4	0.149	0.65
R87/399	33.0	11	23	0.28	33	250	2	-	0.315
R87/423	42.64	11.92	8.63	0.37	36.79	218.26	2.02	-	0.59
R87/442	40.5	10.7	10.8	0.36	37.9	187.9	2.1	0.11	0.7
R87/477	48.53	14.14	15.29	0.172	22.02	278.47	1.46	-	0.788
R87/478	31.88	6.71	9.24	0.265	52.15	179.25	2.64	0.16	0.644
R87/518	52.36	9.85	0.45	0.534	37.34	276.38	2.59	-	0.881
R87/544	35.34	20.11	9.09	0.566	35.46	146.49	4.37	-	0.588

The Harker variation diagrams between SiO_2 and others major oxides (FeO, MgO, Al_2O_3, TiO_2, MnO, Fe_2O_3, K_2O, Na_2O, CaO and P_2O_5; Figure 3a to 3j) shows good correlations which indicates coherent behaviours of element during different processes of metamorphism.

The trace elemental geochemistry of Al-rich pelitic granulites/paragneiss show variable concentration of Cu (75 ppm to 290 ppm; average 83.38 ppm); Li (4 ppm to 38 ppm; average 15.15 ppm); Ni (20 ppm to 39 ppm; average 30 ppm.); Co (7 ppm to 14 ppm; average 10.61 ppm); V (90 ppm to 240 ppm; average 146.62); Zn (107 ppm to 240 ppm; average 167.15 ppm.); Rb (53 ppm to 183 ppm; average 98.84 ppm) and Sr (26 ppm to 298 ppm; average 108.77 ppm) and are enriched in comparison to Rb.

The Harker diagrams between SiO_2 and trace elements (Cu, Li, Ni, Rb, Sr, Co, Zn and V; Figures 4a to 4f), show good correlations, while Rb and Sr show poor correlations, which means the system is more evolved. The Rb/Sr ratios range in between 0.24 ppm to 4.06 ppm and average 0.91 ppm suggestion depletion of Sr.

The Niggli values in Table 3, indicate the silica saturated nature of the Al-rich pelitic granulites/paragneiss. The Niggli values show that the rocks are higher in Al/Alk ratio with an average of 3.60 and low mg number which suggest a highly evolved system.

The plot between K_2O/Al_2O_3 and Na_2O/Al_2O_3 (Figure 5) has clearly differentiated the sedimentary from igneous rocks, Garrels and Machenzie (1971) [26]. It is evident that all samples fall within the field specified for sedimentary rock.

The plots between Al_2O_3 against ($K_2O + Na_2O$) (Figure 6) after Goel, and Chaudhari, (1979) [27] also indicate all samples fall within the sedimentary bearing field. Similarly A-CN-K diagram (Figure 7) after Nesbitt, et al., (2003) [28] also shows sedimentary fields. The chemical variations have also been studied with the help of Niggli values. The 'mg' versus 'c' diagram (Figure 8) most of the samples lie in the pelitic and semi-pelite field Leake, (1964) [29]. Only two samples lie outside this field, this could be due to the post metamorphic changes during poly-metamorphism.

The diagram SiO_2/Al_2O_3 versus K_2O/Na_2O (Figure 9) shows A, B, C and D the compositional fields of pelitic greywacke, pelites, greywacke and arkose Wimmenaure and Fortscher (1984) [30] and the compositional field of greywacke and shale, Condie, et al., (1991) [31], respectively. It is evident from the diagram that most samples fall within the pelitic field specified by Condie, et al., (1991) [31] However, some samples are scattered due to the poly metamorphism or partially metasomatism.

The Niggli values are also used to examine the nature of the protolith. When the values are plotted in the 100 mg-c-(al-alk) diagram (Figure 10) Leake, (1964) [29] all the samples fall within the shale-field Leake, (1964) [29], when c values are plotted against (al-alk) (Figure 11) [26] of the samples fall within the shale and greywacke filed. Few samples show slight scattering which may be due to the poly-metamorphism.

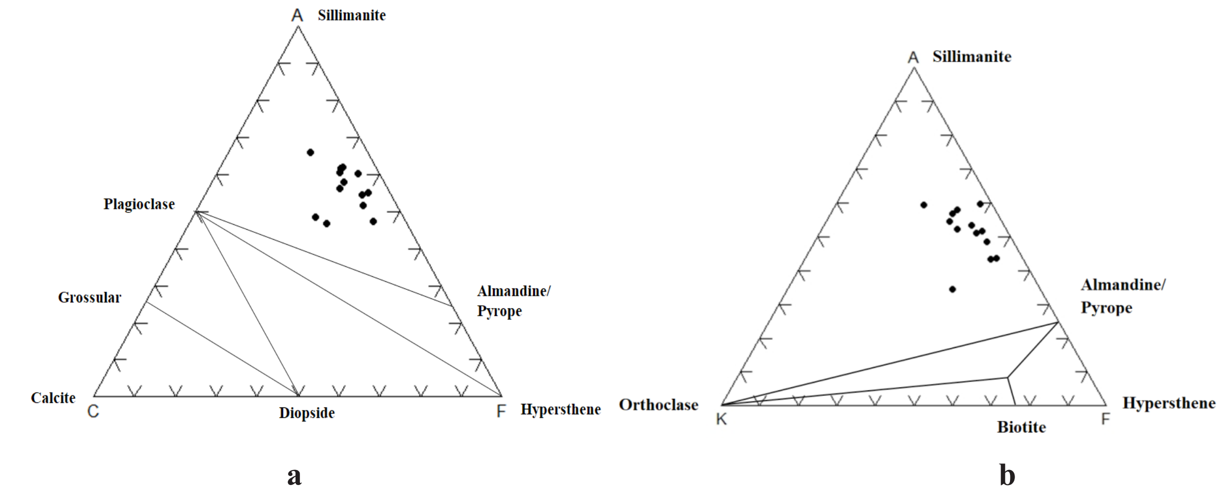
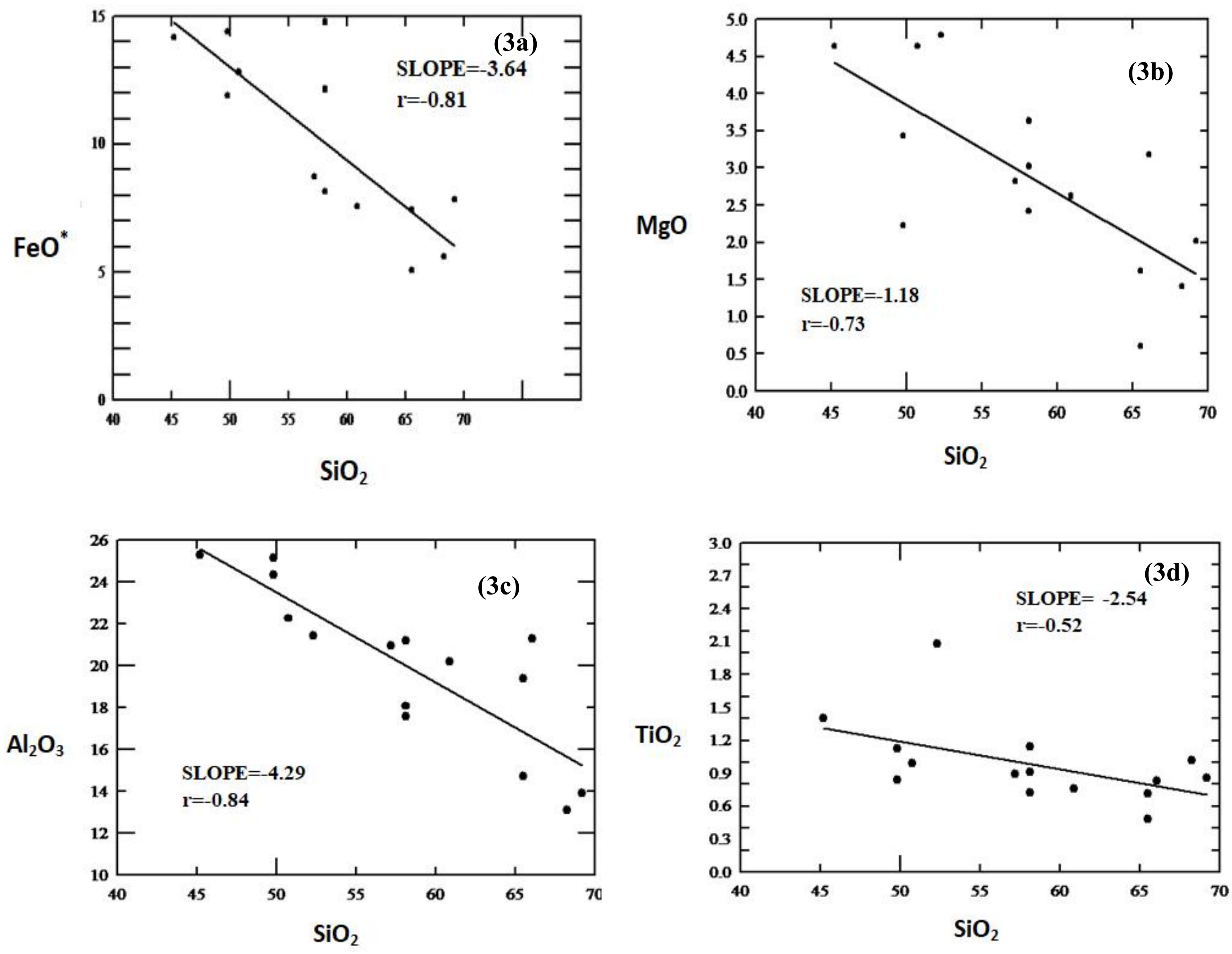


Figure 2. ACF and AKF diagrams showing chemical analysis of Al-rich pelitic granulites/paragneiss from Thana.



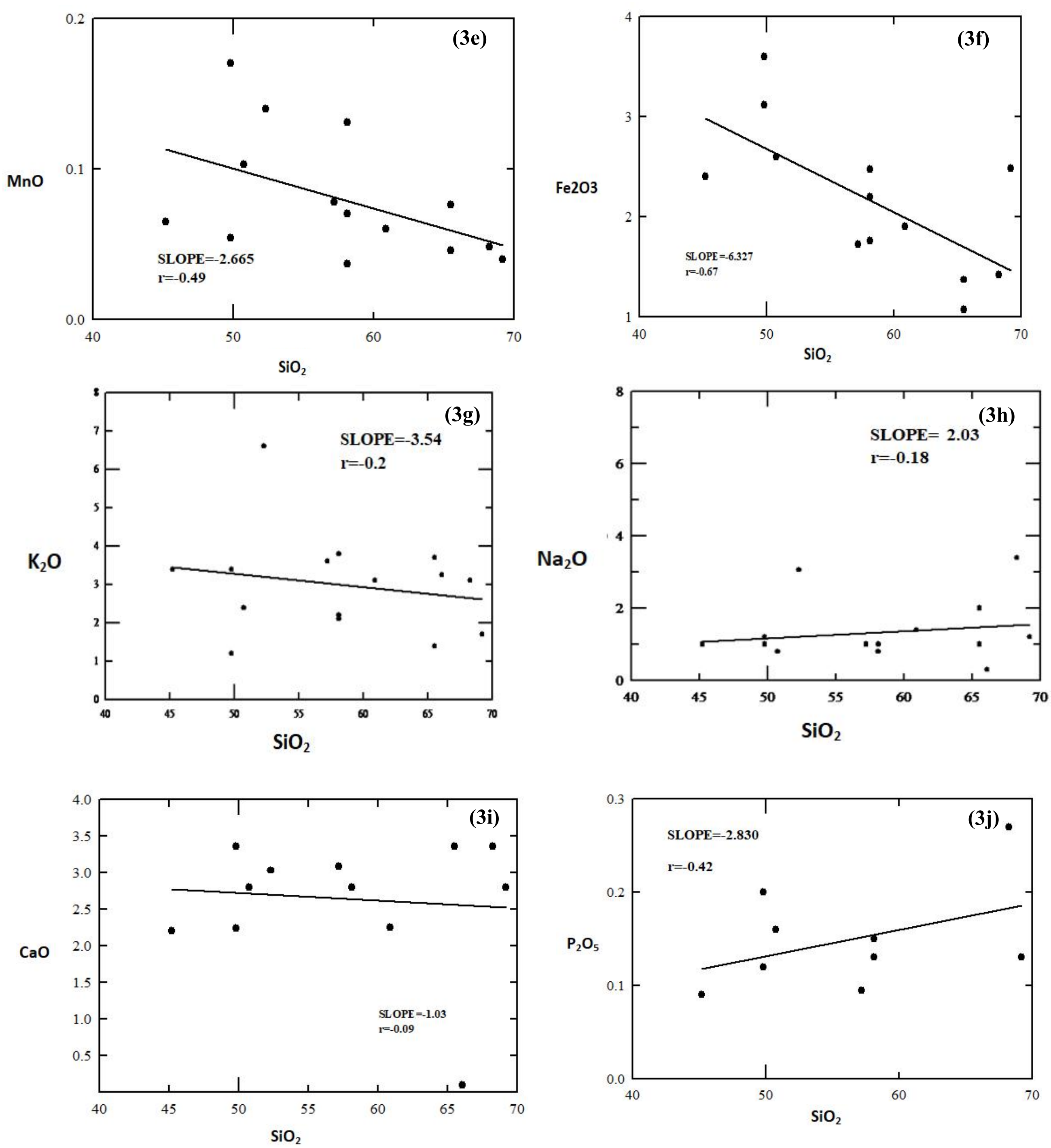


Figure 3. Harker Variation diagrams for Al-rich pelitic granulites/paragneiss from Thana.

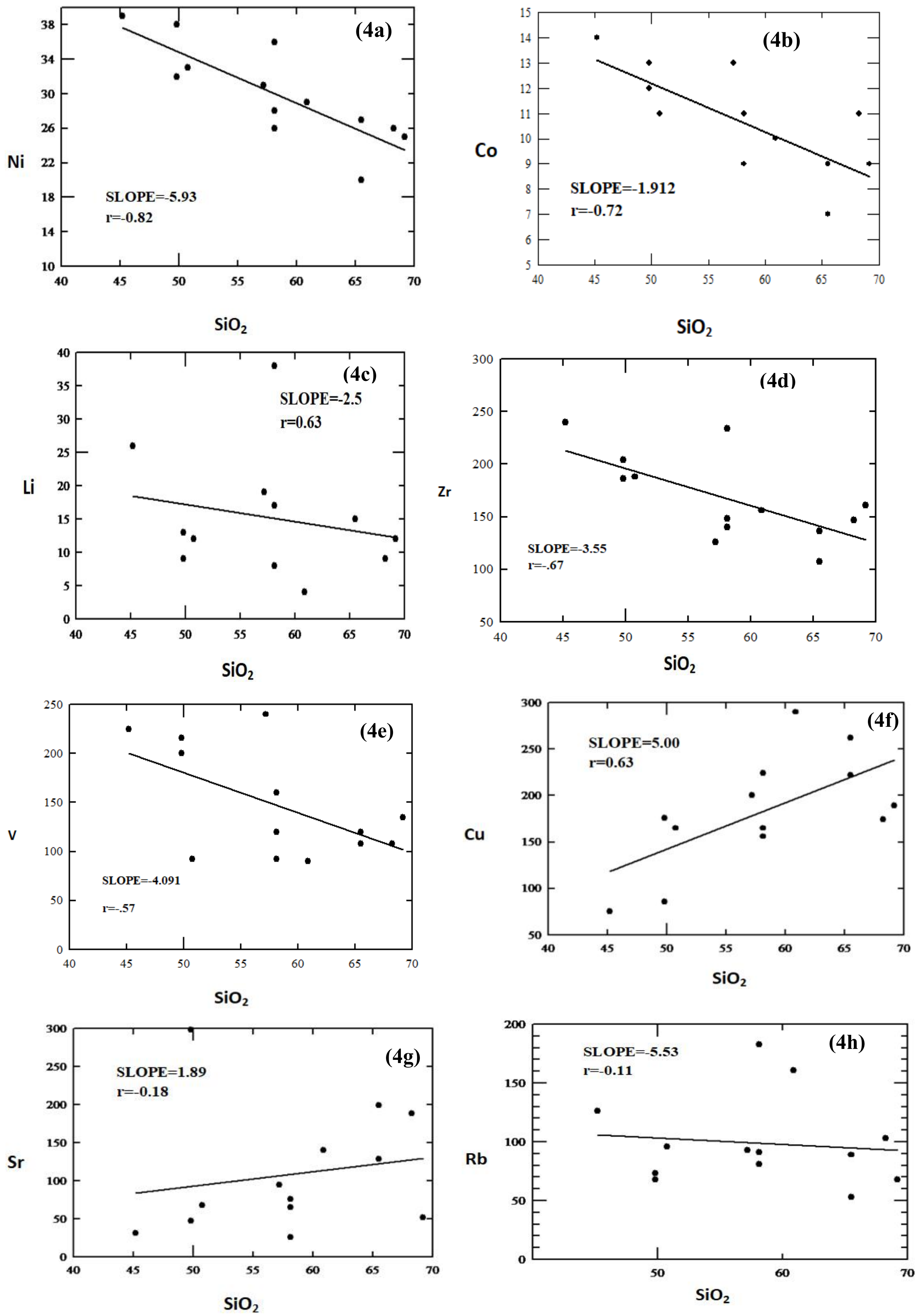


Figure 4. Harker Variation diagrams of SiO_2 verses trace elements for Al-rich pelitic granulites/paragneiss from Thana, Bhilwara, Rajasthan.

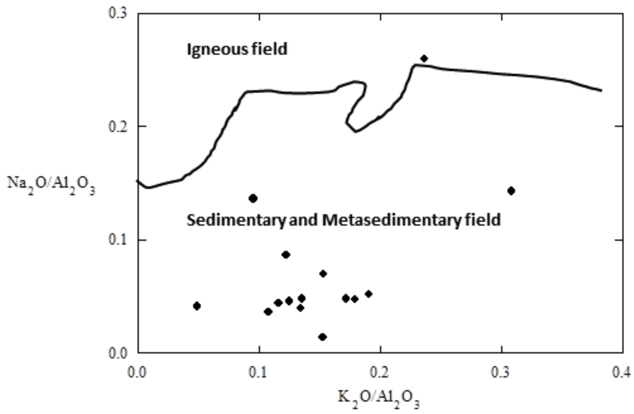


Figure 5. K_2O/Al_2O_3 versus Na_2O/Al_2O_3 after (Garrels and Mackenzie, 1971) for Al-rich pelitic granulites/paragneiss.

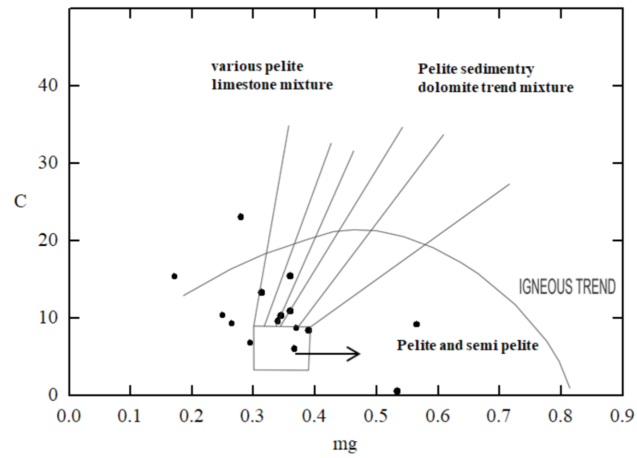


Figure 8. A Niggli mg vs C diagram after Leake (1964) showing plots of rocks from investigated area.

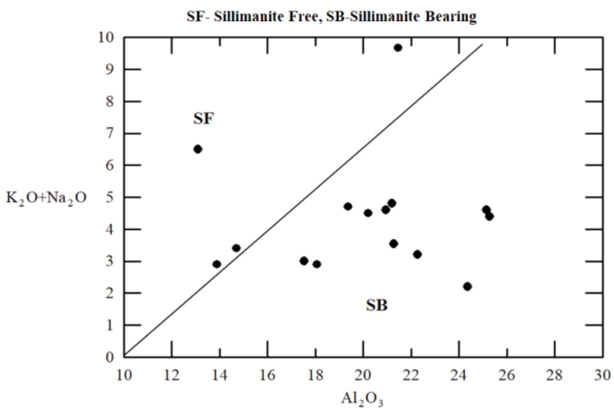


Figure 6. Al_2O_3 against ($K_2O + Na_2O$) diagram after Goel and Chaudhari, (1979).

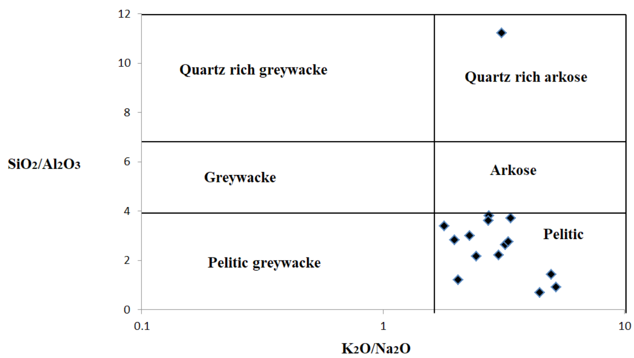


Figure 9. Plot between SiO_2/Al_2O_3 and K_2O/Na_2O for Al-rich pelitic granulites/paragneiss from Thana, Bhilwara, Rajasthan after Wimmenaure (1984) and Condie et al. (1991).

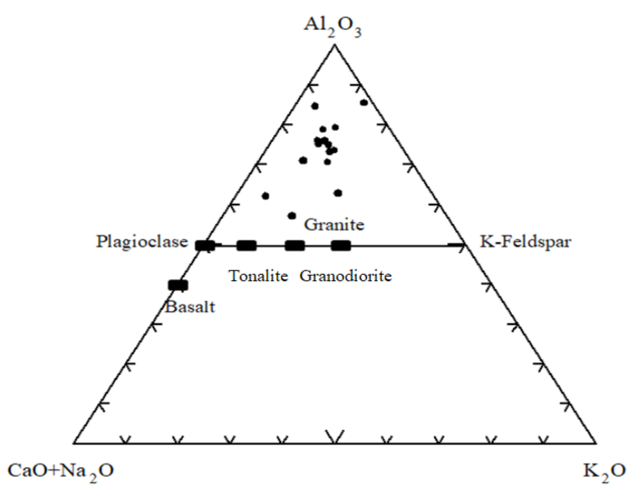


Figure 7. A-CN-K diagram after Nesbitt et al., 2003.

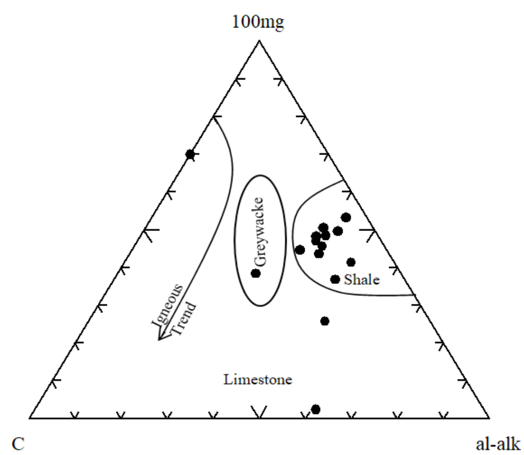


Figure 10. The Niggli 100 mg-c-(al-alk) triangular diagram (Leake, 1964) for Al-rich pelitic granulites/paragneiss from Thana, Bhilwara, Rajasthan.

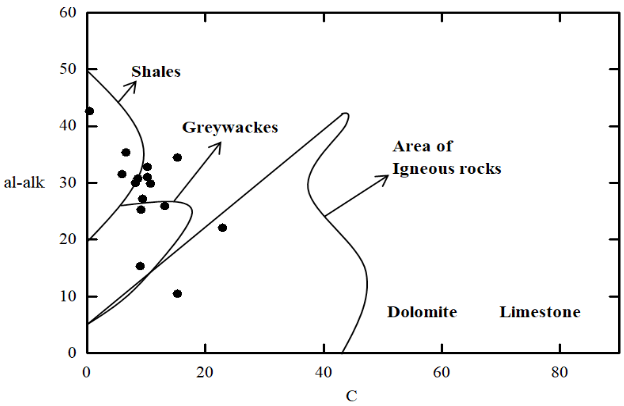


Figure 11. Plot between Niggli c versus (al-alk) values (Leake, 1964) for Al-rich pelitic granulites/paragneiss from Thana, Bhilwara, Rajasthan.

As per Chappel and White, (1974) [32]; Shand, (1943) [33], the A/CNK values of gneisses ranging from 1 to 2.7 support its characterization as strongly peraluminous, S-type source (Figures 12 and 13).

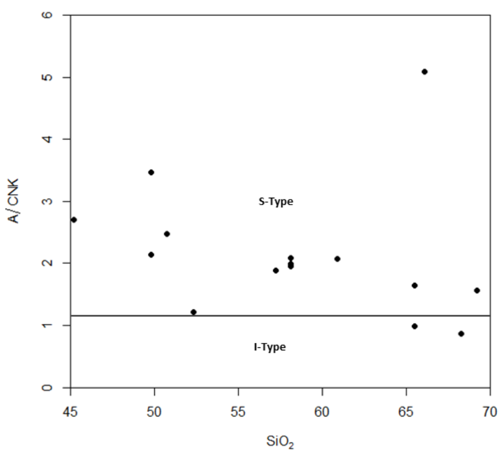


Figure 12. A/NCK vs SiO_2 Plot for Pelitic granulite/Paragneisses after Chappel and White, 1974.

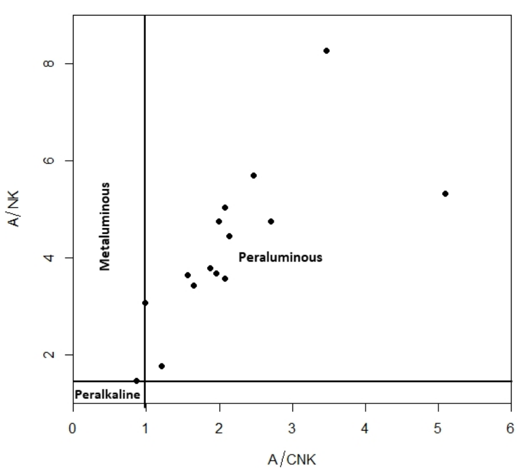


Figure 13. A/NK vs A/CNK Plot for Pelitic granulite/Paragneisses after Shand, 1943.

5. Conclusions

Al-rich pelitic granulites/paragneiss are frequently observed in the medium to high grade metamorphic rocks of Thana. It is dominantly composed of sillimanite-kyanite-garnet-biotite-plagioclase-k-feldspar and a subordinate amount of quartz. Garnet both xenoblastic as well as idioblastic is wrapped round by flaky minerals. Texture is granoblastic to gneissose. Garnet and andalusite occur as porphyroblasts, in a few sections, reaction rims of garnet are present around biotite and kyanite/sillimanite and hornfelsic texture is also observed. Petrographically Al-rich pelitic granulites/paragneiss occupy a substantial portion of the explored area. They are dark, greenish to light in colour and contain garnet, sillimanite, kyanite, staurolite, biotite, K-feldspar, plagioclase, quartz and secondary muscovite and chlorite in several assortments. Garnet is marginally altered into chlorite and, suggests the reaction:

Garnet + fluid = chlorite + quartz + magnetite

The corroded outline of the biotite and its textural relation with fresh garnet and k-feldspar indicate the following reaction.

Biotite + Sillimanite + Quartz = Garnet + K-feldspar + Water

The geochemical plot between SiO_2 vs Al_2O_3/(CaO + Na_2O + K_2O) and A/NK vs A/CNK (Chappell and White 1974) [32] and Shand [33], reflects that Thana pelitic granulite/paragneiss is of S-type and peraluminous in nature. The plot between K_2O/Al_2O_3 and Na_2O/Al_2O_3 Garrels and Machenzie, (1971) [26] and similarly A-CN-K diagram after Nesbitt, et al., (2003) [28] also shows sedimentary field. The chemical variations have also been studied with the help of Niggli values. The 'mg' versus 'c' diagram most of the samples lie in the pelitic and semi-pelite field Leake, (1964) [29] and on the basis of SiO_2/Al_2O_3 versus K_2O/Na_2O diagram Wimmenaure and Fortscher (1984) [30] and Condie, et al., (1991) [31], also indicate sedimentary and metasedimentary fields. Niggli values are also used to examine the nature of the protolith, which strongly support that they are formed by the metamorphism of pre-existing sedimentary rocks. Geochemically, the protolith for these Al-rich pelitic granulites/paragneiss is shale or greywacke.

Author Contributions

This research was conceptualised and interpreted by H. Thomas and Jyoti Bidolya, Aman Soni and Rishabh Batri framed the figures and the manuscript text.

Funding

9/13(687)/94-EMR-I;15/7/94 (CSIR Research Associate Fellowship, New Delhi) to Dr. Harel Thomas.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for profit sectors. The author (HT) is thankful to Head, Department of Applied Geology and Director, Wadia Institute of Himalayan Geology, Dehradun for providing necessary facilities to carry out this research work. Thanks are given to anonymous referees for their constructive and insightful comments that led to the improvement of this research.

Data Availability Statement

Samples of paragneiss/Al-rich pelitic assemblages were analyzed at Wadia Institute of Himalayan Geology Dehradun India by Dr. H. Thomas through Atomic absorption spectrometry (AAS) and flame photometry and data is available in Table 1 in paper.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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