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Whole-rock Geochemistry of Gneiss from Thana, Bhilwara, India

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Abstract:
Gneiss is medium to high grade metamorphic rock present in one third part of Thana. These rocks have been formed by the metamorphism of pre-existing granites under medium to high P/T conditions and it consist essential minerals like quartz, k-feldspar, plagioclase, biotite, hornblende, epidote, garnet and iron-oxides. Geochemically, this gneiss is metaluminous in nature and similar to I-Type granite which is chemically similar to continental arc granitoids. It is also clear that they are formed by the highly fractionated magma. This paper records the petrography, geochemical character and probable origin of this gneiss.

Keywords: *Gneiss, I-Type Granite, Petrography, Mineralogy.*

INTRODUCTION

The investigated Thana area falls in toposheet no. 45K/2. The area comprises of mainly three types of granulite (charnockite/enderbite), paragneiss / Al-pelitic granulite, they are fringed by augen gneiss, migmatite which comprises the main lithounits of Banded Gneissic Complex. These basement rocks are polymetamorphic nature and are characterized by amphibolites to granulite facies grade of metamorphism in association with mafic and felsic orthogneisses and meta-sedimentary rocks (Sharma 2003, Joshi et. al, 1993, Thomas 1991, 1995a, 1995b, 2005a, 2005b, Thomas 2014, Thomas & Sujata 2008, Thomas & Vishwakarma 2009, 2011a, 2011b, Vishwakarma & Thomas 2015, Thomas & Lalu P. 2015, Kavti S. & Thomas H. 2018, Thomas & Rana 2020 and Thomas et. al., 2022). Thana group of rocks has grouped as paragneiss complex, with Aravalli System (Gupta, 1934) and recently the Thana Complex gets the status of group under Bhilwara Supergroup (Gupta, et al., 1980 & 1997) the oldest stratigraphic unit equivalent to the BGC of Heron (1917, 1935 & 1953). The age of charnockite from the study area has been estimated around 1723 ± 14 ma using the U-Pb isotopic method by Sarkar et.al, (1989). The granitic plutons from the BGC were dated at 2.9 Ga by Rb/Sr isotopic systematics Chaudhary et al., (1984). The tonalitic grey gneiss from east of Udaipur yielded age of 3.3 Ga by Sm-Nd systematics Gopalan et al., (1990). Single zircon grains gave 3.23-2.89 Ga by evaporation method (207Pb/206Pb) for these gneisses (Roy and Kräner, 1996). The BGC is generally thought to be an Archaean basement terrain that was partially reworked during the Paleoproterozoic Laser Ablation ICP-MS Zircon U-Pb study of orthogneisses and metapelites reveals that the metasediment in the Sandmata complex have Proterozoic rather than mid- Archaean protolith (Buick et al., 2006). The main rock types exposed in the area are augen gneiss, migmatite which comprises the main lithounits of Banded Gneissic Complex pelitic granulite/paragneiss, charnockite/enderbite and metanorite. The main aim of present paper is to: (i) provide petrographic and geochemical characteristics of gneiss; (ii) find out the petrogenesis of gneiss; (iii) placement of these rocks in the tectonic history of the banded gneissic complex of Central Rajasthan.

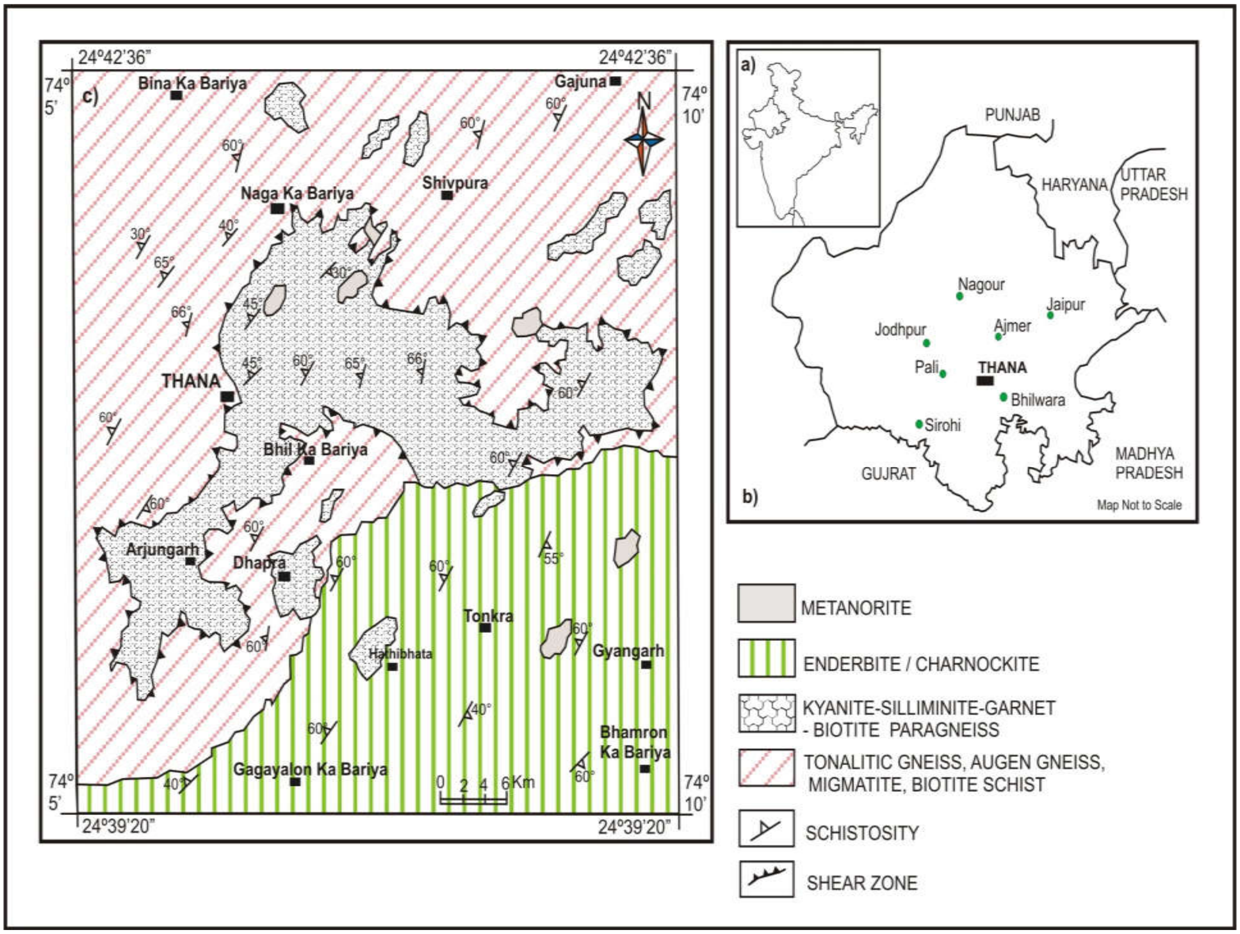


Figure 1: Geological and structural map of Thana, District- Bhilwara, Rajasthan after (Thomas 2005) Stratigraphy of the Area.

Heron (1917, 1935 & 1953) and Gupta (1934) have classified the Pre-Cambrian metamorphic rocks of Rajasthan into four stratigraphic units. They introduced the term "Banded Gneissic Complex (BGC)" to designate the Archaean basement of the Central Mewar region. Gupta (1997) divided BGC of Central Rajasthan into two tectonic-cum-metamorphic domains i.e. the Sandmata Complex and Mangalwara Complex towards west and east respectively which is separated by Delwara lineament. After this several modification has been proposed out of all here is the most accepted stratigraphic succession is:

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 Group, 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

In the interested area, only the BGC of Bhilwara Supergroup is exposed and the detailed sequence of the Pre-Aravalli (after Gupta, 1935) from the oldest to youngest is as follows:

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

Petrography

The rock type comprises the Banded Gneissic Complex and constitutes more than one third of the examined area. The major mineral constituents of the examined rock type are quartz, feldspar and biotite whereas hornblende also occurs as minor constituents; all of these minerals vary in proportion from place to place. Along with the above stated minerals epidote, sphene, apatite, rutile, muscovite also present in the gneisses. Sometimes magnetite and calcite are also found in these rocks. In few places the K-feldspar and plagioclase are well developed as large phenocryst (augen shape) these can be called as augen gneiss or porphyroblastic gneiss.

Megascopic Character

The dominant rocks of the examined area have grain size ranging from fine to medium and colour ranging from light grey to dark. The feldspar porphyroblast has white or pink colour which give rise to augen structure. S-surface lineation can be identified by the arrangement of feldspar and biotite grains. The schist and augen gneiss also alternate on the scale of centimetre to meters and produce migmatites (Dietrich and Mehnert, 1960).

Microstructure/ Texture

All the rocks show well developed foliation and compositional layering. K-feldspar show porphyroclastic texture, quartz and feldspar also show porphyritic texture but very rarely. In gneiss the light coloured mineral shows granoblastic mosaic texture, and the foliated portion is dominated by biotite. In a few samples myrmekitic texture is developed at the contact of K-feldspar and plagioclase. Perthitic texture is also present in some of the sections and microcline shows the inclusion of biotite and quartz. Graphic texture and mortar structure are also marked in some sections.

Following mineral assemblage have been noticed in the rocks:

1. Biotite - quartz-K-feldspar-plagioclase ± sphene ± apatite ± magnetite
2. Biotite - plagioclase - K-feldspar - quartz - garnet - (chlorite - epidote) ± apatite
3. Biotite - plagioclase - K-feldspar - quartz - hornblende - (epidote ± sericite)

Microscopic Character of Minerals

Biotite

Biotite laths are present in some sections and it shows strong preferred orientation, occasionally in two directions. Biotites are often interleaved with muscovite in some of the schistose rocks. Presence of undulose extinction and bent crystals give the indication of post crystallization deformation. Biotites have inclusions of epidote, quartz, muscovite, sphene and apatite.

Quartz

Xenoblastic elongated to equant grains of quartz size varying from 0.01 to 1.5 are found. It is found as inclusions in some minerals like biotite etc. Some quartz grain shows undulose extinction.

Plagioclase

Plagioclase presents as porphyroblast in the gneisses. Equant and prismatic grains of plagioclase can be observed in schistose rocks. In some sections plagioclase is replaced by microcline and quartz where myrmekite structure is present. Zoned plagioclase is present in the hornblende bearing gneiss. Some sections show alteration of plagioclase into clay minerals.

K-feldspar

Microcline is present generally in most of the sections, but in some sections perthite are also present. Large crystals of microcline enclosed biotite and quartz suggest post crystalline deformation.

Epidote

Anhedral grains of epidote are present in most of the sections which are ranging in size from 0.5 to 1.0 mm and are closely associated with sphene. Crystals of epidote arrange linearly along the schistosity. Saussuritization is also indicated as the epidote is developed after the plagioclase**.**

Hornblende

Hornblende is restricted to the dark portion of the rocks. Hornblende grains are associated with the biotite. Inclusion of biotite, epidote and sphene is present in the hornblende.

Garnet

Oval grains of garnet are pink in colour and very rarely present in the examined sections.

Muscovite

Muscovite is generally associated with K-feldspars and the formation of muscovite is supposed to be post metamorphic.

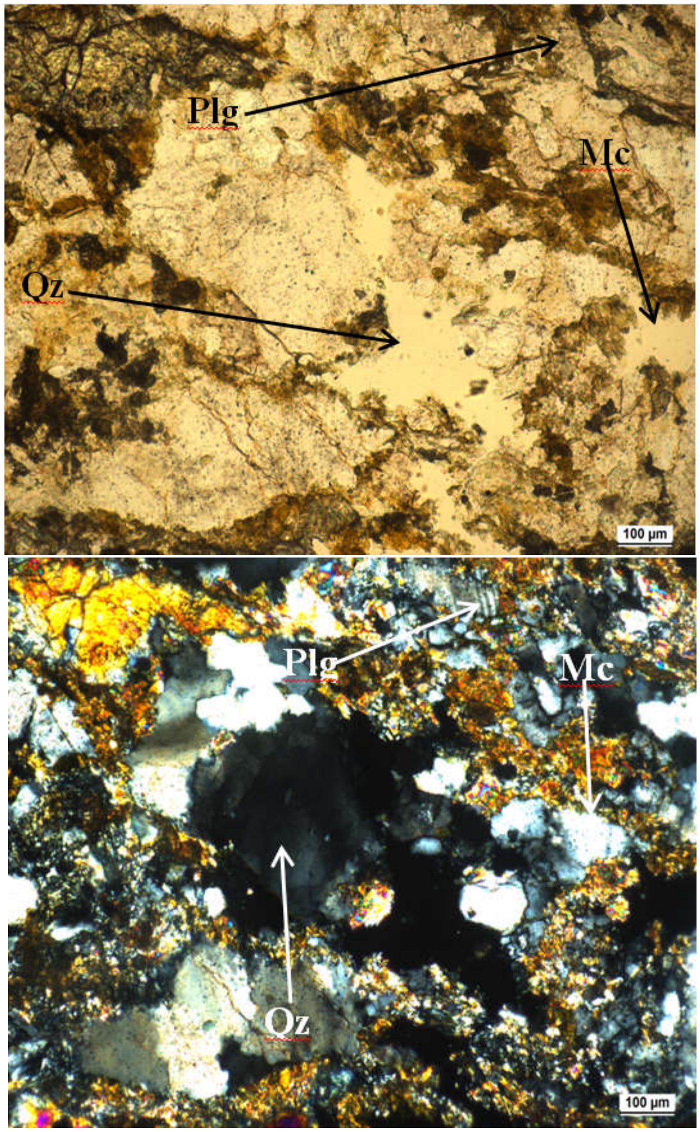


Figure 2: The Photomicrographs showing granoblastic texture.

Geochemistry and Petrogenesis of Granite Gneiss

Twelve gneiss samples have been analysed for major oxides and trace elements by Atomic absorption spectrometry (AAS) and flame photometry from the Wadia Institute of Himalayan Geology. The major elements, trace elements in (ppm) and CIPW norms and Niggli values are given in the table 1and Table2 respectively.

Major Oxides

The SiO_2 and Al_2O_3 content varies between 51.02 wt% to 71.05 wt% and 12.60 wt% to 21.74 wt% respectively. In all the twelve samples the SiO_2 content is generally >51 wt% whereas the percentage of Al_2O_3 content is higher in R87/330, R87/316 and R87/472. The rocks have an average Na_2O and K_2O concentration of 1.94 wt% and 3.61 wt% respectively and the average K_2O/Na_2O ratio is 1.86. Some samples show high Na_2O values but relatively low K_2O values, although quartz, K-feldspar and plagioclase are present in all samples. The average $K_2O/(K_2O+Na_2O)$ for granite is 0.73 in contrast to 0.65 for granite gneiss. The TiO_2 content varies from 0.35 wt% to 1.62 wt%.

The CIPW norm indicates the silica saturated nature of the gneiss. As per the CIPW norm, the normative quartz varies from 10.44% to 34.48% while the plagioclase content varies from 9.42to 35.64 %. As per the alumina saturation index, the Al/(Na+K) vs. Al/(Ca+Na+K) plot, Fig. 3, after Shand 1943 shows that all the samples of gneisses of Thana area falls within a meta-aluminous field. The gneisses fall in the granite field in the normative Ab-An-Or diagram after Feldspar Triangle after Barker, 1979 and O'Connor 1965, Fig. 4 and similarly in Q-A-P diagram Fig.5 field after Streckeisen, 1974fall in granite field.

According to the Chapple and White's classification (1974), Fig. 6 most of the samples fall in the metaluminous field which is a most prominent character of I-type Granite and this can be justified with the help of TAS diagram proposed by Cox *et al.* (1979) Fig.7. Thana gneiss has I-type character (molecular $Al_2O_3/(K_2O+Na_2O+CaO)$ <1.1 with low normative corundum and high normative diopside). The AFM discriminate plot Fig.8 after Irvine & Baragar 1971, shows that most of the samples are of Tholeiite character.

The phase diagram Fig. 9 by Tuttle and Bowen (1958) the granitic rocks of the area lie in the field of eutectic melts, except five samples, which are away from the granite field. These plots and the field occurences (intrusive nature) suggest that the granitic rocks are the product of melting but whether these have anatectic or igneous origin remains a question open for isotopic and rare earth elemental studies.

Trace Elements

The trace element geochemistry of gneiss show variable concentration of Cu (88 to 207 ppm; average 157.11 ppm); Li (3 to 28 ppm; average 15.88 ppm); Ni (11 to 20 ppm; average 14.88 ppm.); Co (4 to 8 ppm; average 6.33 ppm); V (30 to 140 ppm; average 97.75 ppm); Zn (110 to 141 ppm; average 124.22 ppm.); Rb (68 to 201 ppm; average 133.5 ppm) and Sr (48 to 711 ppm; average 279.55 ppm) and are enriched in comparison to Rb.

Table 1: Major element analyses (wt%) and Trace element (in ppm) of gneisses from the Thana, district Bhilwara, Rajasthan.

Ref. No.	1	2	3	4	5	6	7	8	9	10	11	12
Sample No.	**R87/310**	**R87/402**	**R87/412**	**R87/247**	**R87/332**	**R87/327**	**R87/284**	**R87/472**	**R87/382**	**R87/316**	**R87/330**	**R87/418**
SiO_2	69.20	71.05	60.90	59.98	64.60	64.60	58.13	60.90	62.75	60.44	60.55	51.02
Al_2O_3	12.60	14.40	14.93	14.40	13.62	13.36	14.93	21.74	13.62	15.34	15.34	14.49
Fe_2O_3	1.96	0.47	1.36	2.12	1.36	2.36	2.52	1.24	2.52	3.00	1.81	3.0
FeO	2.48	2.16	5.59	7.21	6.40	4.65	7.12	6.08	2.36	7.74	4.36	7.71
MgO	1.21	-	2.42	2.42	1.21	2.22	2.42	1.21	0.81	2.32	1.51	2.04
CaO	3.64	3.64	5.60	5.88	5.60	4.48	7.01	2.80	15.42	4.20	6.29	6.30
Na_2O	1.60	1.40	2.60	2.20	2.0	2.20	2.60	1.00	0.20	1.40	0.88	1.40
K_2O	6.0	5.70	4.10	3.40	4.0	3.60	2.50	3.10	0.20	3.40	3.70	3.69
MnO	0.045	0.02	0.07	0.13	0.08	0.08	0.098	0.06	0.45	0.06	0.04	0.09
TiO_2	0.907	0.35	1.10	1.46	1.0	0.99	1.62	0.56	0.63	0.66	1.33	1.29
P_2O_5	0.47	0.07	0.25	0.08	0.25	0.25	0.07	0.97	-	0.34	0.25	0.49
Total	100.07	99.26	98.92	99.28	100.12	98.79	99.02	99.66	99.00	98.90	96.06	91.52
Trace elements												
Cu	166	163	189	163	154	88	194	207	90	-	-	-
Co	5	4	7	8	7	8	8	5	5	-	-	-
Ni	11	15	13	19	19	19	19	18	20	-	-	-

Li	10	3	24	19	17	16	28	15	11	-	-	-
Rb	201	164	126	111	161	141	96	68	-	-	-	-
Sr	263	174	222	301	242	217	338	48	711	-	-	-
V	135	-	60	140	92	125	140	30	60	-	-	-
Zn	110	113	134	141	118	120	138	116	128	-	-	-
Rb/Sr	0.76	0.94	0.57	0.37	0.67	0.65	0.28	1.42	-	-	-	-
Mol	1.12	1.34	1.21	1.25	1.17	1.30	1.23	3.15	0.86	1.70	1.41	1.27

Table 2: C.I.P.W. norms and Niggli values of gneiss from Thana district Bhilwara, Rajasthan

Ref. No.	1	2	3	4	5	6	7	8	9	10	11	12
Sample No.	**R87/310**	**R87/402**	**R87/412**	**R87/247**	**R87/332**	**R87/327**	**R87/284**	**R87/472**	**R87/382**	**R87/316**	**R87/330**	**R87/418**
Quartz	29.05	32.43	13.78	15.95	22.59	24.62	13.89	33.67	34.48	22.76	24.58	10.44
Orthoclase	35.47	32.43	24.24	20.13	23.69	21.13	14.79	18.29	1.17	20.13	22.24	21.68
Albite	13.52	11.84	21.96	18.60	16.93	18.60	21.96	8.44	1.68	11.84	7.44	11.79
Anorthite	9.42	16.12	16.93	19.32	16.29	15.99	21.63	8.23	35.64	18.85	26.74	22.38
Corundum	-	-	-	-	-	-	-	13.72	-	2.43	-	-
Diopside	4.96	1.37	7.35	7.43	8.43	3.78	10.67	-	8.23	-	7.05	12.41
Hypersthene	2.13	2.31	10.04	11.83	7.90	8.78	9.19	12.33	-	16.52	7.05	12.41
Olivine	-	-	-	-	-	-	-	-	-	-	-	-
Magnetite	2.85	0.67	1.97	3.06	1.97	3.43	3.64	1.79	3.67	4.36	2.62	4.36
Ilmenite	1.72	0.67	2.10	2.77	1.90	1.88	3.09	1.06	1.19	1.26	2.52	2.43
Apatite	1.01	0.17	0.60	0.20	0.60	0.67	0.17	2.28	-	0.81	0.6	1.14
Wollastonite	-	-	-	-	-	-	-	-	12.92	-	-	-
Niggli values												
al	33.61	43.40	30.03	27.89	29.99	30.12	27.50	48.14	26.43	30.85	34.40	27.71
alk	24.34	25.53	17.53	14.14	16.77	16.94	12.80	11.07	1.05	12.03	12.22	12.04
C	17.65	19.94	20.48	20.70	22.42	18.36	23.5	11.26	54.51	15.35	25.64	21.89
fm	24.40	11.13	31.97	37.27	30.82	34.59	36.10	29.50	18.01	41.76	27.74	38.36
Si	313.32	363.43	207.92	197.79	241.40	247.17	181.90	228.90	207.00	206.32	230.44	165.60
mg	0.335	-	0.385	0.318	0.219	0.366	0.310	0.226	0.223	0.283	0.309	0.257
K	0.712	0.730	0.509	0.504	0.588	0.520	0.380	0.67	0.396	0.615	0.734	0.634
ti	3.09	1.35	2.82	3.60	2.81	2.85	3.7	1.58/	1.54	1.69	3.81	3.15
P	0.824	0.15	0.36	0.11	0.395	0.40	-	1.54	-	0.49	0.402	0.67

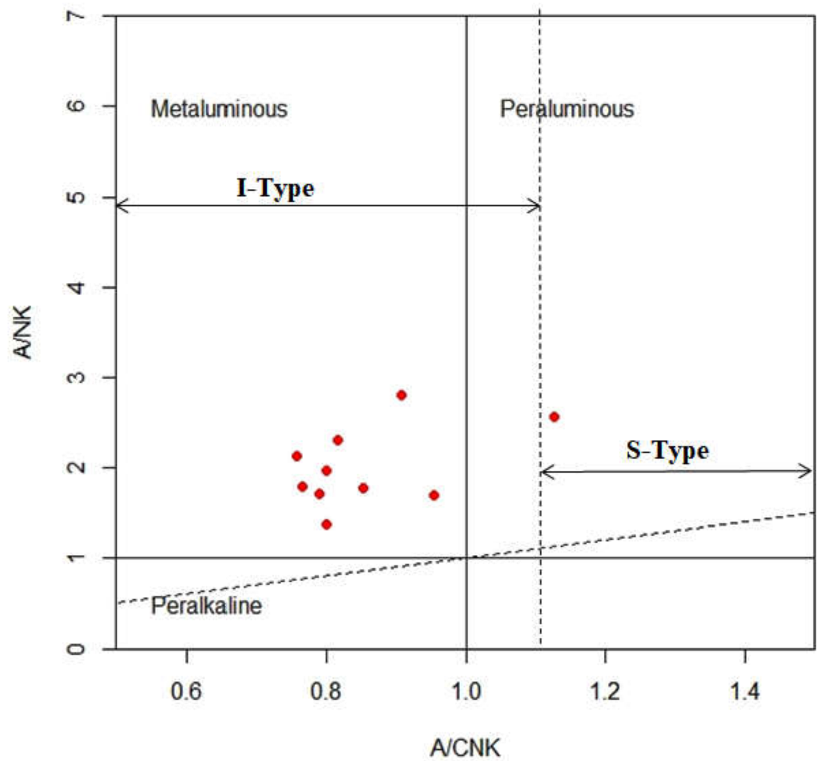


Figure 3: Al_2O_3/Na_2O+K_2O against $Al_2O_3/CaO+Na_2O+K_2O$ (after Shands, 1943)

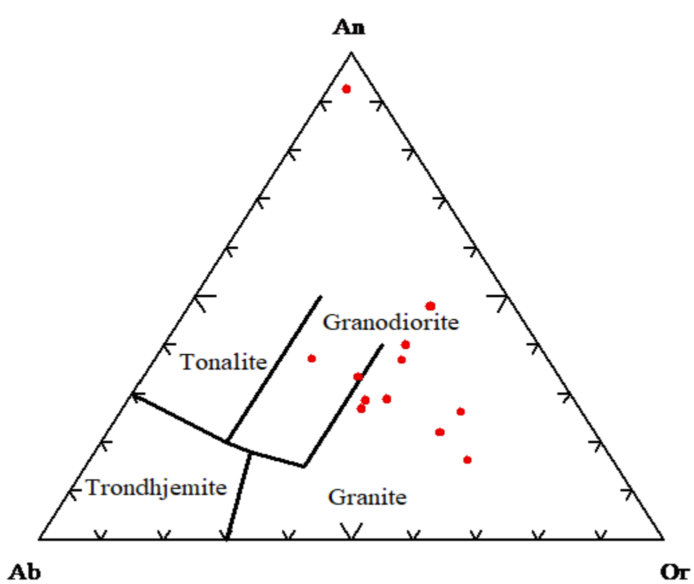


Figure 4: The system Anorthite (An) - Albite (Ab) - Orthoclase (Or) showing the field of different granitic composition (after Barker, 1979).

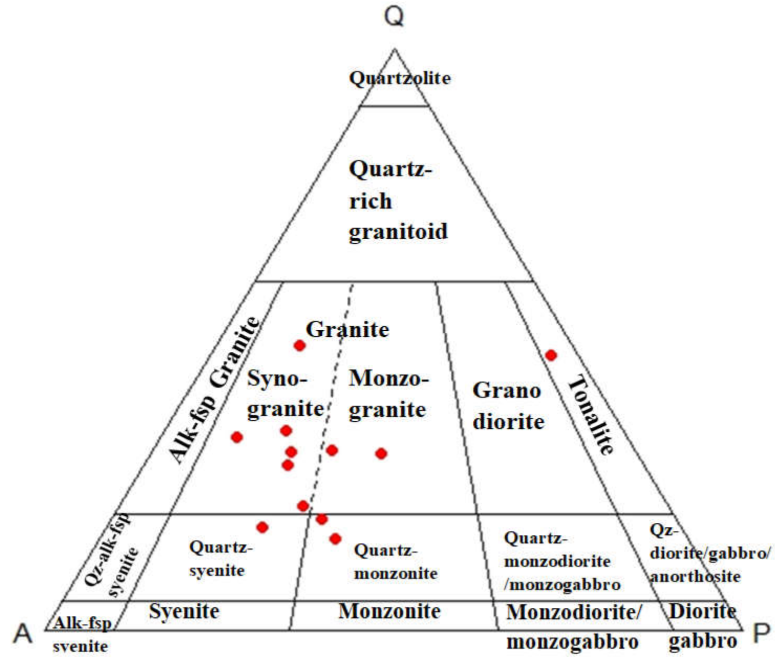


Figure 5: Q-A-P diagram (after Streckeisen, 1974), showing the composition of gneiss.

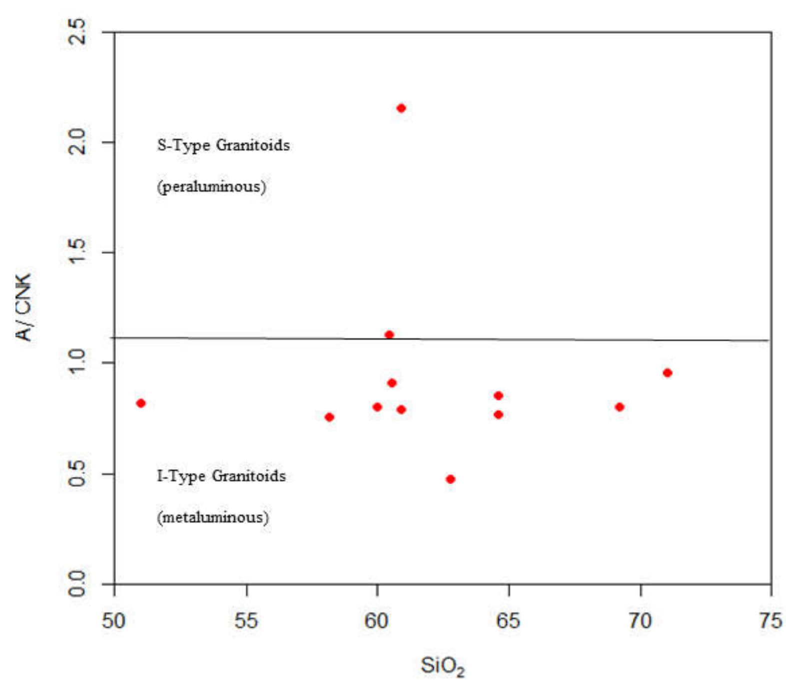


Figure 6: $Al_2O_3/CaO+Na_2O+K_2O$ against SiO_2 (after Chapple & White 1974 and modified by Frost et. al. 2001).

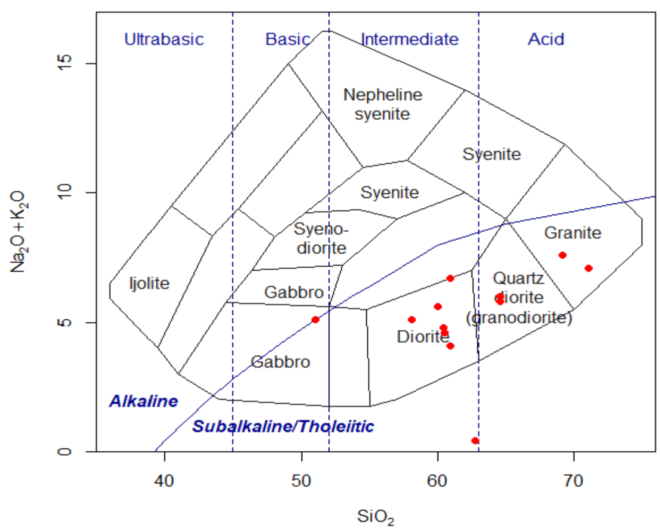


Figure 7: Variation of the TAS diagram proposed by Cox *et al.* (1979) and adopted by Wilson (1989) for plutonic rocks.

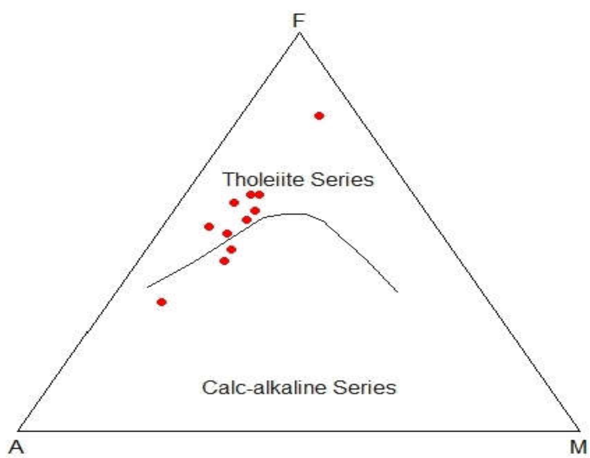


Figure 8: AFM discriminate plot between Calc-alkaline series and Tholeiite series (Irvine & Banger 1971).

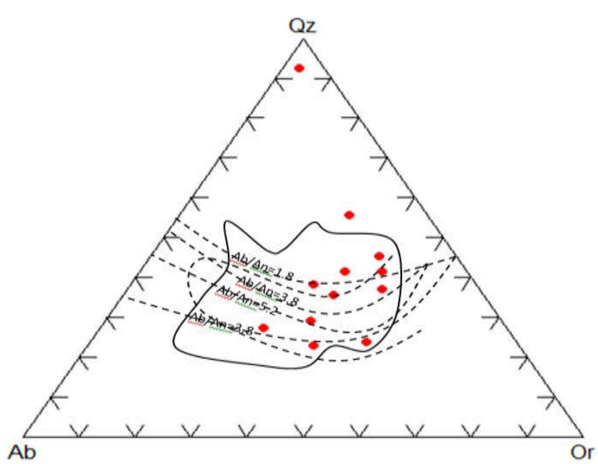


Figure 9: Phase diagram given by Tuttle and Bowen (1958) the granite rock of the arealie in the field of eutectic melts.

The variation in the Rb/Sr ratio with respect to CaO wt% Fig. 10 this and the Sr vs Rb plots Fig. 11 which show the same linear trend as the trend attributed by Robb (1983), indicate progressive partial melting; steep trend is taken to denote the fractional crystallization.

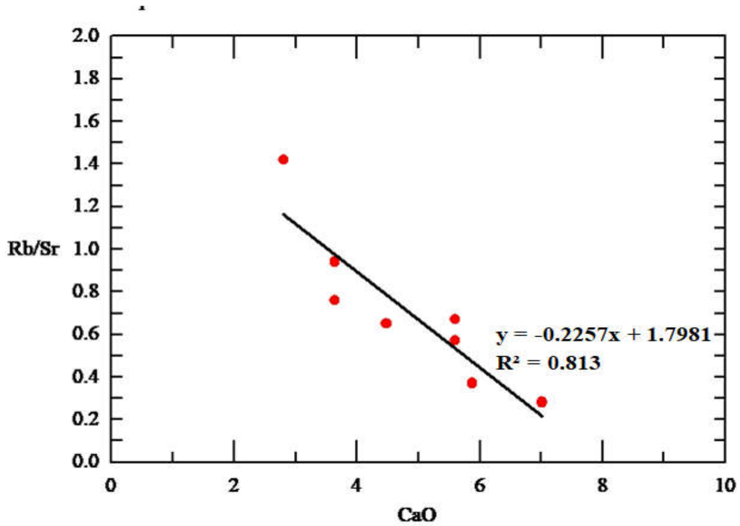


Figure 10: Rb/Sr vs CaO showing linear chemical relationship between granite/tonalite gneiss.

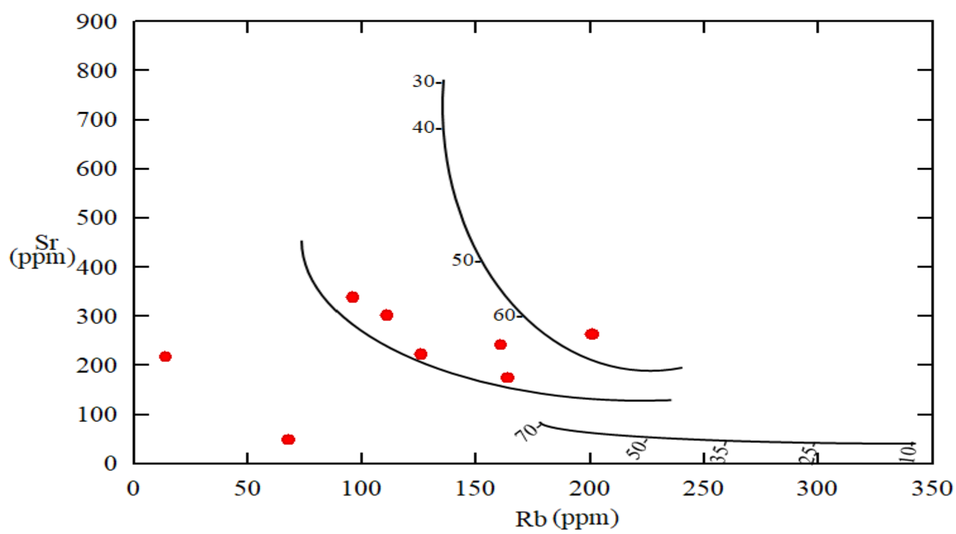


Figure 11: Plot of Sr vs Rb of the Thana showing a close similarity with sub horizontal trend for progressive batch melting established by Robb (1983).

The Niglli values al, alk, C and fm are plotted against Si Fig. 12, in which al and alk values show the positive correlation with Si, whereas the C and fm values show the negative correlation. Harker variation diagram (Fig. 13) are also plotted for the trace elements (Cu, Co, Li, Ni, Sr, Rb, Zn) most of them shows negative correlation with SiO_2 except Rb and V which show positive correlation which is the direct indication towards the highly fractionated granitic magma with the greater number of incompatible and trace elements.

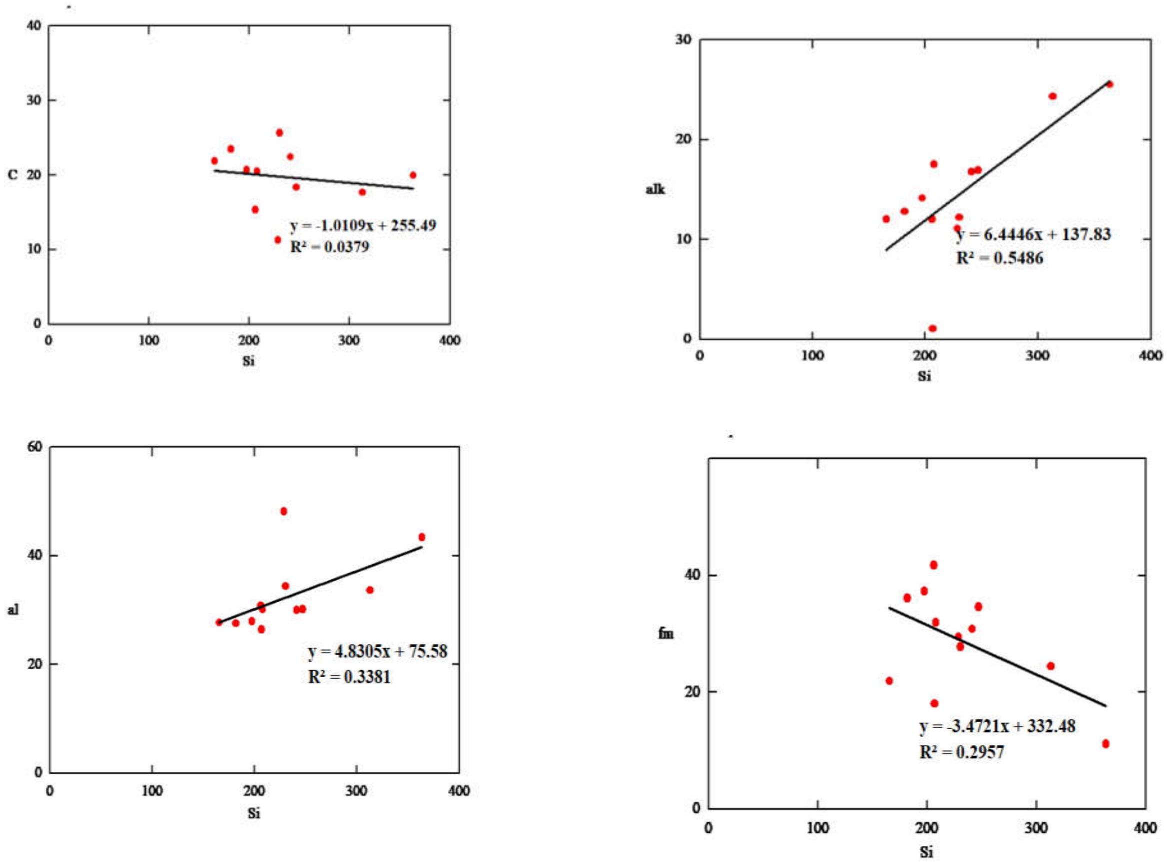
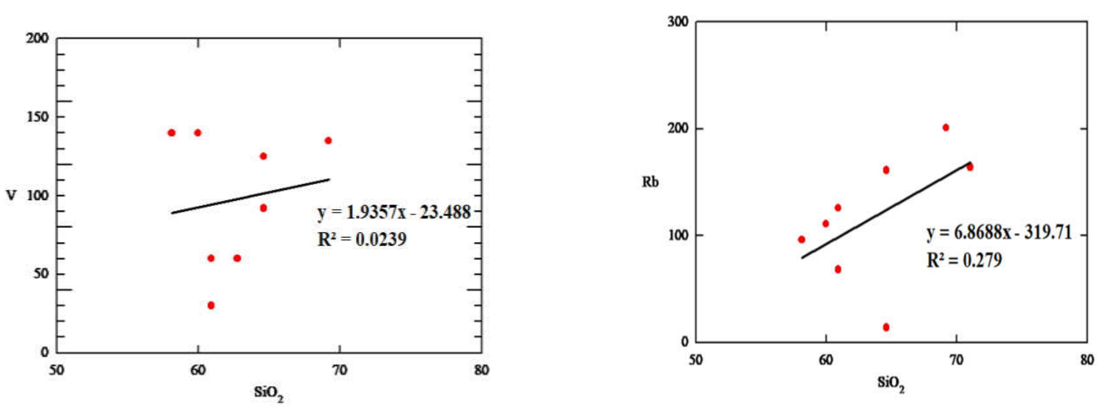


Figure 12: Niglli diagram showing linear chemical relationship between gneiss from Thana area.



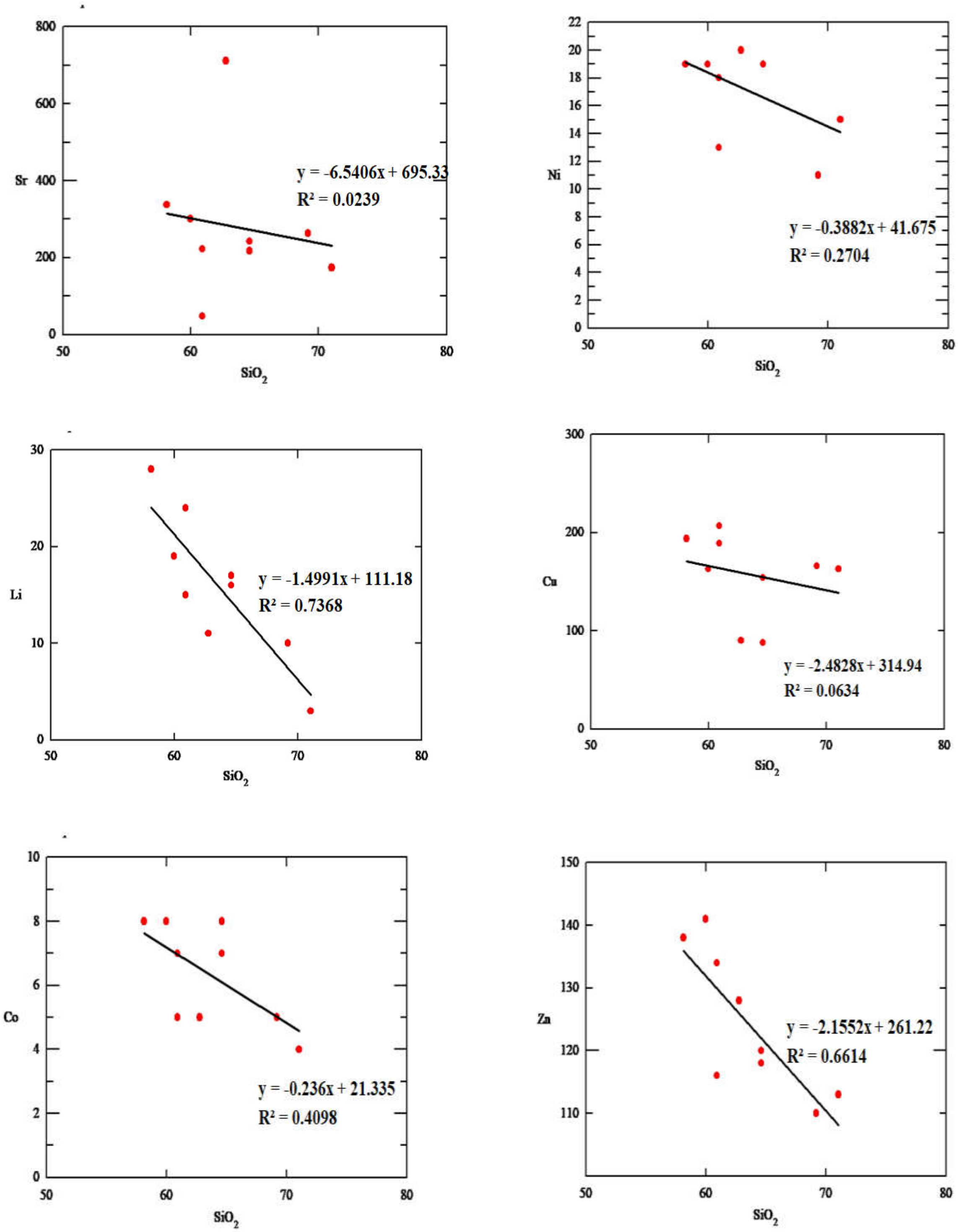


Figure 13: Harker variation diagram of trace elements against $SiO_2$by Harkar (1909).

DISCUSSION

The gneisses rock is present in one third part of the Thana. They are in contact with the garnet mica schists which occur in the folded outcrop pattern. Texturally, they occur as foliated gneiss along with augen gneiss at few places having biotite and muscovite define foliation whereas variation in the mineral composition imparts the compactness and gives colour to these gneisses. Petrographically, it is composed of feldspar, both k-feldspar and plagioclase; perthite, biotite, muscovite and secondary muscovite. Alternate quartzo-feldspathic and mica layers defined the gneissosity. Quartz grains show bulging grain boundaries, pinning in grains and undulose extinction depicts ductile deformation and recrystallization. K-feldspar mostly perthitic in nature, patches are mostly developed both at core and rim of the grains. In a few samples myrmekitic texture is developed at the contact of K-feldspar and plagioclase. Perthitic texture is also present in some of the sections and microcline shows the inclusion of biotite and quartz. Graphic texture and mortar structure are also marked in some sections. At a few places, K-feldspar is altered showing sericitization mostly seen at grain boundaries. Plagioclase feldspar is usually present as subidioblastic showing albite type twinning at most of the places and mechanical twinning at few places.

The geochemical data reflects that Thana gneisses is of I-type and metaluminousin nature. SiO_2 vs $Al_2O_3/(CaO+Na_2O+K_2O)$ plot shows that the gneiss is of I- type (Chappell and White, 1974, Fig.6) and this can be justified with the help of TAS diagram proposed by Cox *et al.* (1979) Fig.7. Thana gneiss has I-type character (molecular $Al_2O_3/(K_2O+Na_2O+CaO)$ <1.1 with low normative corundum and high normative diopside). As per the alumina saturation index, the Al/(Na+K) vs. Al/(Ca+Na+K) plot, Fig. 3, after Shand, 1943 shows that all the samples of gneisses of Thana area falls within a metaluminous field. The gneisses fall in the granite field in the normative Ab-An-Or diagram after Feldspar Triangle after Barker, 1979 and O'Connor 1965, Fig. 4 and similarly in Q-A-P diagram Fig. 5 field after Streckeisen, 1974 fall in granite field.

The phase diagram Fig. 9 by Tutelle and Bowen (1958) the granite rocks of the area lie in the field of eutectic melts, except five samples, which are away from the granite field.

The variation in the Rb/Sr ratio with respect to CaO wt% Fig. 10 this and the Sr vs Rb plots Fig. 11 which show the same linear trend as the trend attributed by Robb (1983), indicate progressive partial melting; steep trend is taken to denote the fractional crystallization. These plots plus the field occurrence (intrusive nature) suggest that the granite rock have been the product of melting but whether these have anatectic or igneous origin remains a question open for isotopic and rare earth elemental studies.

CONCLUSION

On the basis of above discussion we can draw the following conclusions:

- On the basis of the field observation and analysis, it is clear that the gneiss of the study area, the most dominant rock type, covers more than two third of the study area. These rocks may grade into augen gneisses or migmatite at places and their parent rock is granite to granodiorite in nature.

- Gneiss contains characteristic minerals like quartz, feldspar, plagioclase, biotite, sphene, apatite, magnetite as prominent minerals. Saussuritization can also be seen in some of the slides.

- On the basis of above discussion, it is clear that the gneiss of the study area are I-type in character (molecular $Al_2O_3/(K_2O+Na_2O+CaO)$ <1.1) and their parent rock may be granite to granodioritic in nature whose composition was akin to calc-alkaline. This conclusion was also supported by the petrographic observation such as the presence of blebs of quartz in plagioclase which was due to metasomatism or hydrothermal influences. The high concentration of trace elements such as Sr, suggested the participation of a highly enriched mantle source in the petrogenesis of this gneissic rock. Intensive tectonic history and tectonic setting remains the subject of study.

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