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Geochemical Characteristic of Amphibolites from Asind, District Bhilwara, Rajasthan, India

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Amphibolites are frequently observed in the medium to high grade metamorphic rocks of Asind of proterozoic age. These amphibolites are the results 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 sub alkaline derivatives with progressive differentiation. The absence of Nb anomaly and a low Th/La ratio of amphibolites, indicate an asthenospheric or primitive mantle source without any supra subduction imprint or crustal contamination, severally limiting the continental tholeiite option. It is also clear that the parent magma for these rocks was highly evolved in nature. This paper records the geochemical characters and a probable origin of these amphibolites.

Key Words: Geochemical, amphibolite, Asind and Rajasthan

INTRODUCTION

The area exposes rocks of the Banded Gneissic Complex of the proterozoic age. 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[1-9] (Fig. 1).

The amphibolite occurs as isolated bands varying in width from a few cm to 30 m 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.

EXPERIMENTAL

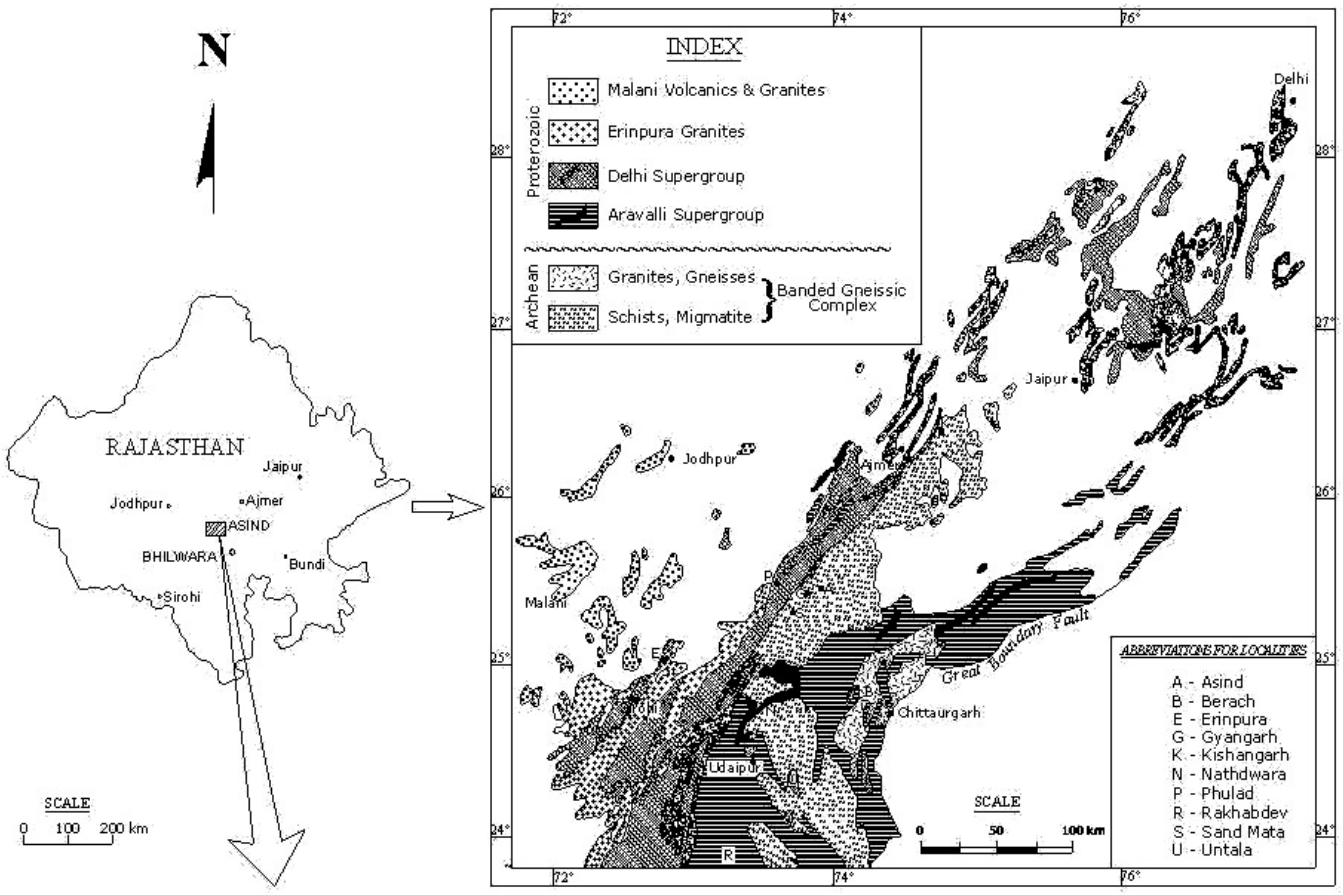
Seven amphibolite samples were selected for geochemical study. Major, trace elements and rare earth elements were determined by X-ray fluorescence method (XRF) and inductively coupled plasma-mass spectrometry (ICP-MS) method, respectively, at the National Geophysical Research Institute, Hyderabad, on GSI standards[10].

Results (major oxides, norms, niggli values, trace elements and REE) of the seven selected samples of amphibolites assemblages are presented in the Tables 1 and 2, respectively.

The chemical analyses of amphibolites show variations in almost all major elements and these variations clearly reflect the minerals phases of those particular samples. The SiO_2 and Al_2O_3 content varies from 48.44 to 60.35 % and from 10.25 to 16.76 %, respectively. The FeO^T, MgO and CaO content varies from 4.95 to 15.06 and 0.09 to 5.68 and from 8.51 to 21.62 respectively. The concentration level of Na_2O, MnO, K_2O, TiO_2 and P_2O_5 do not show much variation. The average K_2O/Na_2O ratio of these rocks is high, except for sample NV157. The plots between SiO_2 and others oxides (Fig. 2) show good correlation, which indicates coherent behaviour of these elements during different processes. The ACF (Fig. 3) diagram clearly indicates that all samples lie within the basic field indicates the basic nature of these rock types.

The plot between Niggli' 'mg' *versus* 'c' values are also used to examine the nature of the protolith[11] (Fig. 4). All samples follow the trend of Karroo dolerite. The amphibolite lies within the middle to late stage of differentiation. The Niggli's 100 mg-c-(al-alk)[11] diagram (Fig. 5) showed that all samples fall within the late basic igneous rocks field. Similarly, the Niggli's c and (al-alk) diagram (Fig. 6) supports an igneous parentage for the amphibolites. The presence of relic laths of plagioclase in some amphibolites along with these chemical discrimination diagrams[11] (Figs. 5 and 6) supports ortho-metamorphic origin for the amphibolites of the area.

On the basis of silica-alkalis (SiO_2 *vs.* K_2O+Na_2O) discrimination diagram (Fig. 7), it is clearly indicated that all samples



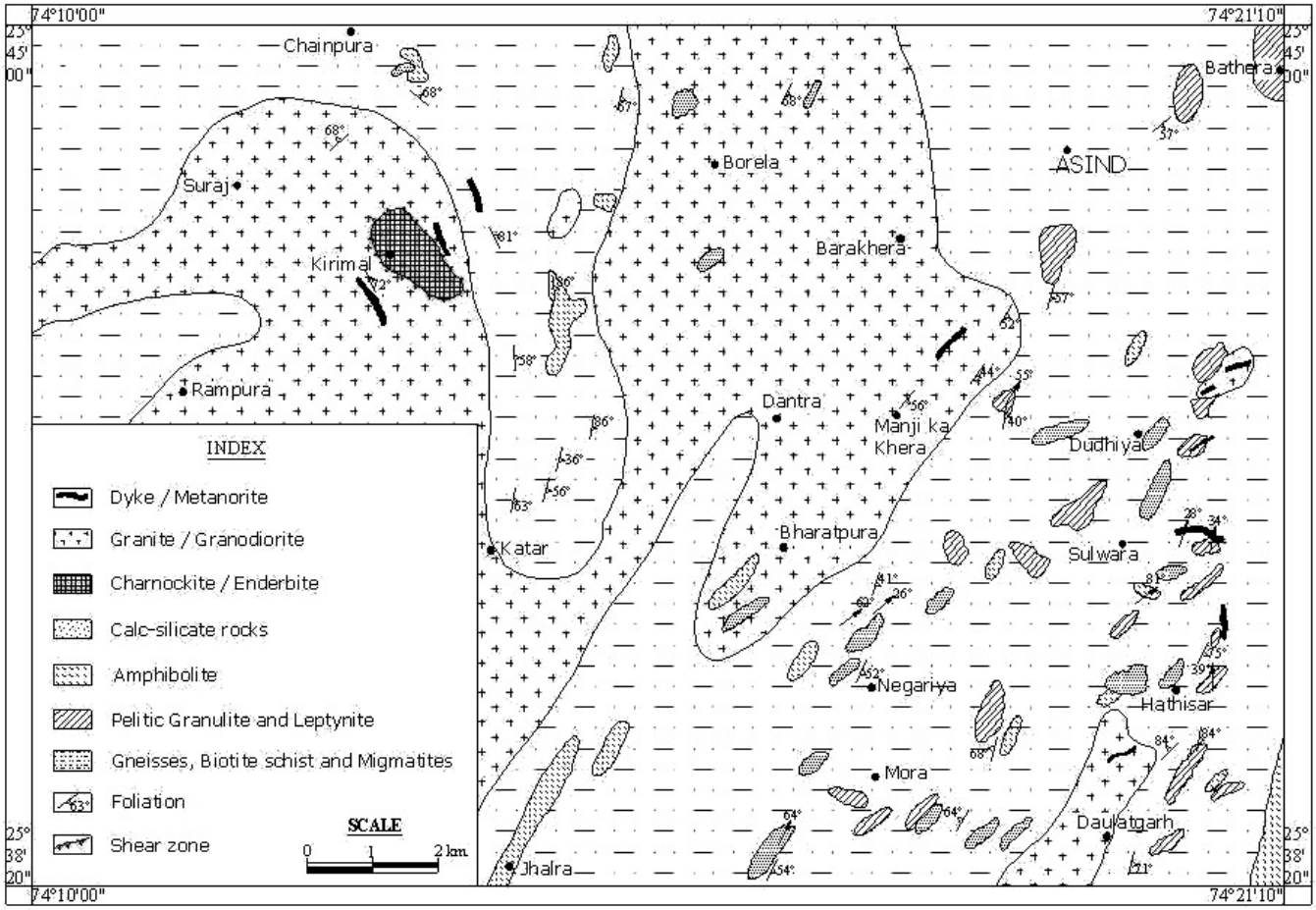


Fig. 1. Geological map around Asind, District Bhilwara, Rajasthan, showing distribution of different lithounits by the authors

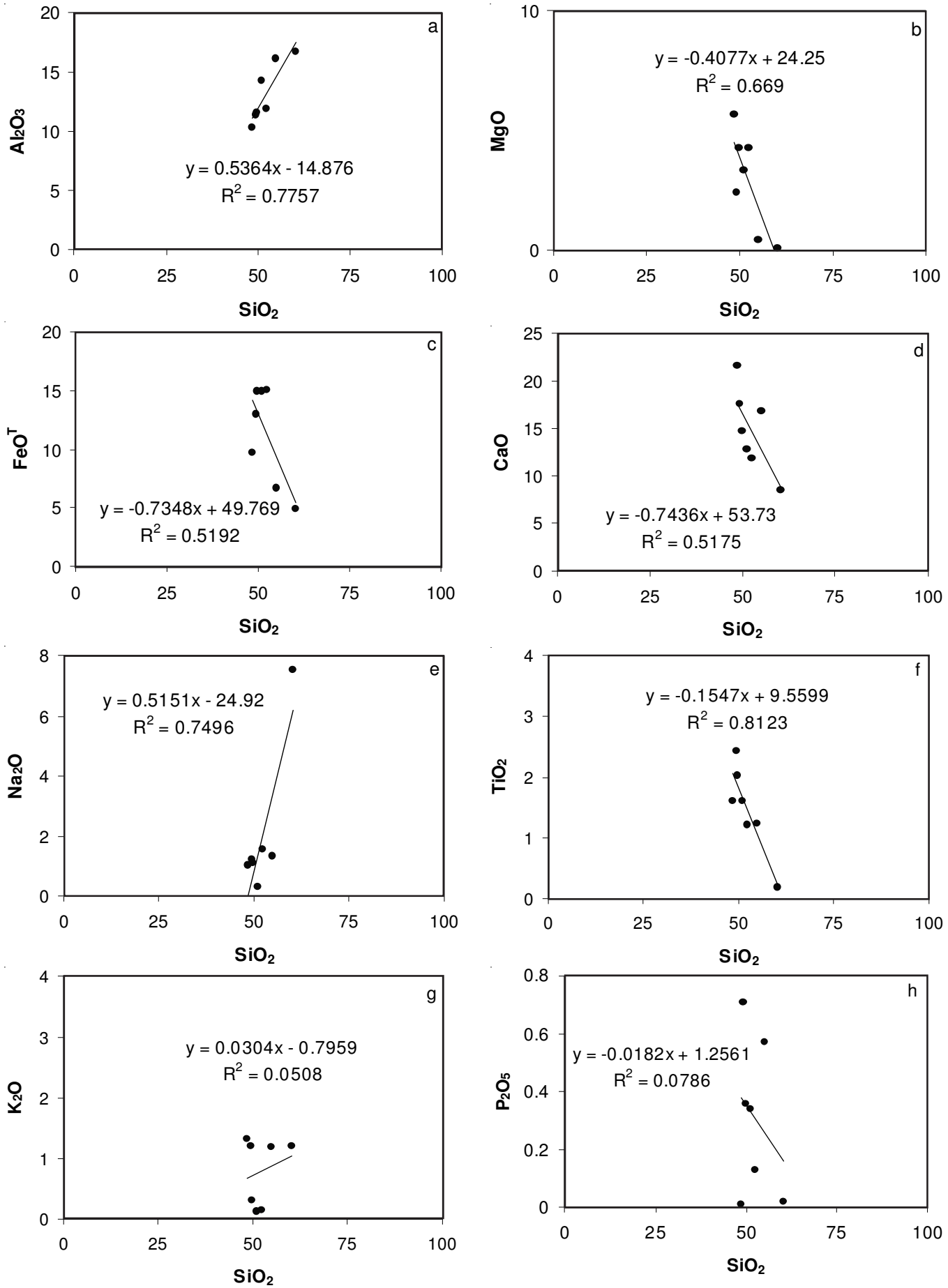


Fig. 2. Harker variation diagrams for the selected seven amphibolite rock samples from Asind area, District Bhilwara, Rajasthan

TABLE-1
MAJOR ELEMENT ANALYSES (wt%), CIPW NORMS AND NIGGLI VALUES OF AMPHIBOLITE FROM ASIND AREA, DISTRICT BHILWARA, RAJASTHAN

Sample no.	NV 86	NV 157	NV 174	NV 184	NV 195	NV 203	NV 221
Major elements							
SiO_2	54.92	48.44	49.76	52.35	50.99	49.25	60.35
Al_2O_3	16.11	10.25	11.56	11.87	14.26	11.42	16.76
FeO^T	6.68	9.77	15.02	15.06	14.97	12.96	4.95
MnO	0.06	0.16	0.17	0.21	0.23	0.45	0.08
MgO	0.42	5.68	4.26	4.25	3.35	2.44	0.09
CaO	16.86	21.62	14.71	11.84	12.75	17.61	8.51
Na_2O	1.32	1.02	1.11	1.58	0.29	1.23	7.56
K_2O	1.20	1.33	0.32	0.15	0.13	1.22	1.22
TiO_2	1.23	1.61	2.02	1.22	1.6	2.44	0.18
P_2O_5	0.57	0.01	0.36	0.13	0.34	0.71	0.02
Total	99.37	99.89	99.29	98.66	98.91	99.73	99.72
CIPW norms							
Q	12.60	-	3.76	6.53	11.08	1.78	-
Or	7.09	0.71	1.89	0.89	0.77	7.21	7.21
Ab	11.17	19.46	9.39	13.37	2.45	10.41	56.64
An	34.49	-	25.61	24.85	37.22	22.04	8.19
Lu	-	5.60	-	-	-	-	-
Ne	-	4.68	-	-	-	-	3.97
C	-	-	-	-	-	-	-
Di	21.71	59.81	38.29	28.16	20.41	51.86	17.30
Hy	-	-	15.67	22.25	23.15	-	-
Wo	8.65	6.55	-	-	-	0.16	6.02
Ol	-	-	-	-	-	-	-
il	2.34	3.06	3.84	2.32	3.04	4.63	0.34
ap	1.32	0.02	0.83	0.30	0.79	1.64	0.05
An%	75.54	100.00	73.17	65.02	93.82	67.92	12.64
Niggli values							
al	26.47	12.63	15.88	17.31	20.94	15.86	31.41
alk	5.70	3.84	2.98	4.03	0.91	4.64	25.78
c	50.37	48.45	36.73	31.39	34.04	44.47	29.00
mg	0.10	0.50	0.33	0.33	0.28	0.24	0.03
fm	17.46	35.08	44.41	47.28	44.12	35.02	13.81
si	158.82	75.80	95.26	103.85	125.62	95.18	188.48
ti	1.54	2.02	2.53	1.53	2.00	3.05	0.23
k	0.37	0.46	0.16	0.06	0.23	0.39	0.10

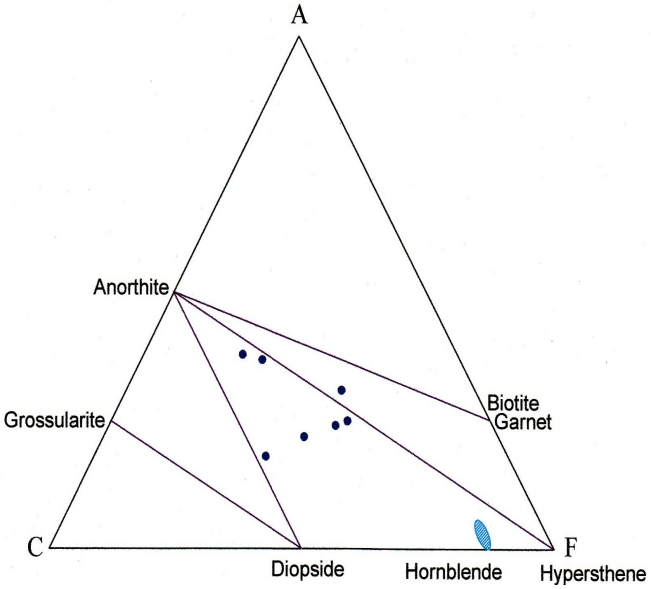


Fig. 3. The ACF plot of the selected seven amphibolite rock samples from Asind area, District Bhilwara, Rajasthan

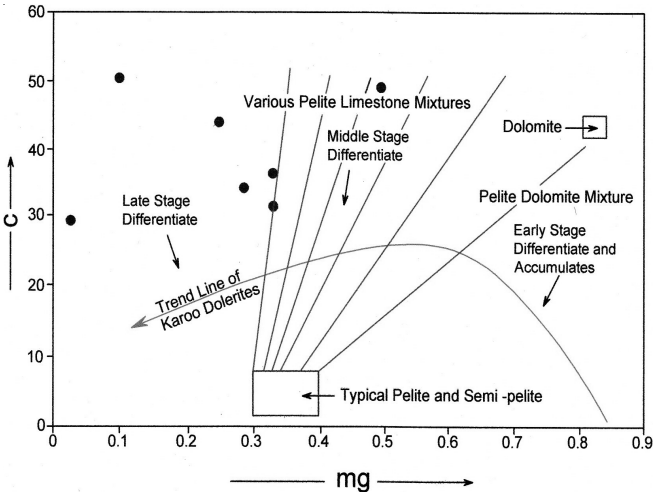


Fig. 4. The Nigglis mg *versus* c plot for the selected seven amphibolite rock samples from Asind area, District Bhilwara, Rajasthan

lie within the sub-alkaline field[12]. Similarly, the Nb/Y ratios, which is less than 0.9, also indicates, they are sub-alkaline in nature[13,14](Fig. 8).

TABLE-2
TRACE AND RARE EARTH ELEMENT ANALYSES (ppm) OF AMPHIBOLITE
FROM ASIND AREA, DISTRICT BHILWARA, RAJASTHAN

Sample no.	NV 86	NV 157	NV 174	NV 184	NV 195	NV 203	NV 221
Sc	21.22	14.05	37.75	40.52	32.01	35.78	3.51
V	54.29	43.36	172.36	196.82	119.37	108.56	15.12
Cr	50.13	60.38	60.25	47.55	122.93	79.50	42.10
Co	1.85	23.34	42.60	49.45	36.57	25.25	1.55
Ni	23.67	23.57	33.04	30.95	32.76	29.62	12.09
Cu	0.62	1.56	2.76	1.37	3.42	3.15	1.53
Zn	52.07	122.36	169.71	84.90	198.85	147.67	18.86
Ga	30.58	19.66	21.17	17.04	25.15	17.43	35.80
Rb	75.30	0.61	5.77	6.89	5.35	6.04	2.33
Sr	1.01	131.48	154.89	92.81	128.84	116.32	1.01
Y	98.97	34.08	36.39	35.91	41.47	56.99	40.90
Zr	30.53	134.91	27.73	13.44	17.72	68.48	80.78
Nb	41.90	99.50	8.55	2.26	4.33	12.13	8.52
Cs	0.32	0.08	0.08	0.09	0.27	0.19	0.21
Ba	125.14	32.94	144.03	55.29	129.58	211.59	83.59
Hf	1.70	5.21	1.60	0.98	1.03	2.76	4.08
Ta	3.92	15.80	0.51	0.18	0.05	0.53	0.59
Pb	11.64	11.92	5.83	6.88	5.36	6.58	9.74
Th	30.28	21.53	0.61	0.29	1.01	1.03	0.58
U	5.95	3.72	0.48	0.10	0.86	2.19	0.86
Rare earth elements							
La	150.38	42.55	8.93	2.60	30.28	15.00	6.11
Ce	308.68	128.91	24.49	7.55	32.48	39.47	14.31
Pr	31.15	17.20	3.49	1.25	4.10	5.61	2.34
Nd	121.02	71.68	17.71	7.44	19.68	28.31	13.28
Sm	21.97	12.73	5.08	2.79	5.62	7.57	4.78
Eu	2.29	1.42	1.22	0.75	1.30	2.13	3.24
Gd	17.67	8.26	4.77	3.33	5.37	7.25	5.23
Tb	2.77	1.16	0.89	0.72	1.01	1.38	1.14
Dy	18.84	7.00	6.49	6.00	7.34	10.30	9.06
Ho	2.07	0.72	0.75	0.74	0.85	1.20	1.07
Er	6.80	2.37	2.49	2.56	2.75	4.00	3.46
Tm	0.87	0.30	0.32	0.35	0.35	0.51	0.46
Yb	8.55	3.06	3.17	3.60	3.51	5.15	5.07
Lu	1.35	0.51	0.52	0.61	0.57	0.86	0.99
ΣREE	694.40	297.84	80.29	40.29	115.22	128.73	70.53
LREE/HREE	611.90	267.64	51.06	11.14	82.44	81.95	28.03
La_N / Yb_N	12.63	9.98	2.02	0.52	6.19	2.09	0.86
La / Eu	65.73	30.03	7.35	3.45	23.31	7.03	1.89
Eu / Lu	1.69	2.80	2.35	1.25	2.27	2.49	3.27

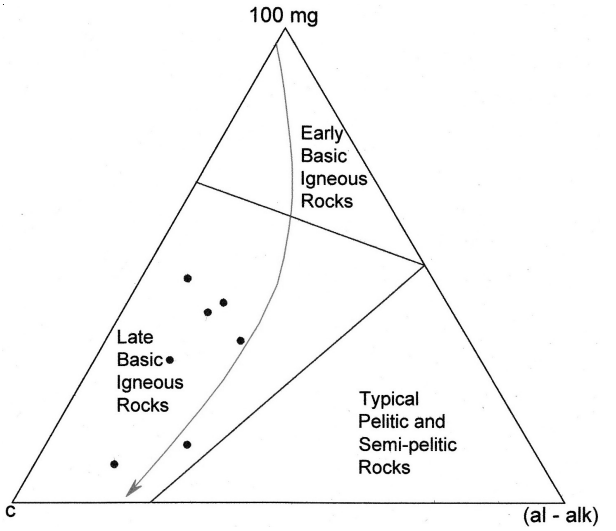


Fig. 5. The 100 mg-c-(al-alk) of the selected seven amphibolite rock samples from Asind area, District Bhilwara, Rajasthan

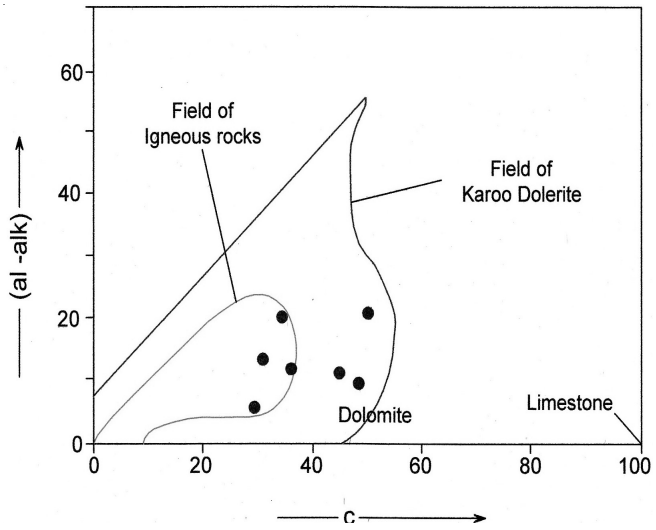


Fig. 6. The Nigglis c *versus* al-alk plot of the selected seven amphibolite rock samples from Asind area, District Bhilwara, Rajasthan

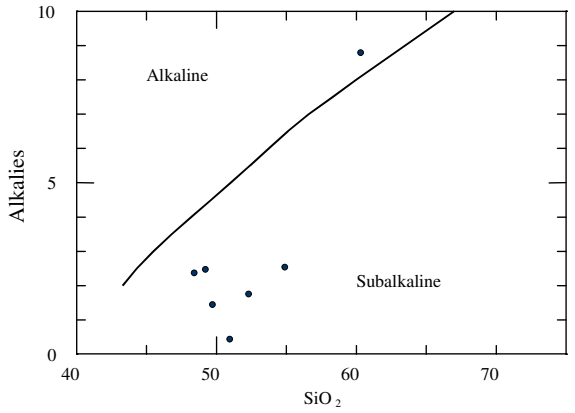


Fig. 7. The silica-alkali discrimination plot of Irvin and Baragar[12] (1971) for the selected seven amphibolite rock from Asind area, District Bhilwara, Rajasthan

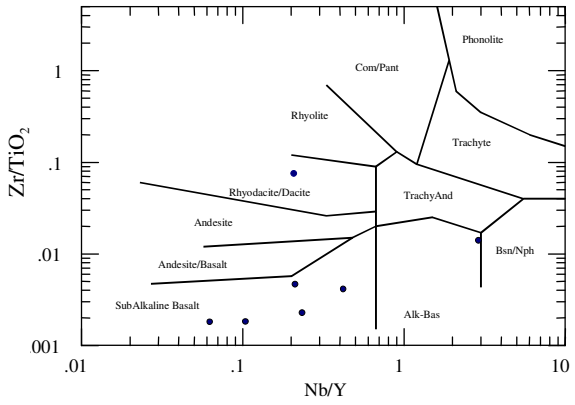


Fig. 8. Discrimination plot[14] of Zr/TiO_2 *versus* Nb/Y for the selected seven amphibolite rocks from Asind area, District Bhilwara, Rajasthan

The results of CIPW norms as shown in Table-1 indicate that two samples (NV157 and NV221) are normative nepheline rich and this may be explained due to the alkali enrichment during metasomatism[15]. In order to differentiate the field of calc-alkaline and tholeiitic basalts, the AFM diagram[12] (Fig. 9) as well as, the FeO^T/MgO and SiO_2 diagram[16] (Fig. 10) showed their tholeiitic nature. The diagram[17] of (Fe^T+Ti)-Al-Mg (Fig. 11) clearly indicated that all the samples fall in the tholeiitic field.

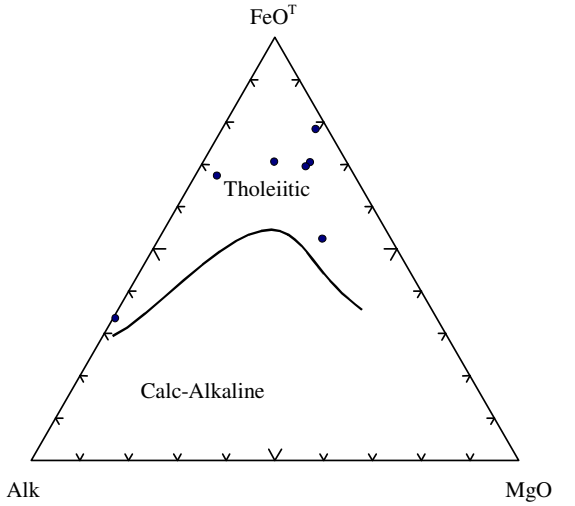


Fig. 9. The AFM discrimination plot[12] for the selected seven amphibolite rocks from Asind area, District Bhilwara, Rajasthan

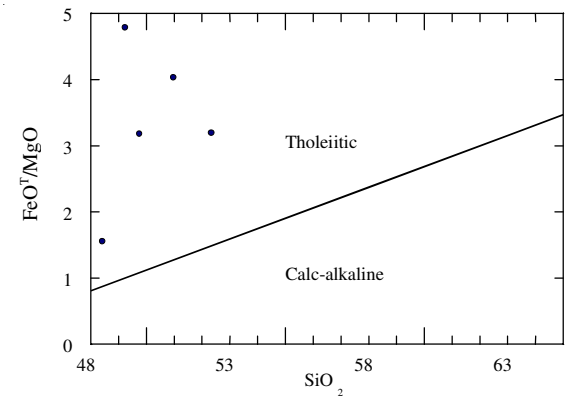


Fig. 10. The plot between SiO_2 *versus* FeO^T/MgO[16] for the selected seven amphibolite rock from Asind area, District Bhilwara, Rajasthan

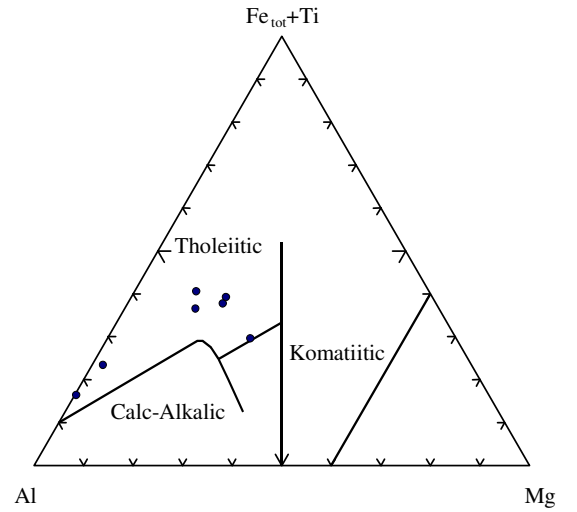


Fig. 11. The $(Fe^T + Ti)$-Al-Mg discrimination plot[17] for the selected seven amphibolite rock from Asind area, District Bhilwara, Rajasthan

In order to find out the tectonic setting, discrimination diagram Th-Zr/117-Nb/16[18] (Fig. 12) showed that amphibolites of the area have close affinity with oceanic island basalt to arc basalt. Similarly, the Cr-Y discrimination plot[19] revealed that the amphibolites form clusters in the within-plate basalt field. The discrimination plot[20] (Fig. 14) between Rb and (Yb+Ta) indicated that all the samples fall between the field of volcanic arc and within-plate basalt. The Nb-Y plot[20] (Fig. 15) showed that all the samples fall between the field of within plate and syn-collisional volcanic arc field. In order to depict the tectonic setting, the diagrams of $MgO-FeO^T-Al_2O_3$[21] (Fig. 16) and $MnO*10-TiO_2-P_2O_5*10$ (Fig. 17)[22] showed that, all samples fall within the field of continental to subcontinental island arc field. The Zr/Y and Zr/Nb ratio is also considered as a feature indicating the nature (depleted/enriched) of the magma source[23]. The Zr/Y and Zr/Nb ratio of the rocks vary from 0.31 to 3.96 and from 0.72 to 9.47, respectively. These lower ratios are indicative of evolved nature of the parent magma of the amphibolites.

The absence of Nb anomaly and a low Th/La ratio of amphibolites, indicate an asthenospheric or primitive mantle source without any supra subduction imprint or crustal contamination, severally limiting the continental tholeiite option[24]. The rare earth data for the selected amphibolites assemblage

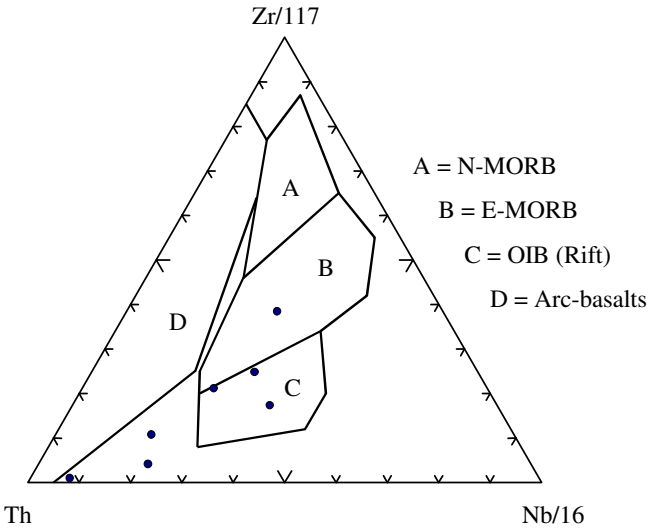


Fig. 12. The Th-Zr/117-Nb/16 discrimination plot[18] for the selected seven amphibolite rocks from Asind area, District Bhilwara, Rajasthan

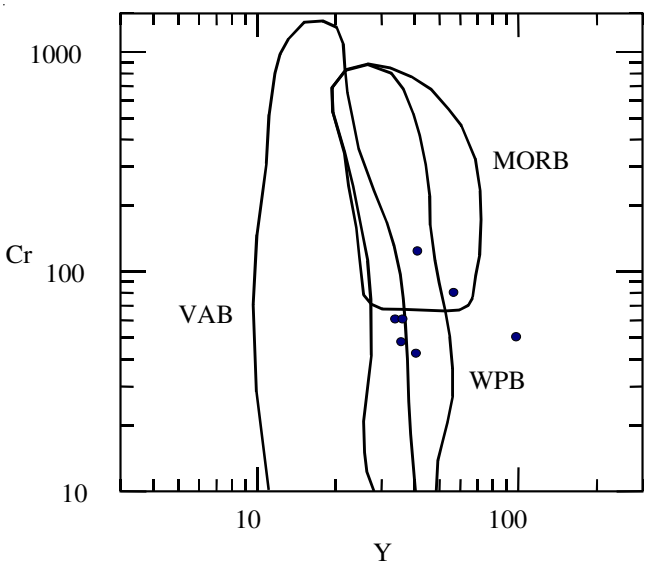


Fig. 13. The Cr-Y discrimination plot[19] for the selected seven amphibolite rocks from Asind area, District Bhilwara, Rajasthan

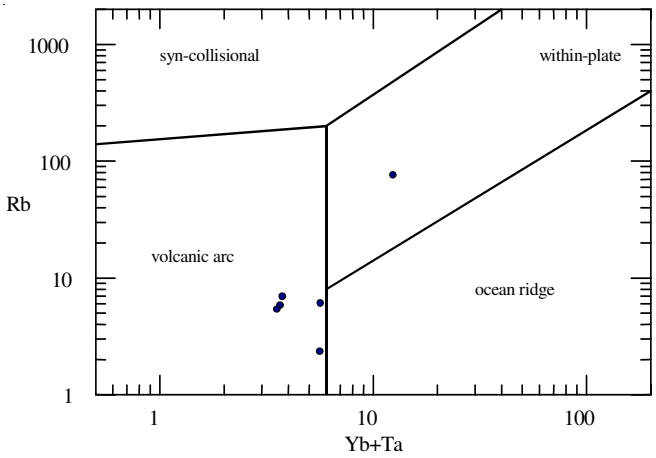


Fig. 14. The Rb *versus* (Yb + Ta) discrimination plot[20] for the selected seven amphibolite rocks from Asind area, District Bhilwara, Rajasthan

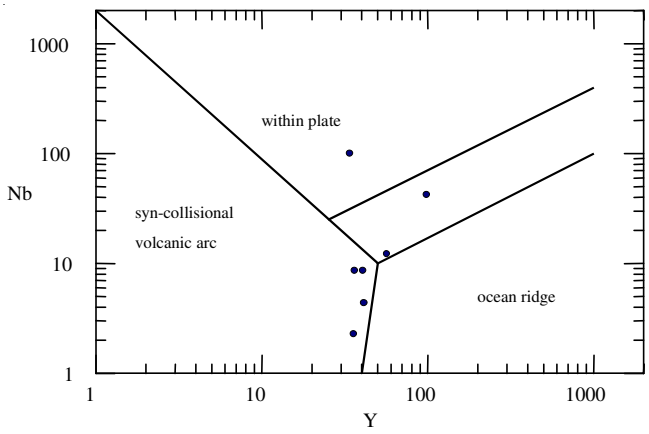


Fig. 15. The Nb-Y discrimination plot[20] for the selected seven amphibolite rocks from Asind area, District Bhilwara, Rajasthan

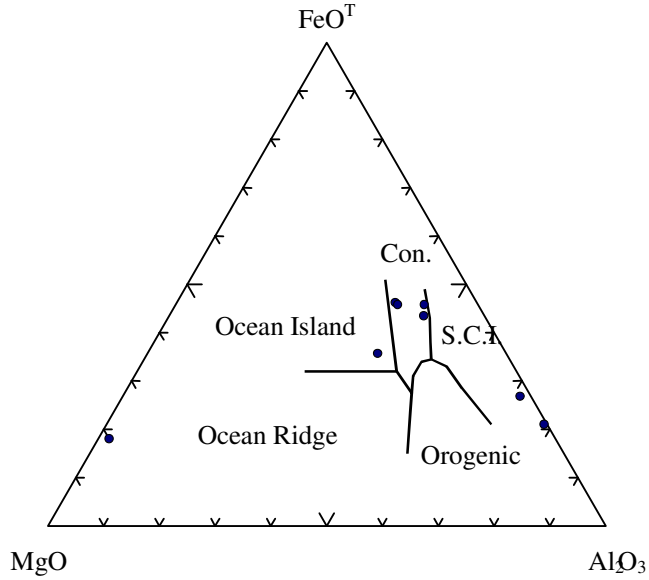


Fig. 16. The MgO-FeO^T-Al_2O_3 ternary plot[21] for the selected seven amphibolite rock from Asind area, District Bhilwara, Rajasthan

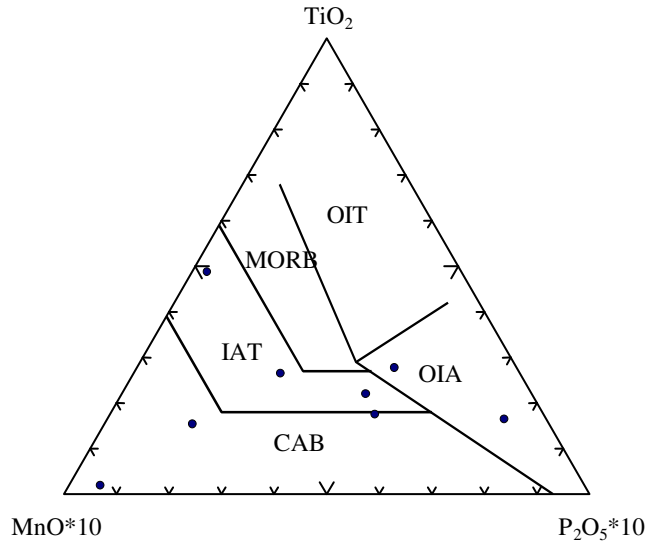


Fig. 17. The MnO*10 - TiO_2 - P_2O_5*10 ternary plot[22] for the selected seven amphibolite rock from Asind area, District Bhilwara, Rajasthan

presented in the Table-2 were normalized to chondrites[25]. Their value are plotted in the Fig. 18 and it shows slightly steeper to almost flatter light rare earth element (LREE) pattern with La/Eu ratio 18.40, relatively flat to slightly enriched heavy rare earth element (HREE) pattern with Eu/Lu ratio 2.58 and slightly negative to positive Eu anomaly with an average concentration of 1.70 ppm. It is clear from the plot that sample no NV221 shows positive Eu anomaly and it may be due to the abundance of plagioclase[15]. Similarly, samples NV86 and NV157 show relatively pronounced negative Eu anomaly, which may be explained by the fact that these rock showing higher degree of fractionation as evident from higher LREE/HREE ratio (Table-2). The flat to slightly enriched heavy rare earth (HREE) pattern may be explained by the abundance of garnet in the rocks[26]. The total value of REE ranges from 40.29 to 694.40 ppm and ratio of LREE/HREE varies from 11.14 to 611.90 ppm, respectively and (La/Yb)N ratio varies from 0.52 to 14.11 ppm, respectively. The pattern of REE in the plot along with the LREE/HREE and (La/Yb)N ratio also suggest toward moderate to strong fractionation.

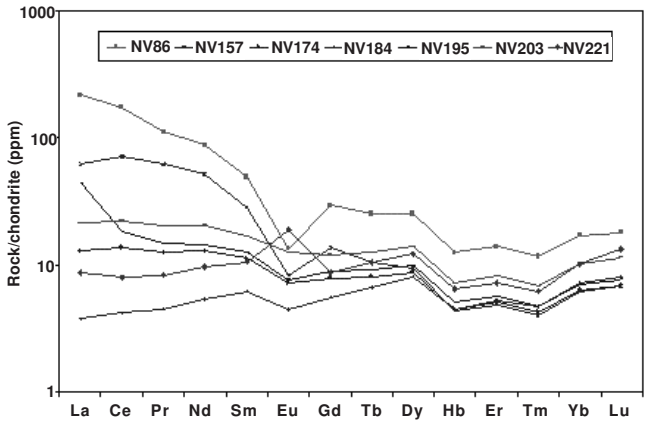


Fig. 18. The chondrite normalized[25] REE plot for seven amphibolite rock samples from Asind, District Bhilwara, Rajasthan

Conclusion

On the basis of the above discussion, the following conclusions were drawn: (i) The present amphibolites occurring as isolated bands varying in width from a few cm to 30 m and also as lensoid bodies within the para-gneiss of Bhilwara Supergroup of Precambrian age are a result of metamorphism of 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 edipote, garnet, scapolite, 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 (ortho type) 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. These rocks have undergone polymeta-morphism and now show upper amphibolite facies to granulites facies assemblages.

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