PETROLOGY AND GEOCHEMISTRY OF THREE GRANITOID BODIES OF NORTH KHETRI COPPER BELT, RAJASTHAN - A PRELIMINARY REPORT

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This is a preliminary report on the detailed petrological and geochemical investigations of Jasrapura, Gorwala and Gothara granitoids, intruding the rocks of Delhi Supergroup in the vicinity of Khetri town (28°00'N; 75°47'E). The field relationships of the granitoids, particularly their intertwinned and overlapping relationship with the mafic magmatic rocks, their common and typical accessory mineral assemblage, their I-type characteristics, and the major, trace and REE geochemistry, all point towards a common mafic magmatic source, fractionation-related petrogenesis and a complex island arc-marginal basin tectonic regime.

Introduction

The Precambrian rocks of Rajasthan have been divided into Banded Gneissic Complex, Aravalli Supergroup, Delhi Supergroup and Vindhyan Supergroup (Heron, 1953; Sinha-Roy et al. 1998). The Khetri Copper Belt, characterised by the rocks of Delhi Supergroup, extends for a distance of 80 km from Singhana (28°06'N; 75°53'E) in the NE to Sangarva (27°34'30"N; 75°19'E) in the SW, in the Jhunjhunu and Sikar districts of Rajasthan. It is further divided into North Khetri Copper Belt (NKCB) and South Khetri Copper Belt (SKCB) across Kantli Fault along the Kantli River (Das Gupta, 1968; Gupta et al. 1998). Following Heron (1917, 1923) and Das Gupta (1968) the rocks of Delhi Supergroup (originally 'System'), of this area, have been subdivided into Alwar and Ajabgarh Groups (originally 'Series'). The geological setting of the Khetri area, as worked out by the present authors, is given in Table 1. The petrologically and geochemically investigated Jasrapura, Gorwala and Gothara granitoids are shown in Fig.1.

Geological Setting and Petrography

The Jasrapura granitoids form a lenticular sheet like body, approximately 9 km in length and a maximum width of 1 km, extending in the NE-SW direction. The rock is dominantly leucocratic, grey coloured, medium to coarse grained, equigranular and foliated biotite-granite with subordinate granodiorite as a compositional variant. Quartz, microcline/microcline-perthite, plagioclase (An_{23-44}) and biotite are the main mineral constituents. A few small localised dykes of leucogranite intrude either parallel or slightly oblique to the foliation of the main Jasrapura granite.

The Gorwala pluton is approximately 2 km in length and 0.9 km in width in its middle part. The Gorwala granitoids comprise a crudely foliated, medium to coarse grained, equigranular and homogeneous biotite granite and a later unfoliated, amphibole granite (Das Gupta, 1968). The former contains quartz, microcline/microcline-perthite, sodic oligoclase (An_{7-15}) and biotite, while the latter has quartz, chess-board albite (An_{4-8}) and actinolitic hornblende without biotite and K-feldspars. Thus, biotite and amphibole are mutually exclusive.

The Gothara pluton is approximately 3 km long, 0.7 km wide, elongated pluton gradually tapering in the NNE direction. The Gothara granitoid, comprising of quartz, chess-board albite (An_{2-5}), and actinolitic hornblende, represents a single, amphibole granite phase that is very similar to the Gorwala amphibole granite. The Gorwala and Gothara amphibole granites exhibit profuse granophyric intergrowths between quartz and chess-board albite (Fig. 2a).

Table 1. Stratigraphic sequence of the Delhi Supergroup near Khetri, North Khetri Copper Belt, Rajasthan

	Quartz and Carbonate veins
	Pegmatites
	Granitoids
	Amphibolites and Metadolerites
Ajabgarh Group	Micaceous quartzite
	Marble and Calc-silicate rocks
	Pelitic schists
	Metavolcanics
Alwar Group	Amphibole quartzite
	Ferruginous quartzite
	Feldspathic quartzite
	Mica schist
	Basement not exposed

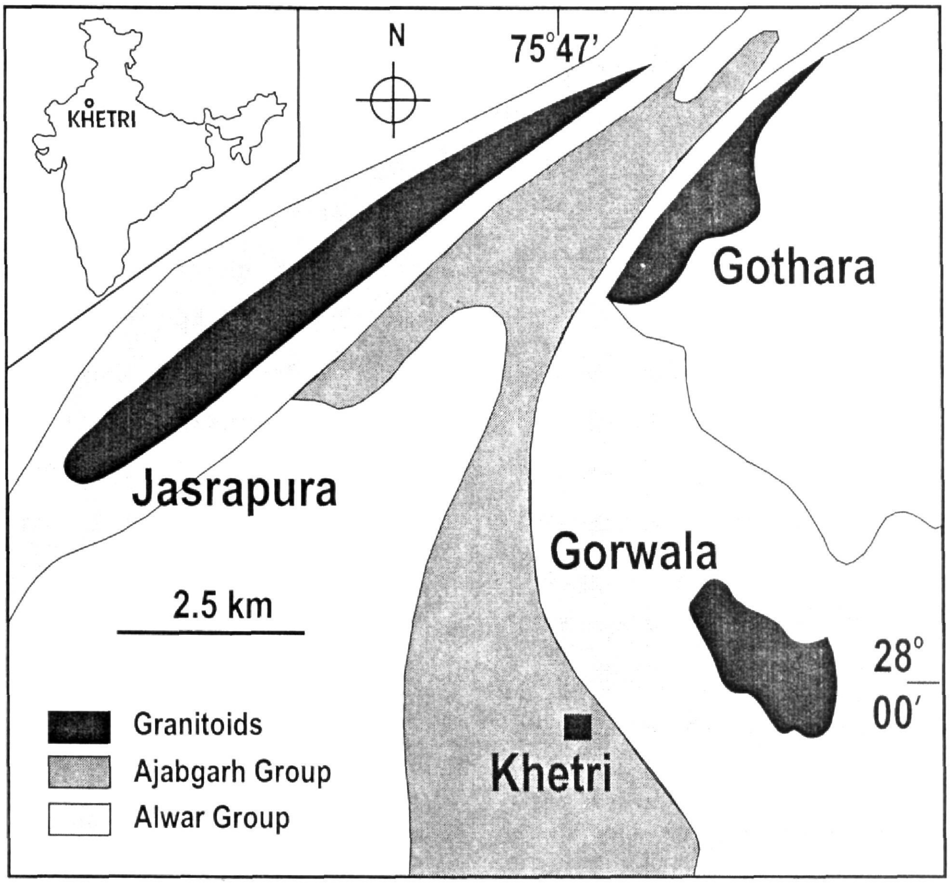


Fig. 1. Geological map of part of the North Khetri Copper Belt (*modified after* Heron, 1923), showing location of the investigated granitoid bodies.

Interestingly, all the three granitoids of the area contain identical accessory mineral assemblage comprising titanite, allanite, epidote and magnetite, besides zircon and apatite that actually correspond to the 'magnetite series' of Ishihara (1977).

The amphibolites and metadolerites within the granitoids correspond to the 'post-granitic' younger amphibolites of Das Gupta (1968). They exhibit complex dual relationships with the granitoids. Their dismembered blocks and fragments engulfed in the granitoids (Fig. 2b) suggest that they largely pre-date the granitoids. At the same time, their tongues back-penetrating the granitoids (Fig. 2c) also suggest that their emplacement overlapped with that of the granitoids (Pitcher, 1997). Therefore, an interrelated spasmodic mafic-felsic magmatism has been envisaged (Mehta et al. 2000).

A 10 m-20 m thick zone of breccia surrounds the Gorwala pluton and the western fringe of the Gothara pluton. The nature of the breccia supports explosive volcanic activity and forceful, shallow-level, emplacement of these granitoids (Das Gupta, 1968; Mehta et al. 2000).

Following the IUGS recommendations (Streckeisen, 1976), the Jasrapura granitoids classify as monzogranite with subordinate granodiorite, the Gorwala biotite granite plots in the monzogranite field while the amphibole bearing Gorwala and Gothara granitoids, that plot on the QA side of the QAP triangle (Fig. 3a), correspond to albite-granites.

GEOCHEMISTRY AND PETROGENESIS

Geochemically, the CaO-Na_2O-K_2O (Glikson, 1979) and normative An-Ab-Or (Barker, 1979) classifications replicate the modal QAP classification of these granitoids. Textural, mineralogical and chemical homogeneity is one of the most noticeable features of the three investigated Khetri granitoids. Although the Jasrapura granitoid exhibits a limited chemical range, the Gorwala granite and the Gorwala and Gothara albite-granites are examples of exceptinal homogeneity as evident from extremely low standard deviations (Table 2). Taken together, however, they depict serial variations.

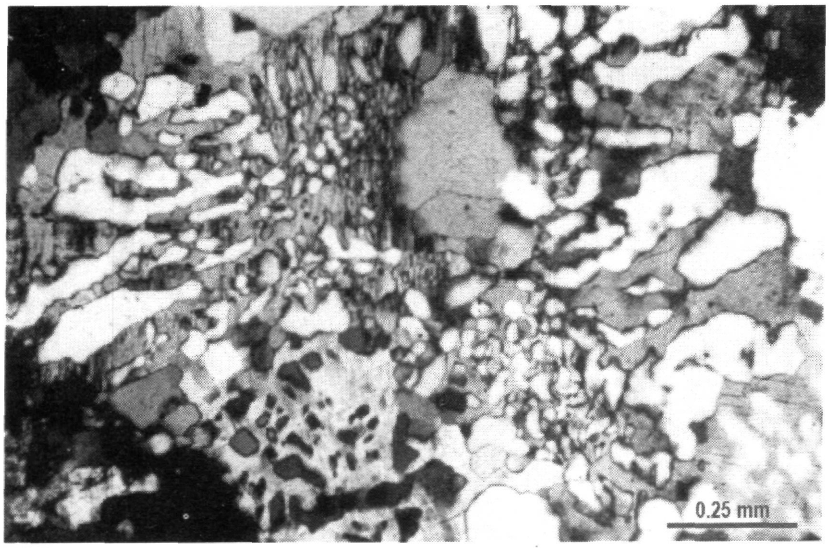


Fig.2a. Chess-board albite with profuse development of granophyric intergrowth between albite and quartz extending like a cauliflower around central albite in Gothara albite-granite (XN).

Fig.2b. Dismembered blocks of Gothara meta-dolerite engulfed in the albite-granite. Dyke-lets of albite-granite cut across and dislodge the mafic enclaves, at the same time rectangular fragments of the albite-granite are incorporated within the amphibolitised mafic enclaves

Fig.2c. A thin, pointed tongue of metadolerite penetrating the Gorwala granitoid.

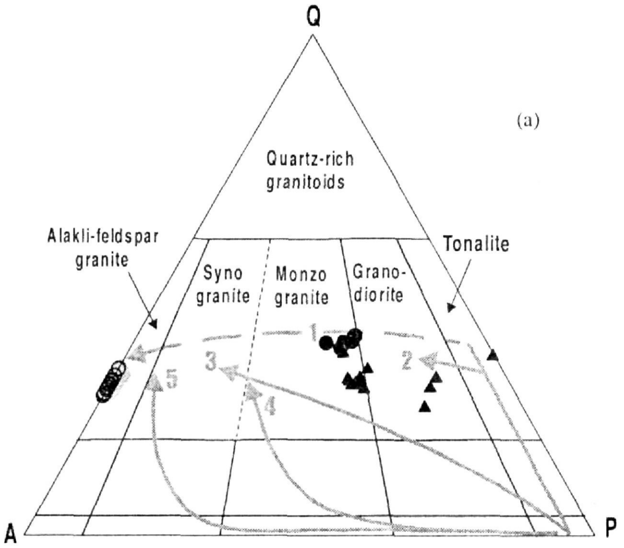
Table 2. Average major, trace and REE compositions of Jasrapura, Gorwala and Gothara granitoids

Sample No.	JS (8)	S.D.	JS (3)	S.D.	JS12	JS13	GW (6)	S.D.	GW (11)	S.D.	GT (14)	S.D.
SiO_2 (wt%)	64.95	1.23	63.14	2.84	74.03	73.41	70.82	0.51	72.53	0.60	73.95	1.27
TiO_2	0.60	0.08	0.71	0.09	0.03	0.04	0.64	0.02	0.65	0.03	0.64	0.02
Al_2O_3	15.38	0.29	16.43	0.86	14.17	15.31	12.58	0.05	12.83	0.17	12.60	0.27
Fe_2O_3	5.24	0.51	5.68	1.09	0.62	0.42	5.08	0.32	3.26	0.69	1.57	1.01
MnO	0.06	0.01	0.05	0.01	<0.01	<0.01	0.03	0.01	0.04	0.01	0.03	0.01
MgO	2.03	0.21	2.52	0.14	0.20	0.38	0.70	0.10	0.85	0.19	0.58	0.18
CaO	3.03	0.62	3.44	0.63	1.52	1.59	0.99	0.18	1.67	0.35	1.75	0.35
Na_2O	2.92	0.29	3.77	0.45	3.99	6.63	3.73	0.47	6.99	0.26	7.24	0.17
K_2O	4.19	0.13	2.57	0.24	3.69	0.16	4.14	0.47	0.08	0.03	0.06	0.02
P_2O_5	0.18	0.03	0.24	0.08	0.10	0.08	0.13	0.01	0.13	0.01	0.12	0.01
A/CNK	1.04	0.05	1.08	0.01	1.06	1.10	1.02	0.03	0.88	0.04	0.83	0.04
A/NK	1.65	0.12	1.83	0.17	1.34	1.38	1.19	0.03	1.11	0.03	1.05	0.02
Ba (ppm)	1034.00	251.56	782.33	212.46	332.00	61.00	519.00	159.00	<20-37	-	<20-36	-
Rb	153.88	12.36	112.00	15.72	57.00	<5	135.00	34.00	<5	-	<5	-
Sr	370.63	62.70	310.67	57.12	276.00	188.00	27.00	4.00	20.00	3.00	24.00	4.00
Pb	25.88	3.23	<5-16	-	20.00	21.00	8.00	2.00	<5-11	-	<5-12	-
Th	25.13	5.46	17.67	8.62	10.00	<5	34.00	2.00	38.00	3.00	40.00	3.00
U	<5	-	<5-8	-	<5	<5	11.00	3.00	12.00	2.00	14.00	4.00
Zr	212.63	35.67	225.00	3.61	38.00	39.00	345.00	6.00	351.00	16.00	377.00	12.00
Nb	10.00	2.20	11.00	1.00	10.00	<5	20.00	1.00	21.00	1.00	24.00	1.00
Y	27.13	3.14	32.33	9.71	18.00	20.00	57.00	2.00	57.00	8.00	70.00	14.00
Sc	<10-16	-	<10-16	-	<10	<10	<10-13	-	<10-13	-	<10-17	-
V	64.13	6.62	80.00	9.54	10.00	10.00	41.00	6.00	42.00	3.00	51.00	16.00
Co	24.63	3.58	31.67	2.52	21.00	41.00	18.17	4.75	20.82	5.27	22.43	5.63
Cr	67.75	7.74	85.33	9.07	<10	13.00	<10-17	-	<10-22	-	<10-17	-
Ni	13.50	2.88	16.33	3.79	<5	<5	<5	-	<5-10	-	<5-8	-
Zn	65.13	14.67	54.33	15.01	7.00	<5	11.00	3.00	<5-11	-	<5	-
Ga	17.50	3.63	21.33	4.04	16.00	15.00	18.80	3.00	17.60	3.00	16.10	3.00
	Avg. (3)		(n=1)		(n=1)	(n=1)	Avg. (3)		Avg. (3)		Avg. (3)	
La (ppm)	71.37		32.22		6.51	4.05	58.24		72.65		103.33	
Ce	133.69		64.15		12.38	7.26	117.70		136.51		181.33	
Nd	49.88		29.76		4.98	2.63	49.17		53.89		66.41	
Sm	6.81		5.88		0.71	-	7.99		7.99		10.11	
Eu	1.69		1.95		0.44	0.51	1.52		1.51		2.46	
Gd	5.56		7.57		1.34	0.78	8.77		8.33		10.37	
Dy	4.41		7.78		1.71	0.87	8.71		7.91		9.75	
Ho	1.05		1.85		0.73	0.53	1.87		1.56		2.01	
Er	2.14		3.71		1.17	0.77	5.13		4.50		5.34	
Yb	2.07		2.16		1.01	0.73	4.86		4.36		4.96	
Lu	0.29		0.28		0.13	0.11	0.68		0.63		0.68	
ΣLREE	263.43		133.96		25.02	14.41	234.61		272.55		363.64	
ΣHREE	15.51		23.35		6.09	3.79	30.03		27.28		33.12	
ΣREE	278.95		157.31		31.11	18.24	264.64		319.93		396.76	
ΣLREE/ΣHREE	17.00		5.74		4.11	3.80	7.81		10.08		10.42	
Eu/Eu*	0.86		0.89		1.38	8.84	0.56		0.56		0.73	
$(La/Yb)_N$	25.57		10.70		4.62	4.00	8.59		12.18		14.99	
$(La/Sm)_N$	6.72		3.54		5.92	65.73	4.72		5.84		5.21	
$(Sm/Yb)_N$	3.77		3.02		0.78	-	1.83		2.07		2.28	

JS (8)-Jasrapura granite, JS (3)-Jasrapura granodiorite, JS-12, 13-Jasrapura leucogranites,

GW (6)-Gorwala granite, GW (11)-Gorwala albite-granite, GT (14)-Gothara albite-granite;

Figures in parantheses indicate number of analyses in each category.



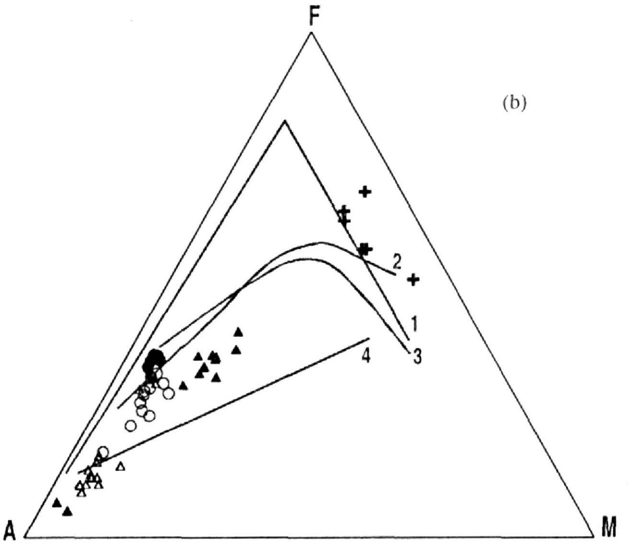


Fig. 3a. Jasrapura, Gorwala and Gothara granitoids in the QAP diagram (*after* Lameyre and Bowden, 1982). 1=tholeiitic trend; 2=calc-alkaline trondhjemitic trend; 3=calc-alkaline granodioritic trend; 4=calc-alkaline monzonitic trend and 5=aluminous trend. Filled triangles-Jasrapura granitoids, filled circles-Gorwala granite, unfilled circles-Gorwala albite-granite, shaded area-Gothara albite-granite; **b.** Composite AFM diagram (*after* Wager and Deer, 1939) for the Jasrapura granitoids-filled triangles, Gorwala granite-filled circles, Gorwala albite-granite-unfilled circles, Gothara albite-granite-unfilled triangles, Jasrapura amphibolites, Gorwala and Gothara metadolerites-pluses The trends refer to: 1. Skaergaard tholeiitic trend after Wager and Deer (1939), 2 and 3. Boundaries between tholeiitic and calc-alkaline fields after Kuno (1968) and Irvine and Baragar (1971), and 4. Daly's (1933) average calc-alkaline trend.

MgO, Fe_2O_3 (T), CaO, TiO_2 , Al_2O_3 and compatible trace elements Ni, Co, Cr, V decrease and incompatible trace elements Nb, Y, Zr increase with increasing SiO_2 from Jasrapura granitoids to Gothara albite-granite. The Gorwala and Gothara albite-granites are characterised by extremely low K_2O, Ba, Rb and Sr which together with granophyric intergrowth between albite and quartz compare favourably with the plagiogranites (Coleman and Peterman, 1975; Coleman and Donato, 1979; Pearce et al. 1984; Gurmeet Kaur, 2002). The A/CNK and A/NK ratios characterise the Jasrapura granitoids as peraluminous, the Gorwala granite as transitional between peraluminous and metaluminous and the Gorwala and Gothara albite-granites as metaluminous. All the granitoids are characterised by broadly comparable REEs and moderate LREE enrichment (Table 2).

In terms of their major, trace and rare earth chemistry (Table 2), these granitoids compare best with the I-type granites amongst the average MISA type granitoids (Whalen et al. 1987) and the A/CNK and SiO_2 parameters characterise, all the three as I-type granitoids.

The various mineralogical and geochemical parameters suggest genetically linked evolution of these granitoids from a common mafic magmatic source. On QAP (Lameyre and Bowden, 1982) and AFM (Wager and Deer, 1939) ternary plots (Figs.3a and 3b), the Jasrapura granitoids depict a calc-alkaline trend, whereas the Gorwala and Gothara granitoids follow the tholeiitic trend of evolution. The

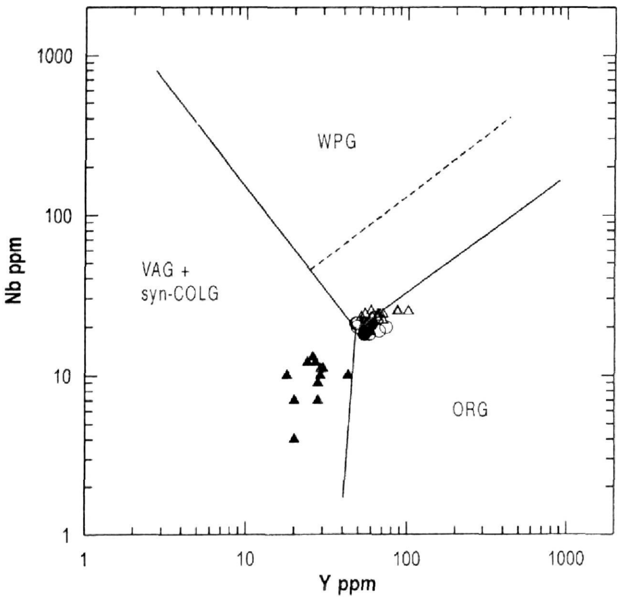


Fig.4. Nb *vs.* Y discrimination diagrams (*after* Pearce et al. 1984) for the Jasrapura, Gorwala and Gothara granitoids. Filled triangles - Jasrapura granitoids, filled circles - Gorwala granite, unfilled circles - Gorwala albite-granite, unfilled triangles - Gothara albite-granite.

amphibolites and metadolerites occurring within the granitoids depict an early iron enrichment trend, whereas the Gorwala and Gothara granitoids conform the late stage fractionation of tholeiitic magma which are characteristic of the Skaergaard intrusion (Wager and Deer, 1939). The calculated zircon saturation temperatures (Watson and Harrison, 1983) and Fe-Ti oxide saturation isotherms after Green and Pearson (1986), indicate that initiation of zircon crystallisation in the Gorwala and Gothara granitoids began at ca. 835°C-900°C and that in the Jasrapura granitoids at ca. 800°C-850°C. Such higher temperatures are consistent with the derivation of these granitic magmas from mafic magmas of mantle origin rather than of crustal origin.

TECTONOMAGMATIC REGIME

In the Rb-(Y+Nb) bivariate plot, the samples of Jasrapura granite and granodiorite plot in the field of volcanic arc granites (VAG), those of the Gorwala and Gothara albite-

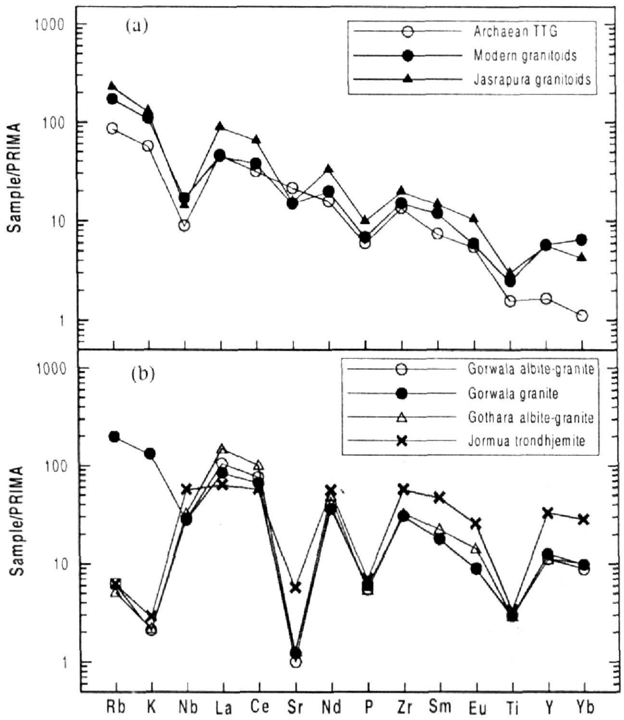


Fig. 5a. Primitive mantle (PRIMA)-normalised spider patterns for the average Jasrapura granitoids compared with arc related I-type granitoids (source: Martin, 1994); **5b.** PRIMA-normalised average spider patterns for the Gorwala and Gothara granitoids compared with those of ocean ridge granites (shaded area, source: Pearce et al., 1984; Pederson and Malpas, 1984; Wildberg, 1987; Flager and Spray, 1991; Borsi et al., 1996) and the Jormua trondhjemite (Kontinen, 1987). Normalising values are after Sun and McDonough (1989).

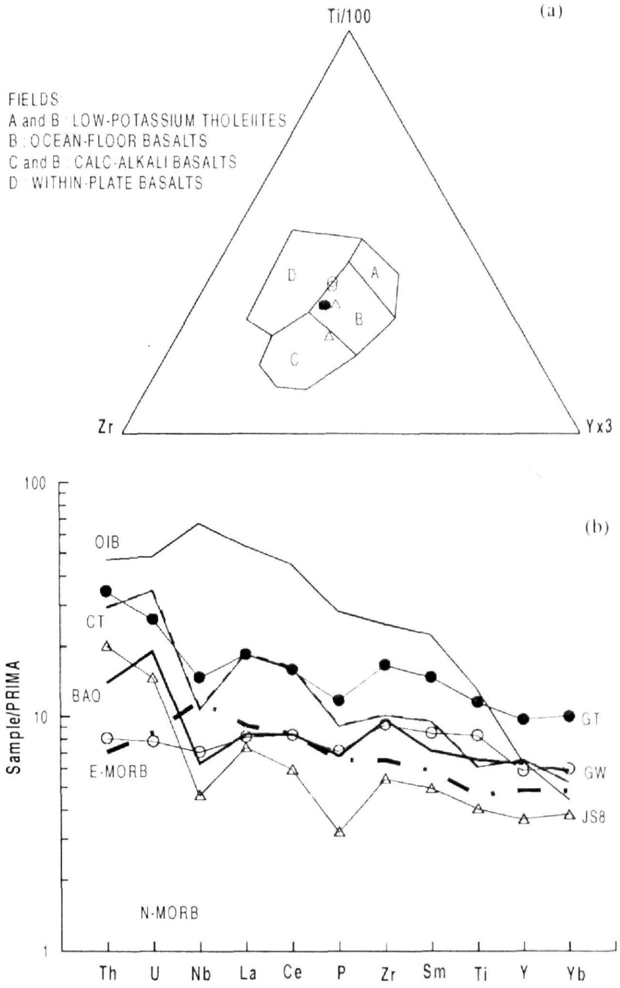


Fig.6.(a) Ti/100-Zr-Yx3 ternary plot for amphibolites and metadolerites (Pearce and Cann, 1973). Unfilled triangles-Jasrapura amphibolite, unfilled circles-Gorwala meta-dolerite, filled circles-Gothara metadolerite; **(b)** Primitive mantle normalised spider diagram for amphibolites and metadolerites in relation to average N-MORB, E-MORB, BAO, CT and OIB. Data sources: N-MORB, E-MORB and OIB-Sun and McDonough (1989); BAO and CT-Holm (1985). Primitive mantle normalising values after Sun and McDonough (1989).

granites plot in the field of ocean ridge granites (ORG) and the samples of Gorwala granite plot in the within plate granites (WPG) field. In the Y-Nb diagram, the Jasrapura granitoids conform to their VAG tectonic setting, while the Gorwala granite and the Gorwala and Gothara albite-granites cluster together in the extended ORG field (Fig. 4) like the MAR 45°N granitoids (Pearce et al. 1984).

The spider pattern of the average Jasrapura granite and granodiorite taken together matches well with the post-Archaean arc granitoids (Fig.5a).The average spider patterns of the Gorwala granite and Gorwala and Gothara albite-granites compare best with those of the Phanerozoic Ocean Ridge Granites (Fig.5b). Therefore, these spider diagrams together confirm an island arc tectonic setting for the Jasrapura granitoids and an ocean ridge tectonic setting for the Gorwala and Gothara granitoids.

The amphibolites and metadolerites that occur within the three granitoid bodies, have formed by partial melting of a mantle source of spinel-lherzolite composition and the various discrimination diagrams, such as Ti/100-Zr-Yx3 ternary plot (Fig.6a; *after* Pearce and Cann, 1973), point towards their oceanic tholeiitic character (Gurmeet Kaur, 2002). This is in consonance with the tectonic regime of the granitoids.

The spider diagrams of the amphibolites and metadolerites further suggest a back-arc tectonic setting (Fig.6b), meaning thereby that oceanic crust was created in the marginal basin formed as a direct consequence of the formation of the Jasrapura arc which is characterised by calc-alkaline magmatism typical of the island arcs. Spreading of the marginal basin was caused by rifting and development of an oceanic ridge in this basin, through which more juvenile mafic magmas were tapped from the mantle that followed the tholeiitic fractionation trend and gave rise to the Gorwala and Gothara granitoids bearing the signatures of the oceanic ridge tectonic regime. Closing of the back-arc basin culminated in bringing the granitoids of the two, i.e. island arc and ocean ridge, tectonic regimes to occur together in a small area around Khetri.

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ERRATA

In the short communication by A.C. Pande and others (J.G.S.I., v.63, no.6, 2004, pp. 665-669) following additions may be made in Plates 1 & 2 showing Palynomorphs from Manjir Formation, Chamba District, Himachal Pradesh: (All magnifications are x 500). Figure numbers read left to right: 1, 2, 3 (first row); 4, 5, 6 (second row); 7, 8, 9 (third row) and 10, 11, 12 (fourth row). The omission is regretted.

In the paper by Kukillaya et al. (J.G.S.I., v.64, no.1, July 2004, p. 35), the bar scale in Fig.2 corresponds to 500 m and not 500 km.