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Petrogeochemistry of Amphibolites from Shivpura District Bhilwara, Rajasthan, India

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ABSTRACT

Amphibolites are frequently observed in the medium- to high-grade metamorphic rocks of Shivpura. These amphibolites are the result of the metamorphism of pre-existing mafic igneous rocks under medium to high grade P-T conditions and consist essentially of hornblende–plagioclase–garnet–clinopyroxene-epidote–iron oxide. Geochemically, these ortho-amphibolites are tholeiitic, show association with non-orogenic environment and shift to subalkaline derivatives with progressive differentiation. It is also clear that the parent magma for these rocks was highly evolved in nature. Paper records the petrography, geochemical characters and a probable origin of these amphibolites.

Keywords: Amphibolite petrology, geochemistry Shivapura, tholeiite, origin of amphibolite

INTRODUCTION

The area exposes rocks of the banded gneissic complex of the Proterozoic age (Buick *et al.* 2006). They predominantly include basic granulite, pelitic granulites and are surrounded by augen gneiss, migmatite and amphibolites, and constitute the main litho units of the gneissic complex (Fig.1) (Sharma 2003, Joshi *et al.* 1993, Thomas 1991, 1995, 2005a, 2005b, Thomas 2014, Thomas & Sujata 2008, Thomas & Vishwakarma 2009, 2011a, 2011b, Vishwakarma & Thomas 2015).

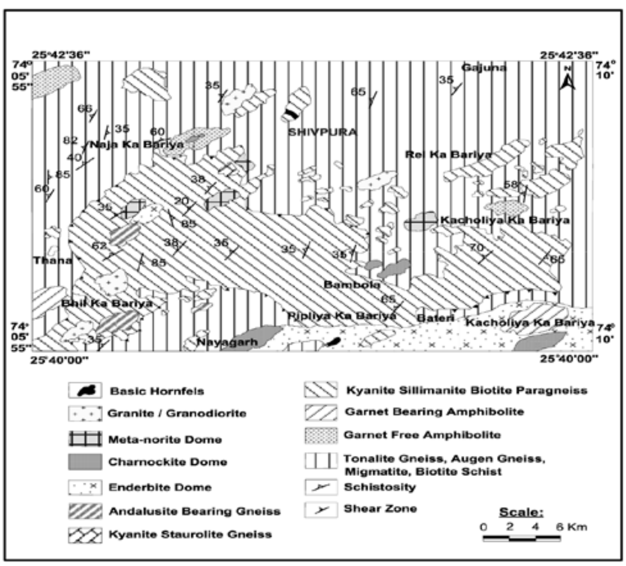


Fig. 1. A combined lithological and structural map of Shivpura, District-Bhilwara, Rajasthan (Thomas 2005).

The Amphibolite occurs as isolated bands varying in width from a few centimeters to 30 meter, and also as lensoid bodies within the para-gneiss. At places the amphibolites are mixed with gneisses to form migmatite on mesoscopic and megascopic scales. This mixed rock is characterized by a conspicuous schistosity due to the presence of equi- dimensional hornblende in varying amounts. The aim of this paper is to describe the petrography, chemical characters and a probable origin of these amphibolites.

Petrography

Amphibolite occurs as isolated bands varying in width from a few centimeters to 40 meter, and also as lensoid bodies within the paragneiss. At places the amphibolites are mixed with gneisses to form migmatites on mesoscopic and megascopic scales. This mixed rock is characterized by conspicuous schistosity due to the presence of equidimensional hornblende in varying amounts. This rock group consists of different assemblages. Therefore, on the basis of paragenesis the amphibolites can be divided into two major groups:

(a) Garnet–bearing amphibolite and

(b) Garnet–free amphibolite

Despite this difference in mineralogy and texture, their petrography is described together to avoid repetition.

Megascopic Character

The rock is medium- to coarse-grained and moderate to highly compact. Sometimes the rock contains fine laminations. Hornblende is the main constituent and is accompanied by plagioclase, garnet, quartz, feldspar and sphene, etc. Lineation due to preferred dimensional orientation of hornblende is often discernible.

Microstructure/Texture

Schistosity is distinct in hand specimens. Porphyroblastic texture is revealed by hornblende and also by garnet which are often sieved with hornblende, sphene and quartz (Plate 1AB). Symplectitic reaction rim also occurs due to the development of hornblende between clinopyroxene and plagioclase (Plate 1CD) or by the presence of garnet reaction rims between hornblende and plagioclase (Plate 2AB). Epidote occasionally formed through the hydration reaction of plagioclase few sections (Plate 1AB). Potash feldspar is generally perthitic and at times in large size to appear as a porphyroblast. In a few sections, granophyric intergrowth was also noticed. The different assemblages recorded in the rocks are:

(a) Garnet-Bearing amphibolite

I. Hornblende–garnet–diopside–plagioclase–epidote–quartz-K-feldspar–ilmenite–magnetite (Sample No.R87/225)

II. Hornblende–plagioclase–garnet-K-feldspar(±epidote)-magnetite (Sample No.R87/489)

(b) Garnet-Free amphibolite

I. Hornblende–epidote–plagioclase–quartz K-feldspar–sphene ± zircon

(Sample No.R87/422)

II. Hornblende–diopside–plagioclase–K-feldspar–quartz±epidote-rutile± ilmenite (Sample No.R87/329)

Microscopic Description of Minerals

Hornblende

Hornblende crystals are medium to coarse grained with the pleochroism.

Γ = light yellowish brown,

B = green

A = dark bluish green

Grains often show schiller structure due to the presence of opaque dust and streaks along the cleavage traces. Some laths are studded with several inclusions of quartz, ilmenite, epidote and plagioclase. Hornblende is commonly present in the garnet free and garnet bearing amphibolites.

The reaction rim of hornblende at the clinopyroxene-plagioclase interface (Plate 1CD), and the inclusions of small diopside crystals in hornblende suggest that these phases are possibly related by reaction such as:

Clinopyroxene + Plagioclase + H_2O = Hornblende + Quartz

The above reaction is a hydration reaction and thus indicative of retrograde metamorphism. This makes hornblende–plagioclase and hornblende – quartz as stable associations. However, at other places the hornblende – plagioclase is incompatible. The two phases are separated by a rim of garnet. A possible reaction for this relationship is (Plate 2AB):

Hornblende + Plagioclase = Garnet + Quartz + H_2O

This is certainly a prograde metamorphism reaction during granulite facies metamorphism.

Garnet

Equant crystals of garnet are rare. Fractured crystals with irregular outline are common (Plate 1AB & 2AB), suggesting post crystalline deformation. The garnets are brownish in coloured and occur as fresh granules and/ or as an aggregate at the hornblende/plagioclase contacts (Plate 2AB). The textural relation in the formation of garnet in the rock may suggest the following reaction:

Hornblende + Plagioclase = Garnet + Quartz + H_2O

Diopside

Diopside is non-pleochroic but shows light pink or light green colour the crystals are embedded in hornblende or are rimmed by hornblende, against its contact with plagioclase (Plate 1C-D). At places epidote granules are also present near hornblende. However, at other places the clinopyroxene–plagioclase is incompatible. The probable reaction for this textural relationship is:

Diopside + Plagioclase + H_2O = Hornblende ± Quartz

Some clinopyroxene shows schiller structure.

Plagioclase

Plagioclase crystals are without any dimensional orientation. In a few sections, plagioclase is altered or kaolinized near the margins and the altered crystals show bent lamellae and mortar structure. The feature may indicate hydration of plagioclase during post crystalline deformation (cataclasis). Most grains are free of inclusions but at places plentiful epidote is found in the outer region of plagioclase contacting hornblende, which suggests the reaction:

Plagioclase + H_2O = Epidote

The anorthite percentage of the plagioclase varies from An_{32} to An_{47}.

Epidote

Epidote occurs as defined idioblasts in columnar aggregates, associated with the hornblende or mica and sometimes seen flattened along them. It is usually associated with garnet. In one section it is showing myrmekite structure (Plate 1AB). The epidote is generally formed by the hydration reaction of plagioclase as follows:

Plagioclase + Calcite = Scapolite

Quartz

Quartz is generally more sutured and shattered. The crystals show a high degree of deformation, as revealed by their elongation and undulose extinction.

Sphene

A large number of xenoblastic sphene crystals are seen in aggregate masses which are slightly flattened along the plane of schistosity. Rhomb shaped idioblasts are rather rare. Magnetite is always included within sphene. Sphene also contains inclusions of rutile. The possible reaction is:

$$TiO_2 + CaCO_2 + SiO_2 = CaTiSiO_5 + CO_2$$

Magnetite

It is present either as minute inclusions with other minerals or as bigger isolated grains. Apatite, rutile, ilmenite and zircon are the other minor mineral constituents.

Whole-rock geochemistry

Analytical techniques

Eleven amphibolites samples were selected for geochemical study. Major and few trace elements were determined by ASS method, at the Wadia Institute of Himalaya Geology, Dehradun, U.P. now Uttarakhand Results (major oxides, norms, niggli values, and trace elements) of the eleven selected samples of amphibolites assemblages are presented in the Tables 1 and 2, respectively.

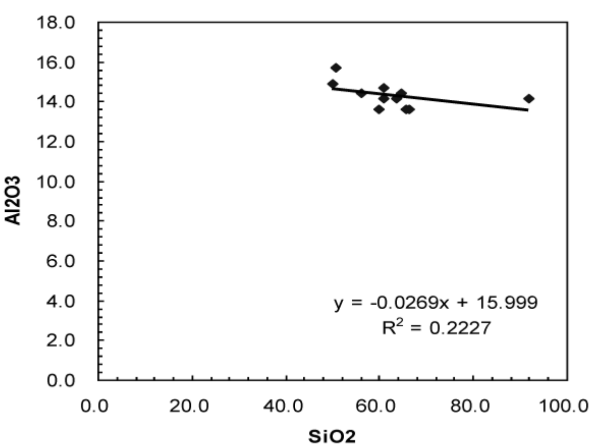
Table 1. Major element analyses (in wt %) and trace element analyses (in ppm) values of amphibolites from Shivpura, District Bhilwara, Rajasthan

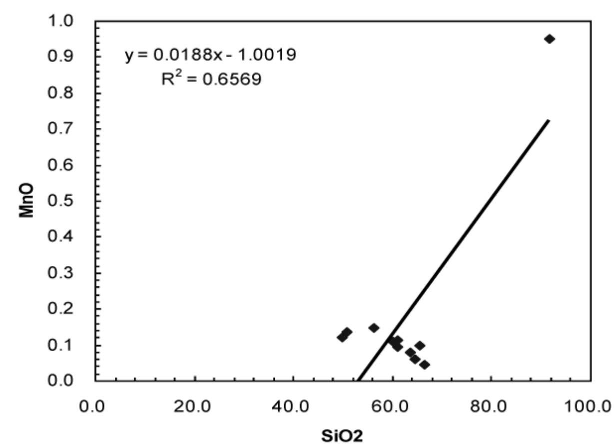
S. No	R87/266	R87/351	R87/357	R87/495	R87/371	R87/329	R87/400	R87/422	R87/237	R87/277	R87/487
SiO_2	59.98	63.67	64.6	60.90	49.84	66.40	50.68	61.81	65.51	56.20	60.90
Al_2O_3	13.62	14.14	14.4	14.14	14.93	13.62	15.71	14.14	13.62	14.40	14.70
Fe_2O_3	1.17	1.16	1.16	2.12	2.16	1.36	1.31	2.00	1.33	2.28	2.20
FeO	7.97	6.23	4.84	7.33	8.16	4.64	8.08	6.26	6.12	9.11	7.50
MgO	2.42	1.00	1.81	3.02	7.46	1.41	8.67	2.02	2.42	3.02	2.60
CaO	6.17	5.60	4.48	4.48	11.22	7.29	10.65	6.16	3.64	7.29	5.60
Na_2O	3.00	2.40	2.00	2.00	3.40	0.80	2.00	1.40	2.20	2.20	2.20
K_2O	3.00	4.10	5.00	3.10	0.30	3.60	2.60	3.70	3.50	2.70	2.80
MnO	0.11	0.08	0.06	0.11	0.12	0.04	0.14	0.95	0.10	0.15	0.10
TiO_2	1.30	0.88	0.75	1.32	0.82	0.59	0.84	1.22	1.07	1.54	1.36
P_2O_5	0.00	0.07	0.07	0.07	0.78	0.25	0.13	0.15	0.08	0.36	0.20
Total	98.74	99.33	99.16	98.59	99.19	100.01	100.80	99.61	99.59	99.25	100.16
Trace elements											
Cu	187	191	160	37	200	165	187	194	37	70	160
Co	11	008	86	08	17	86	13	07	07	11	10
Ni	22	20	20	14	55	18	53	13	16	17	32
Li	19	9	15	19	13	11	08	19	24	19	20
Rb	98	141	121	116	0	191	53	101	136	113	106
Sr	222	157	281	260	248	354	260	182	236	257	307
V	108	81	69	120	216	75	180	240	115	243	138
Zn	141	148	131	114	147	115	128	141	107	164	126

Table 2. CIPW norms and Niggli values of amphibolites from Shivpura, Bhilwara, Rajasthan

Sam. No	R287/ 266	R287 /351	R287 / 357	R287 /495	R287 /371	R287 /329	R287 /400	R287 /422	R87/ 237	R287/ 277	R287/ 487
Quartz	12.32	19.08	20.03	19.28	---	30.48	--	21.83	24.28	11.03	18.53
Orthoclase	17.74	24.24	29.58	18.35	1.78	21.29	15.57	21.91	20.68	15.96	16.57
Albite	25.36	20.28	16.93	16.93	28.72	6.76	16.77	11.84	18.60	18.60	18.60
Anorthite	14.79	15.65	15.48	20.38	24.58	22.88	26.13	21.29	16.90	20.68	21.91
Diopside	13.05	09.98	5.06	1.44	21.61	9.56	21.18	6.79	0.97	19.29	3.96
Hypersthene	11.32	06.58	8.78	16.55	5.54	5.38	--	9.72	14.11	14.40	14.38
Olivine	-	-	-	-	10.57	-	17.40	---	---	---	----
magnetite	1.69	1.67	1.69	3.09	3.13	1.97	1.90	2.90	1.93	3.32	3.20
Ilmenite	2.46	1.67	1.41	2.51	1.55	1.12	1.67	2.33	2.04	2.93	2.58
Apatite	-	0.17	0.17	0.71	1.85	0.60	0.27	0.37	--	0.84	0.47
Niggle Values											
Al	26.15	30.96	32.57	28.39	20.00	27.59	20.64	29.26	30.83	24.88	23.94
Alk	15.70	18.36	19.72	13.34	7.92	12.41	8.02	13.05	16.76	11.30	13.67
C	21.53	22.29	18.20	16.35	27.33	31.57	25.03	23.17	14.98	22.89	20.93
Mg	0.32	0.20	0.35	0.37	0.56	0.30	0.62	0.31	0.37	0.32	0.33
Fm	36.62	28.38	29.50	41.93	44.72	28.42	46.31	34.52	37.98	40.92	41.46
Si	195.43	236.65	248.37	207.51	113.35	268.48	113.01	217.13	251.66	164.81	212.54
Ti	3.17	2.46	2.14	3.38	1.40	1.80	1.41	3.17	3.09	3.39	3.57
P	-	0.11	0.12	0.10	0.75	0.43	0.11	0.22	0.13	0.45	0.30
K	0.40	0.53	0.62	0.51	0.05	0.75	0.46	0.36	0.51	0.45	0.46

The compositional ranges for major elements are displayed in Harker variation diagrams (Fig. 2). The SiO_2 contents of amphibolites ranges from 49.84 to 66.40 percent averaging at 60.04 percent. With increasing SiO_2 content, Al_2O_3, FeO and MgO decreases markedly from 13.62 to 15.71 percent, 4.64 to 9.11 percent and 1.00 to 8.67 percent respectively. The K_2O varies from 0.30 to 5.00 percent and averages at 3.13 percent while Na_2O ranges from 0.80 to 3.40 percent with an average of 2.15 percent. The CaO content ranges from 3.64 to 11.22 percent averaging at 6.60 percent. The K_2O, Na_2O and CaO contents are seem to be good correlated with SiO_2 (Fig. 2).





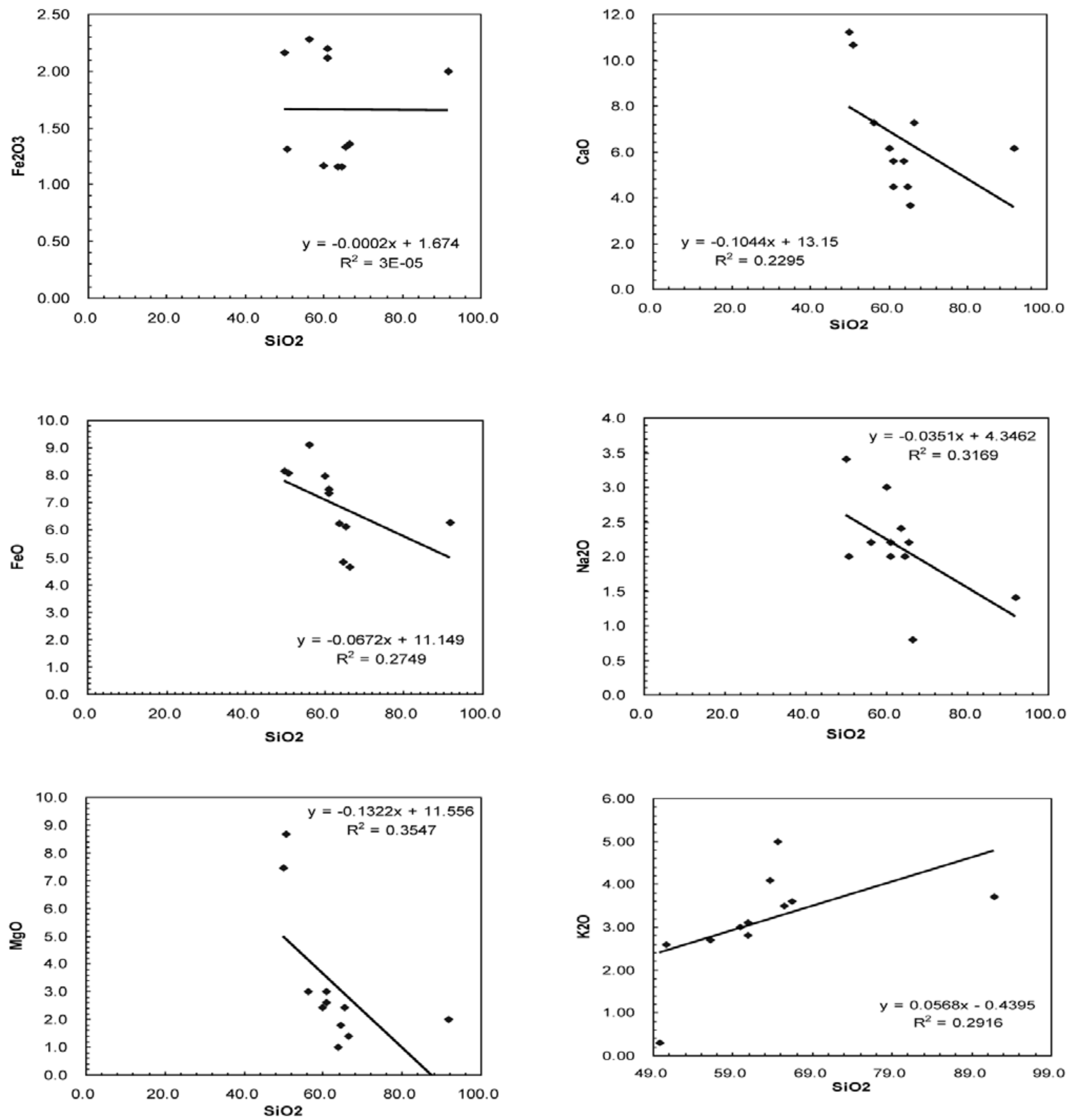


Fig. 2. Harker variation diagram for amphibolite from Shivpura, Rajasthan, India

The Niggli's 100mg–c–(al–alk), Leake (1964) diagram (Fig. 3), shows that all samples fall within the late basic igneous rocks field. Similarly, the Niggli's "c" and (al–alk) diagram (Fig. 4) supports an igneous parentage for the amphibolites. On the basis of silica–alkalis (SiO_2 vs. K_2O+Na_2O) discrimination diagram (Fig. 5), (Irvine & Baragar 1971), clearly indicates that all samples lie within the sub-alkaline field.

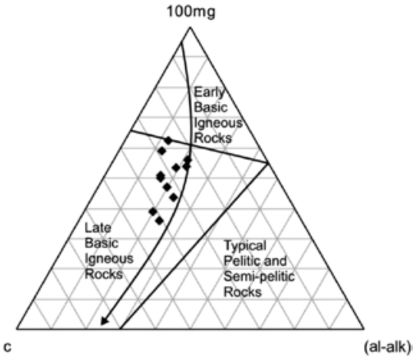


Fig. 3. The 100mg–c–(al–alk) of the selected eleven amphibolite rock samples from Shivpura area, District Bhilwara, Rajasthan.

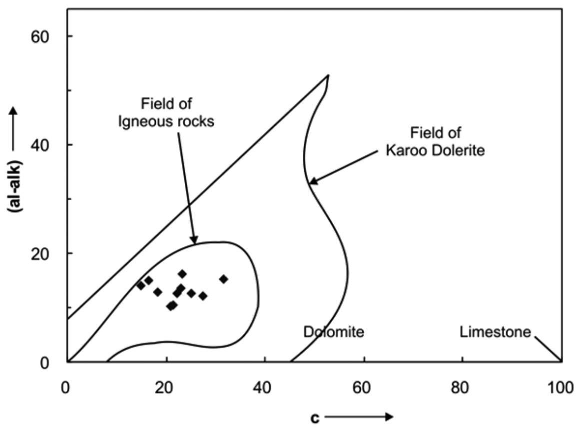


Fig. 4. The silica–alkali discrimination plot of Irvin and Baragar (1971) for the selected eleven amphibolite rock from Shivpura area, District Bhilwara, Rajasthan.

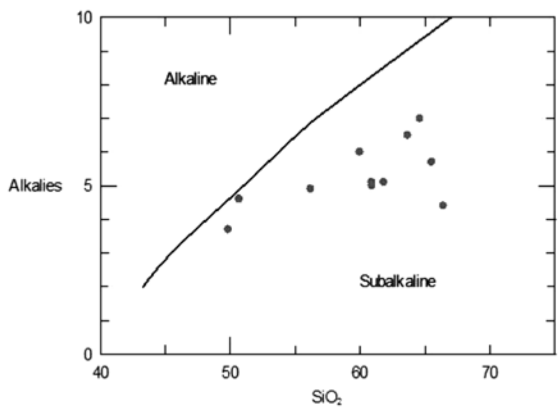


Fig. 5. The silica–alkali discrimination plot of Irvin and Baragar (1971) for the selected eleven amphibolite rock from Shivpura area, District Bhilwara, Rajasthan.

In order to differentiate the field of calc-alkaline and tholeiitic basalts, the AFM diagram (Fig. 6) (Irvine & Baragar 1971) as well as, the FeO^T/MgO and SiO_2 diagram (Fig. 7), (Miyashiro 1974), show their tholeiitic nature.

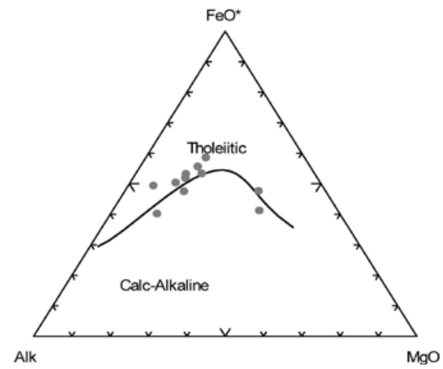


Fig. 6 The AFM discrimination plot of Irvin and Baragar (1971) for the selected eleven amphibolite rocks from Shivpura area, District Bhilwara, Rajasthan.

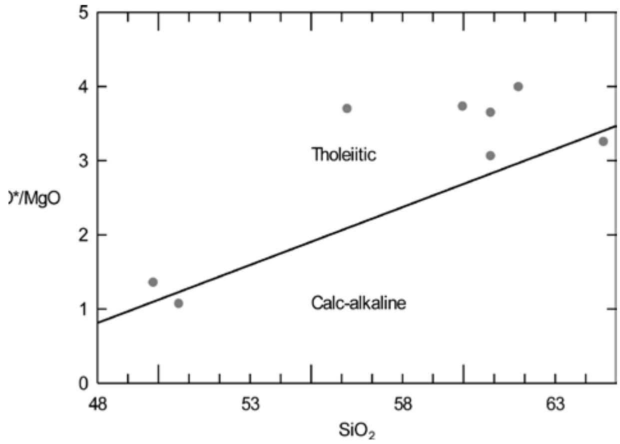


Fig. 7. The plot between SiO2 versus FeOT/MgO of Miyashiro (1974) for the selected eleven amphibolite rock from Shivpura area, District Bhilwara, Rajasthan.

The diagram of (Fe^T+Ti)–Al–Mg, (Fig. 8), (Jenson & Pyke 1982), clearly indicates that the samples fall in the tholeiitic field.

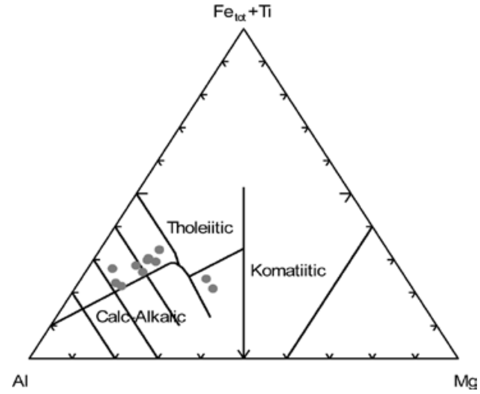


Fig. 8. The (FeT + Ti) – Al – Mg discrimination plot of Jenson and Pyke, (1982) for the selected eleven amphibolite rock from Shivpura area, District Bhilwara, Rajasthan.

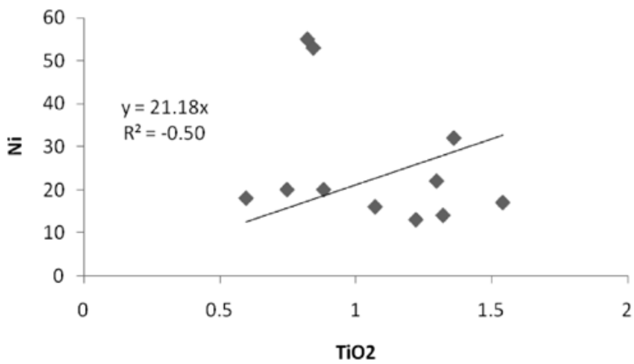


Fig. 9. Plot of Ni ppm vs TiO2 wt%

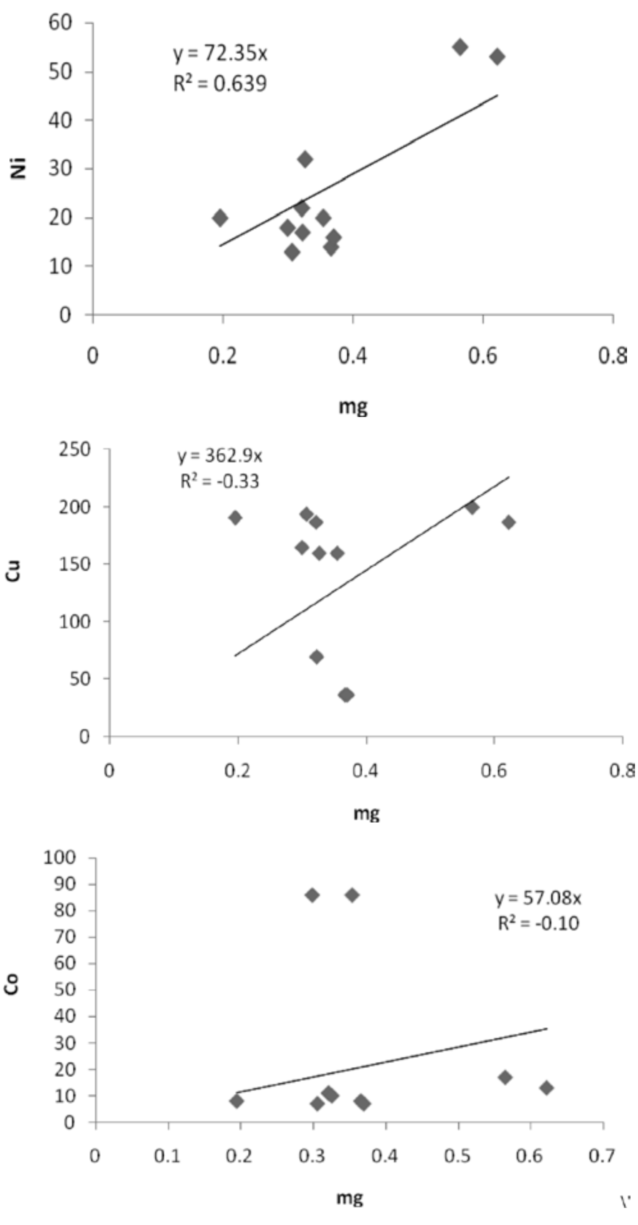


Fig. 10. Niggle mg vs Ni, Cu and Co after Leake (1964)

A negative correlation of TiO2 wt% with Ni ppm (Fig. 9) is observed in mafic igneous rocks. Plots of Niggli mg vs Ni, Co, Cu (Fig. 10) define igneous fractionation as Leake (1964) suggest that positive correlation of mg with Ni indicates igneous fractionation. But with Co it show negative correction because cobalt does not vary with differentiation so much as Ni in most basic rocks (walker *et al.* 1960).

It can be thus concluded that tholeiite has been the parent composition of amphibolite. The presence of relic laths of plagioclase in some amphibolites along with these chemical discrimination diagrams supports ortho-metamorphic origin for the amphibolites of the area. Still REE is required in support of possible source of origin of these amphibolites which will be cover in future studies.

CONCLUSION

On the basis of the above discussion, the following conclusions can be draw:

i) The present amphibolites occurring as isolated bands varying in width from a few centimeter to 40 meter, and also as lensoid bodies within the para-gneiss, and result of metamorphism of pre-existing mafic igneous rocks like gabbroids (gabbro/dolerite) under medium to high grade P-T conditions.

ii) The mineralogy of the amphibolites which include hornblende, epidote, garnet, albite etc appears to be derived from original calcic plagioclase-pyroxene. Alteration of pyroxene (relicts) is also the concurrent effects.

iii) The chemical characters of these amphibolites can be compared with that of the other known amphibolites. Diagrams and their interpretations indicate its igneous nature (orthotype) and affinity with sub-alkaline basalt whose composition was akin to tholeiites. It is also clear that the parent magma for these rocks was highly evolved in nature.

ACKNOWLEDGEMENTS

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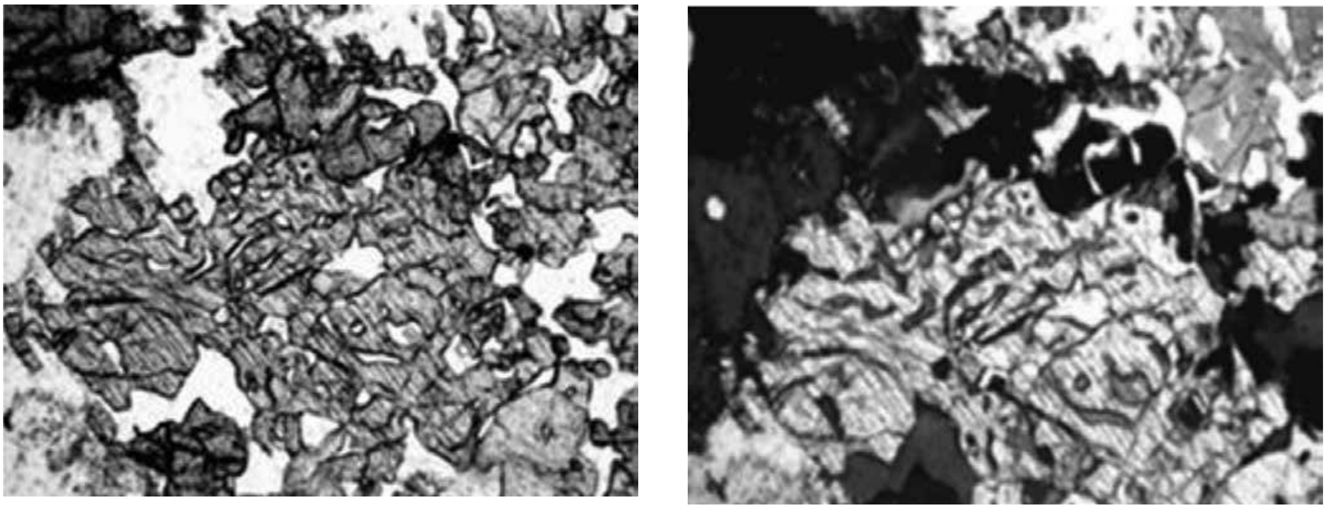
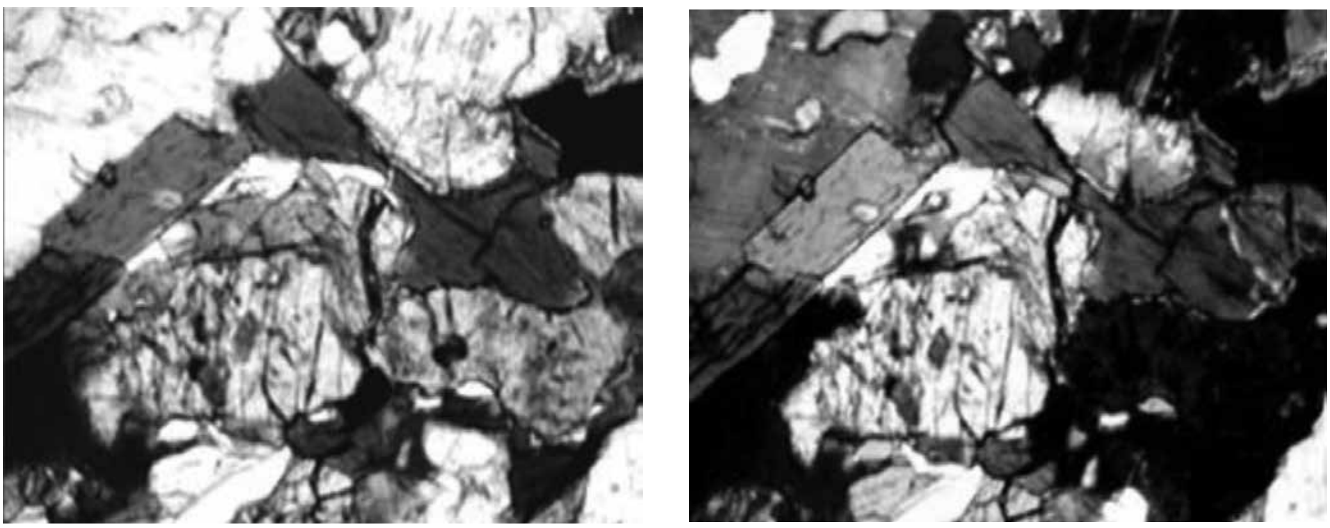
PLATE – 1

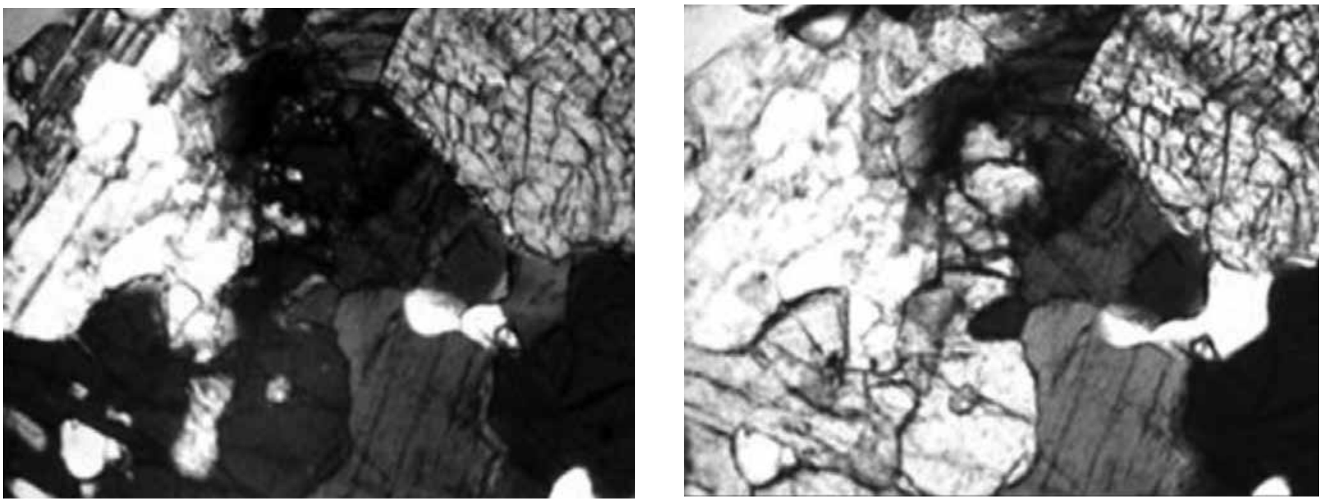


1AB Development of epidote, which might have been formed through the hydration reaction of plagioclase.
Plagioclase + H_2O = Epidote
Also notice the garnet having irregular out line. (Sample No. R87/225)



1CDRim of hornblende around clinopyroxene against its contact with plagioclase indicates towards the reaction:
Clinopyroxene + Plagioclase + H_2O = Hornblende + Quartz
Notice the iron leaching in clinopyroxene. (Sample No. R97/422)

PLATE – 2

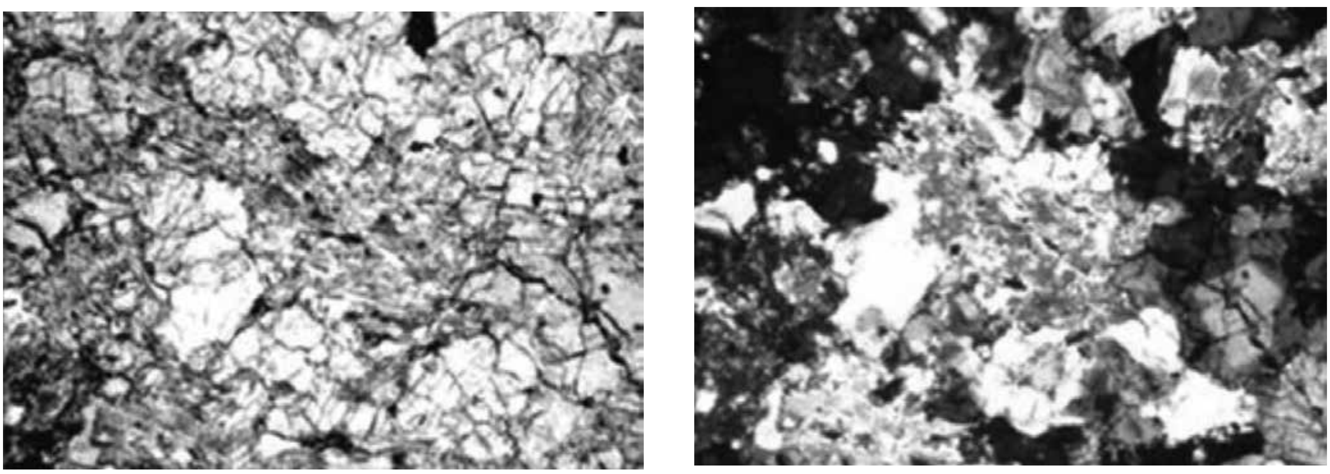


2AB Clinopyroxene rimed by hornblende and hornblende itself rimed by garnet against its contact with plagioclase, suggests the reaction:

Clinopyroxene + Plagioclase + H_2O = Hornblende + Quartz

Followed by

Hornblende + Plagioclase = Garnet + Quartz + H_2O(Sample No.R87/329)



2CD - Replacement of plagioclase by epidote through the reaction:

Plagioclase + H_2O = Epidote

Also notice the zoning in epidote. (Sample No.R87/302)

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