

The Association of Hypersolvus-Subsolvus Granites: A Study of Malani Igneous Suite, India

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Abstract: Detailed field, petrographical and the chemical studies of the Jalor granites, Western Rajasthan show that the Jalor magmatism is not exclusively peraluminous in nature but has peralkaline component closely associated in space and time. The Jalor complex is a classic example of hypersolvus-subsolvus granite association. The similar abundances of trace elements such as Ba, Th, U, Ga, Y and Zr in the hypersolvus and the subsolvus granites suggest that both magmas have common source and are coeval. The hypersolvus granites show enrichment of LREE as compared to the subsolvus granites, but the subsolvus granites have more pronounced Eu anomaly. Tectonic significance of the find is also discussed.

Key Words: Malani Igneous suite, Petrology, Geochemistry, Granites, Jalor, Rajasthan.

INTRODUCTION

The Jalor igneous complex is a part of the Malani igneous suite (750Ma) and is located in the northwestern part of the Indian peninsular shield (Fig. 1). The Jalor area has been described by La Touche (1902), but no detailed work has been done in the Jalor area. This paper describes the occurrence of hypersolvus granites from the Jalor area. Previous descriptions of the Jalor area only reported subsolvus biotite-bearing granites, whereas the adjoining Siwana area is essentially composed of hypersolvus granites. The hypersolvus components of the Jalor magmatism have been confirmed on the basis of field, petrographical and chemical (major and trace element) studies.

MAJOR LITHOLOGICAL UNITS OF THE COMPLEX

Besides pink biotite granites, rhyolite, and basic dykes (La Touche, 1902) the authors have recognised additional rock types : biotite - hornblende granite, biotite granite, alkali granite, rhyolite, olivine gabbro, basalt flows, olivine dolerite and microgranite. There is no country rock exposed in the area.

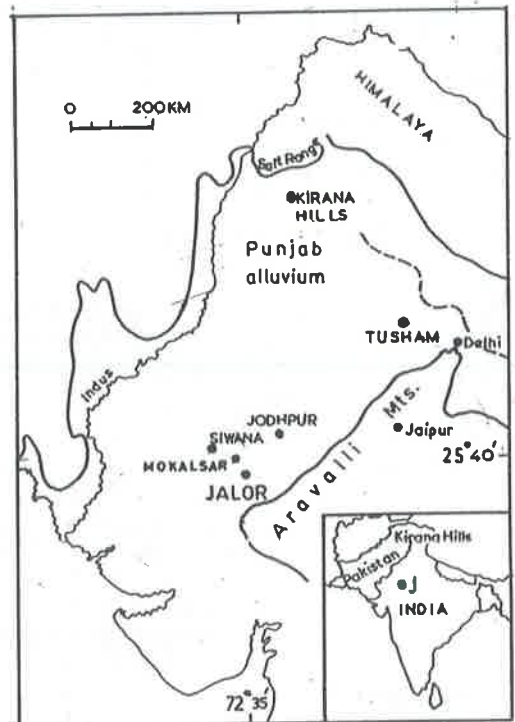


Fig.1. Location map for Jalor area, India.

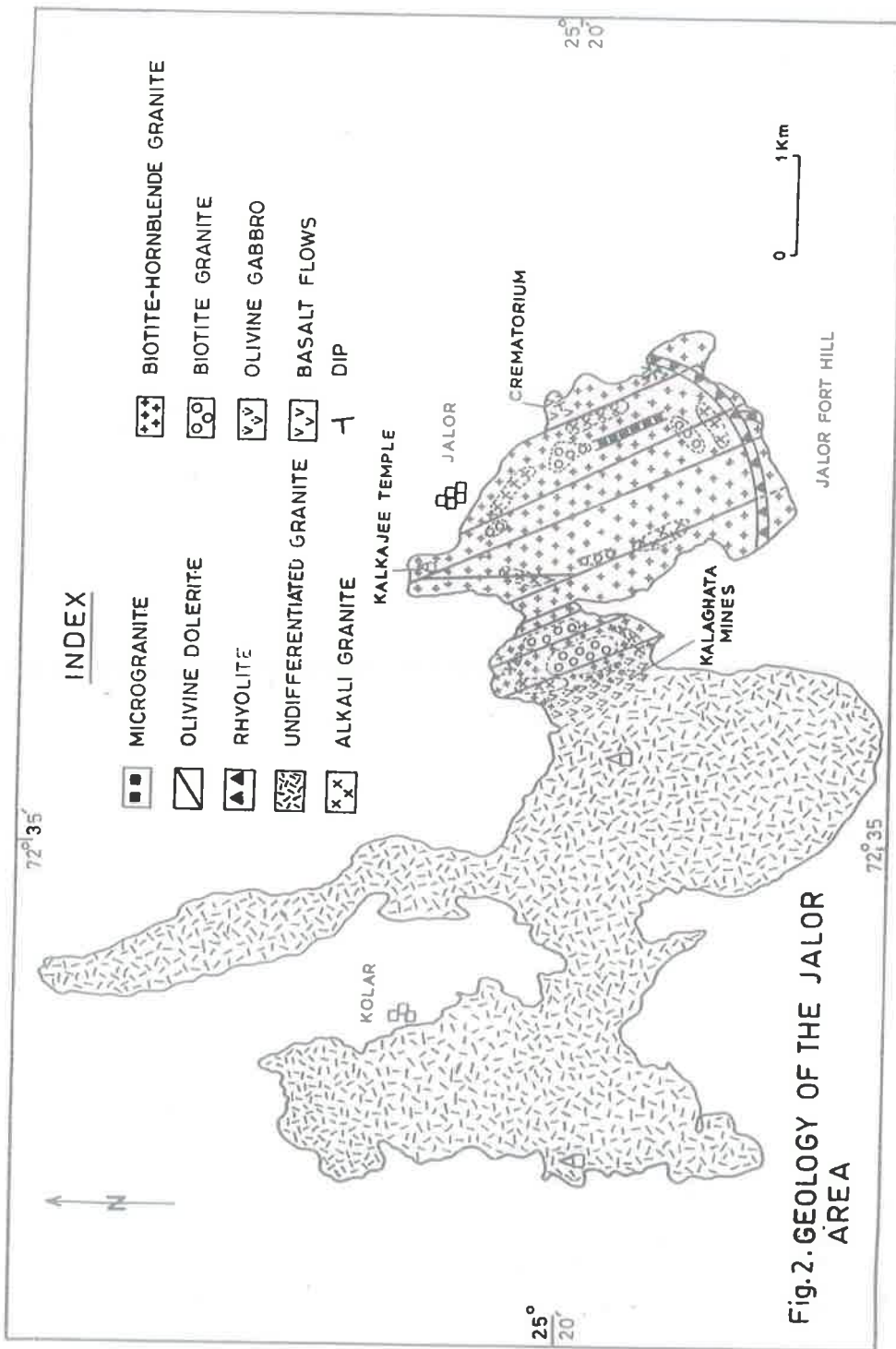


Fig.2. GEOLOGY OF THE JALOR AREA

The various rock types in the area can be broadly grouped as follows:

- Dyke Phase — Rhyolite, olivine dolerite (youngest) and microgranite.
 Intrusive Phase — Olivine gabbro, biotite-hornblende granite, alkali granite. Quartz syenite has been reported in the adjoining Kolar area.
 Extrusive Phase (oldest) — Basalt

The above listed lithologic units are exposed on Jalor Fort hill and area around Kalaghata (Fig. 2).

PETROGRAPHY

Biotite-hornblende granite :

The granite is pink in colour, porphyritic, massive and coarse-grained. It is the dominant lithologic unit in the Jalor area. In the field it can be differentiated from biotite granite and alkali granite only on the basis of its pink colour. In the Kalaghata area the granite is in contact with the olivine gabbro (Fig. 3). It is a two feldspar granite containing alkali feldspar (perthite and orthoclase) mostly altered to sericite, quartz (high quartz and subhedral - anhedral variety), biotite, plagioclase, hornblende and accessory magnetite, zircon, fluorite, apatite and tourmaline. In a few sections (Js14 and Js16) fayalite is also observed (Fig. 4).

Biotite granite

This granite occurs as lenses on Jalor Fort hill and on the western side of the hill. It is white, coarse-grained, two feldspar granite containing perthite, orthoclase, quartz, biotite and plagioclase. Accessory minerals include magnetite, zircon and fluorite.

Alkali granite

This granite occurs as sheets of varying size (length 200 to 300 meters, width 20 to 40 meters) near the periphery and in the

roof zones (fig. 2) of the biotite-hornblende granite. The contact with the biotite-hornblende granite is not well marked. This granite can only be distinguished in the field by a bluish tinge which is due to the abundance of alkali amphiboles and pyroxenes (Fig. 5). Orthoclase and perthite are by far the dominant feldspars, followed by minor plagioclase which is extensively altered to kaolinite. Quartz occurs as high quartz and the late subhedral- anhedral variety. Mafic minerals include arfvedsonite (pleochroism X = dark blue, Y = bluish green, Z = yellowish green, extinction angle $X \wedge C = 12$ to 15°), and ferro-hornblende (pleochroism X = yellowish green, Y = green and Z = dark green, extinction angle $Z \wedge C = 14$ to 22°). Aegirine (pleochroism X = dark green, Y = light green, Z = yellowish green, extinction angle $X \wedge C = 4$ to 7°). Biotite, which is annite-rich is often broken down to iron oxides (Fig. 6). Accessory minerals include magnetite, apatite, fluorite, zircon and riebeckite.

Olivine gabbro

It forms an arc shaped outcrop dipping inwards. Field relationship suggests that olivine gabbro predates the granites, as enclaves of the gabbro are encountered in the adjacent granites. It is a massive compact rock, black in colour. Euhedral disoriented laths of plagioclase are enclosed in extensive plates of augite resulting in ophitic texture. Minerals present are plagioclase, augite, olivine, chlorite and accessories include iron oxides, rutile and green spinels with occasional interstitial quartz found intergrown with feldspar.

Rhyolite

The rhyolite occurs as an arcuate band which may be a partial ring dyke. It intrudes the southern side of the Jalor Fort hill (Fig. 2). The unit is about 3 meters wide and 1 km long, trends $N 70^\circ E$ and dips away from the granite with which it makes a sharp contact. It is pink, yellowish pink and brownish blue in colour, compact, porphyritic



Fig.3. Olivine gabbro associated with biotite-hornblende granite. Kalaghata area.

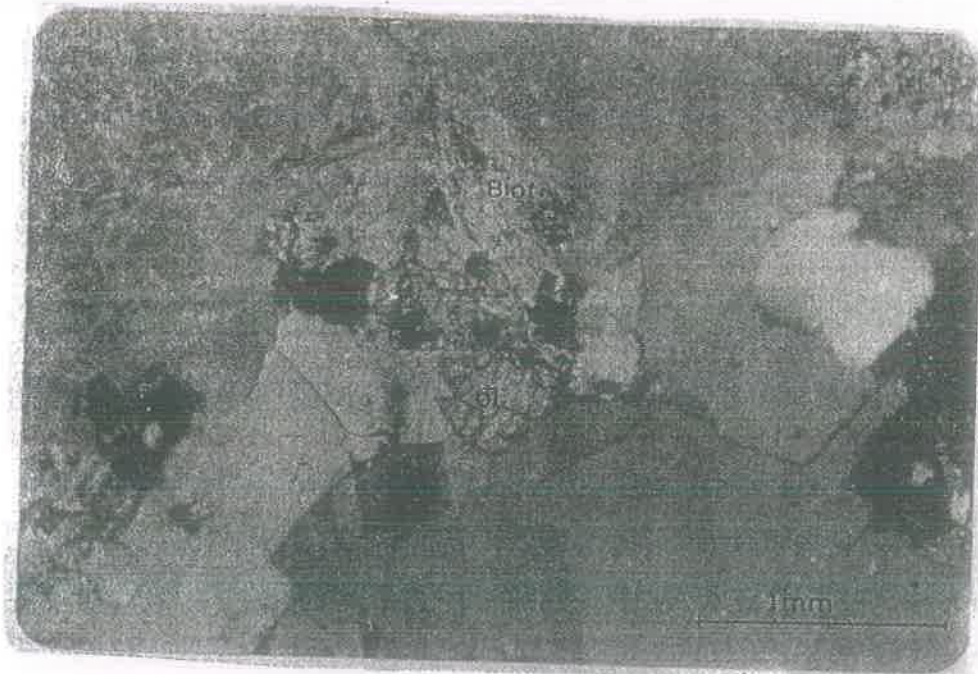


Fig.4. Fayalite in biotite hornblende granite; XPL

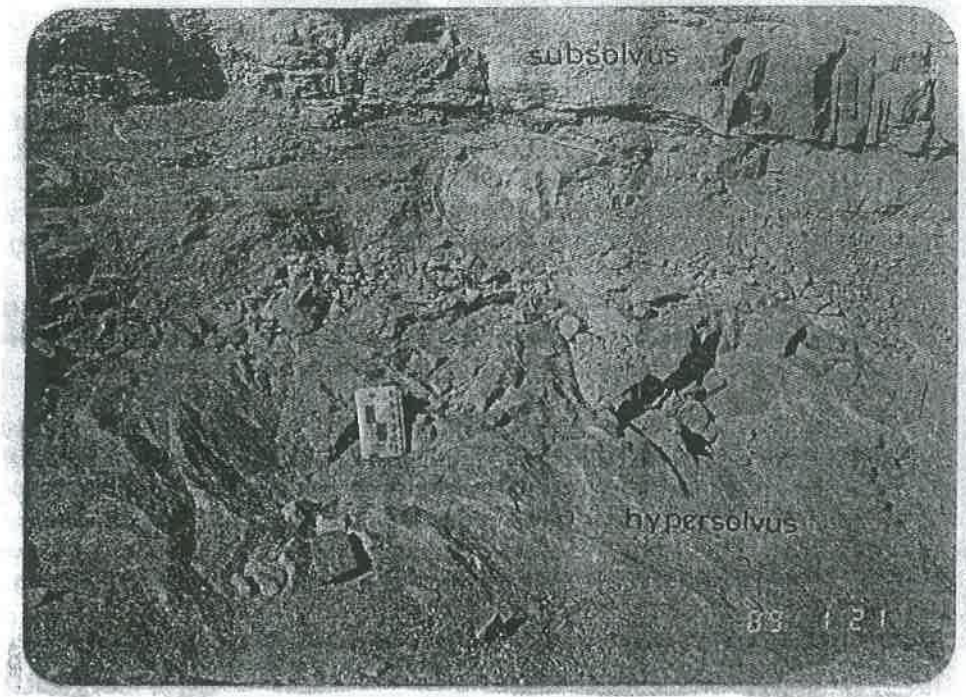


Fig.5. Sheets of alkali granite in the biotite hornblende granite.

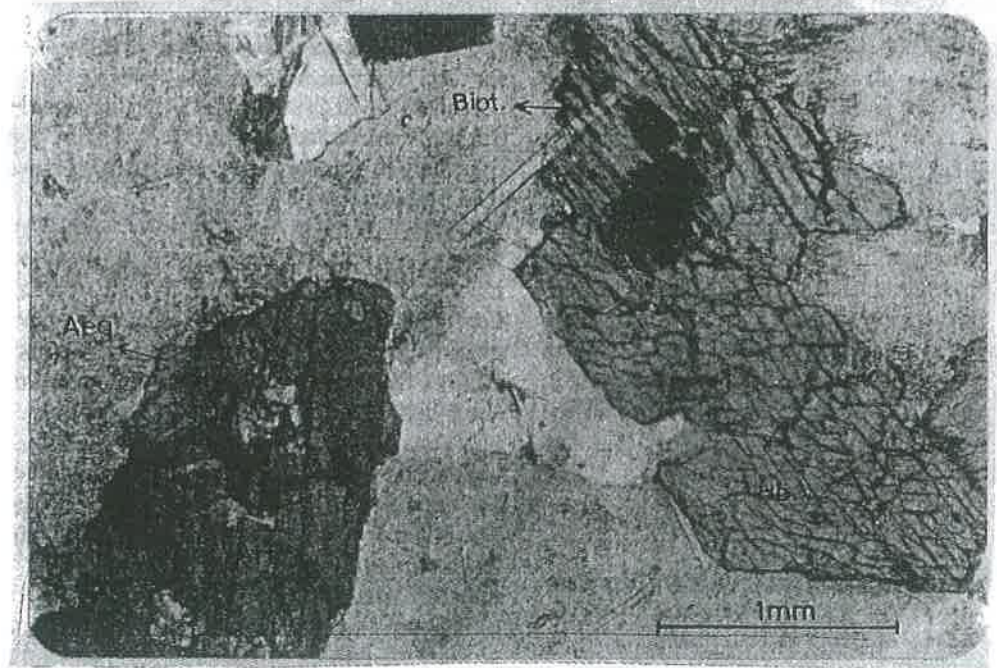


Fig.6. Intergrowth of arfvedsonite, aegirine, and ferro-hornblende with biotite, alkali granite; PPL

and non-porphyritic. The porphyritic phase has a microcrystalline groundmass whereas non-porphyritic variety shows flow structure and spherulitic texture. The rock contains alkali feldspar (orthoclase), high quartz, hornblende, biotite, aegirine and riebeckite as euhedral and subhedral phenocrysts in a cryptocrystalline quartzo-feldspathic groundmass.

The pink biotite-hornblende granite and the white biotite granite are subsolvus granites whereas the alkali granites are hypersolvus granites (Tuttle & Bowen, 1958, Bonin, 1972). The subsolvus granites are characterised by two discrete Na-K feldspars, whereas the hypersolvus granites have only a single feldspar. Subsolvus granite consists of quartz (22 - 35%), orthoclase (27 - 43%), perthite (8 - 19%), plagioclase (5 - 14%) biotite (8-15%) and hornblende (1-6%). The hypersolvus granite consists of quartz (27-37%), orthoclase (35-41%), perthite (10 - 20%), biotite (3 - 5%), ferro-hornblende (4 - 6%) and arfvedsonite plus aegirine (1 - 4%). The recalculated modal volume percentage of the Jalor granites, when plotted on the QAP diagram (Streckeisen, 1967), straddle the true granite and alkali granite fields. The subsolvus granites fall in the granite field whereas the hypersolvus granites cluster in the alkali granite field. Superposition of the fields of Lameyre & Bowden (1982) on the Streckeisen plot shows that the subsolvus granites plot in the field of aluminous granitoids found in alkaline provinces formed by crustal fusion and show affinity to A-type granites of the Lachlan fold belt, Australia (Collins *et al.* 1982) whereas the hypersolvus granites fall in the alkaline & peralkaline field of Nigerian Younger Granites.

CHEMICAL CHARACTERISTICS OF THE JALOR ROCKS

Major elements were determined at Panjab University following the methods of Shapiro and Brannock (1962). Alkalis were deter-

mined by flame photometer, CaO, MgO and FeO by titration and the other elements by Uvispec spectrophotometer. Trace elements were determined by AAS at Jammu University. Usual precision for all these techniques is better than +/-5% relative and accuracy is comparable. Rare earth element (REE) on selected samples were determined by ICP-MS at N.G.R.I. Hyderabad as per the methods given by Balaram & Saxena (1988). Major element and trace element data are reported in Tables I, II, III and IV.

The agpaitic index (A.I = Molecular proportion $\text{Na}_2\text{O} + \text{K}_2\text{O} / \text{Al}_2\text{O}_3$ for the subsolvus granites ranges between 0.73 - 0.97, whereas for the hypersolvus granites it ranges between 1.02 - 1.12. Corundum appears in the norm for most of the subsolvus granites whereas the hypersolvus granites have acmite in their norm. The agpaitic index for the rhyolites ranges from 0.81 - 1.09. Rhyolites which have an agpaitic index < 1 usually show normative corundum, whereas those with agpaitic index > 1 (J13 & J112) show normative acmite. The granites have high alkali contents, $\text{K}_2\text{O} + \text{Na}_2\text{O}$ of 6.81 - 9.40% for the subsolvus granites and 8.13 - 9.60 for the hypersolvus granites. The average contents of CaO and MgO for subsolvus granites are 0.88 and 1.00, whereas for hypersolvus granite these values are 0.52 and 0.83 respectively.

Major element variations in terms of weight percent oxide versus differentiation index (D.I.) are shown in Fig. 7. SiO_2 , Fe_2O_3 , FeO, Al_2O_3 , Na_2O , K_2O for Jalor granites and rhyolites show a linear trend. Al_2O_3 , MgO and CaO for subsolvus granites show higher values, compared to hypersolvus granites, while for hypersolvus granites, higher contents of Na_2O and K_2O are seen. CaO and MgO for rhyolites define a uniform linear trend. TiO, PO and MnO for Jalor granites and rhyolites are low and show a constant linear pattern.

In the $(\text{Fe}_2\text{O}_3) - \text{M} (\text{MgO}) - \text{A} (\text{K}_2\text{O} + \text{Na}_2\text{O})$ diagram, the granites and the rhyolites of the Jalor area plot close to the AF tie line and depict an iron enrichment

Table I. Major Element Analyses and CIPW Norms of the Jalor Rocks, W.Rajasthan.

Sample No.	J116	K1	J117	K11	J118	B	J14	K33	IK	KG	A	C	K35	J16	J16	J17	J10	W6	J10	J19	F	PKG	BKG	J11	PA	PAG		
	Biotite hornblende granite, biotite granite (Subsolvus)																											
	Alkali granite (Hypersolvus)																											
Oxides	68.15	72.88	71.01	70.25	72.53	70.83	70.57	71.10	72.53	68.74	68.57	72.63	71.82	73.10	71.42	69.86	72.65	71.25	69.64	71.32	74.61	69.47	70.62	73.49	72.31	73.23	73.74	
SiO ₂	0.58	0.72	0.47	0.63	0.26	1.00	0.28	0.06	0.30	0.27	0.72	0.17	0.08	0.21	0.05	0.37	0.22	0.05	0.37	0.41	0.24	0.27	0.92	0.08	0.37	0.23	0.34	
TiO ₂	14.25	12.04	10.41	12.64	13.21	11.69	14.48	12.52	12.54	13.23	12.82	12.61	12.30	12.31	12.53	12.97	11.48	13.12	13.17	12.10	10.21	10.84	11.61	11.27	11.28	10.71	100.58	
Al ₂ O ₃	1.72	1.52	1.72	1.30	1.27	2.04	1.35	2.43	2.15	1.97	1.83	1.31	1.53	1.42	2.71	1.38	1.04	2.36	0.31	2.18	1.52	6.02	2.31	1.37	2.19	3.31	1.58	
Fe ₂ O ₃	2.28	0.96	3.41	2.98	2.61	2.31	2.36	1.57	1.37	3.51	4.21	2.73	2.21	1.87	0.98	3.25	2.67	1.45	4.26	1.40	1.33	2.01	2.05	2.21	1.43	1.10	1.43	
FeO	0.08	0.07	0.12	0.07	0.04	0.21	0.08	0.08	0.03	0.05	0.10	0.17	0.04	0.05	0.08	0.11	0.66	0.28	0.03	0.02	0.08	0.08	0.31	0.08	0.02	0.05	0.08	
MnO	1.25	1.41	1.31	1.36	0.63	1.39	1.05	1.45	0.37	0.30	0.55	0.43	0.39	0.45	1.21	1.25	1.20	1.14	1.87	0.82	0.95	0.72	0.84	0.45	1.21	0.82	0.89	
MgO	0.78	1.88	1.21	1.70	0.30	1.20	0.54	1.63	0.60	1.71	0.12	0.37	0.87	0.34	1.42	0.10	0.91	0.87	0.29	0.12	0.80	0.25	1.37	0.09	0.52	0.37	0.64	
Na ₂ O	3.61	2.66	3.15	3.21	3.31	3.32	3.15	3.22	4.31	4.40	3.74	3.32	3.72	3.12	3.31	3.09	3.15	3.71	3.83	4.00	3.31	3.61	4.51	3.91	4.24	4.13	3.42	
K ₂ O	5.28	4.15	4.60	4.53	5.15	4.23	5.15	4.85	4.72	4.42	5.71	4.82	5.28	5.45	4.82	5.53	4.15	4.45	4.24	5.60	5.23	5.45	4.23	5.64	5.10	4.00	5.61	
P ₂ O ₅	0.25	0.35	0.18	0.02	0.28	0.39	0.12	0.29	0.43	0.15	0.13	0.06	0.13	0.27	0.11	0.17	0.14	0.05	0.32	0.03	0.13	0.13	0.39	0.21	0.02	0.03	0.13	
H ₂ O*	1.75	1.69	2.63	1.25	1.20	1.79	1.35	1.63	0.91	1.74	1.62	1.75	1.68	1.47	1.72	2.10	1.54	1.56	1.52	2.10	1.87	1.38	1.25	1.58	1.45	2.10	1.85	
Total	100.08	100.02	100.22	99.84	100.79	100.12	100.1	100.43	100.46	100.32	100.11	100.04	100.05	100.32	100.35	100.18	100.17	100.29	99.85	100.10	100.07	100.23	100.41	100.38	100.13	100.08	100.25	
C.I.P.W. Norms	22.84	36.38	29.99	27.39	31.23	31.93	28.82	29.01	31.19	21.67	2.91	33.10	27.12	32.15	29.45	27.10	31.48	28.69	25.43	22.57	33.56	27.62	25.84	59.09	26.40	32.81	31.10	
qtz	31.79	24.53	27.18	26.77	30.44	25.00	30.44	28.66	27.89	28.12	33.74	26.48	31.20	32.21	28.49	32.68	26.65	26.30	25.06	33.09	30.91	32.21	25.00	33.33	30.14	21.64	33.15	
ab	30.55	22.51	26.65	27.16	28.01	27.25	26.65	27.25	36.47	37.23	31.65	28.09	31.48	26.40	28.01	26.15	26.65	31.39	31.41	31.06	23.40	25.42	36.17	26.57	29.63	28.01	23.19	
an	2.24	7.04	0.68	6.70	-	3.41	1.91	4.84	-	3.30	-	1.49	1.27	5.01	5.01	3.63	3.98	-	-	-	-	-	-	-	-	-	-	
cor	1.67	0.59	-	-	2.32	0.57	3.02	2.39	0.59	1.77	1.31	-	-	-	-	2.11	0.09	0.74	2.52	-	2.15	4.06	4.42	1.76	3.96	5.51	1.87	4.46
ac	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
vo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
di	en	3.46	1.33	-	-	-	-	-	-	-	1.07	1.80	0.96	-	-	-	-	-	-	0.33	1.77	0.33	3.47	-	2.00	1.29	1.92	
fs	vo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
hy	en	5.07	3.51	5.82	6.21	4.95	4.43	5.52	3.66	1.06	2.84	5.03	2.75	3.78	2.57	7.53	7.90	4.00	11.67	2.72	3.58	1.64	1.81	5.20	1.64	1.45	3.47	
ol	fo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
fa	en	2.49	1.22	2.49	1.88	1.84	2.96	1.96	3.52	3.41	2.86	1.91	2.22	2.06	3.27	2.00	1.51	3.42	0.45	1.93	0.17	5.96	2.47	-	0.42	3.05	0.16	
wt	hm	0.68	-	-	-	-	-	-	-	-	-	-	-	0.45	-	-	-	-	-	-	-	-	-	-	-	-	-	
il	ap	1.10	1.37	0.89	1.20	0.49	1.90	0.53	0.11	0.57	0.51	1.37	1.05	0.40	0.09	0.38	0.32	0.12	0.74	0.07	0.29	0.29	0.90	0.49	0.04	0.06	0.30	
ap	ap	0.58	0.81	0.42	0.05	0.65	0.90	0.27	0.67	1.00	0.35	0.30	0.14	0.63	0.25	-	-	-	-	-	-	-	-	-	-	-	-	
RATIOS																												
D.I.	85.18	83.42	83.82	81.32	89.47	84.18	85.91	84.92	95.55	85.02	87.30	87.67	89.80	90.76	87.30	85.93	84.78	86.38	82.90	86.72	87.91	85.25	87.01	88.92	86.17	89.27	87.44	
A.I.	0.82	0.73	0.97	0.80	0.83	0.92	0.73	0.85	0.97	0.91	0.96	0.84	0.96	0.89	0.84	0.85	0.84	0.78	0.82	1.04	1.08	1.08	1.02	1.11	1.12	1.03	1.10	
A/CNK	1.07	0.97	0.84	0.95	1.14	0.96	1.23	0.91	0.94	0.87	1.02	1.10	0.91	1.05	0.94	1.15	1.01	1.04	1.15	0.93	0.83	0.88	0.80	0.88	0.83	0.90	0.82	
KH/C	11.52	3.5	6.40	4.55	28.2	6.20	15.27	4.95	15.05	5.15	78.75	23.00	10.34	25.20	5.72	86.2	8.02	9.37	27.82	80.00	14.32	36.24	6.37	106.11	17.76	21.97	14.10	

D.I. : Differentiation Index, A.I. : Appaitic Index (Mol.prop.Na₂O-K₂O/Al₂O₃), A/CNK: Mol.prop.Al₂O₃/CaO+Na₂O/CaO, KH/C : Wt% K₂O/Na₂O/CaO

Table. II. Major Element Analyses and CIPW norms of the Jalor rocks, W. Rajasthan

ROCK-----	RIHYOLITE-----								
	Oxides	J13	J14B	J112	J119	KO8	JS21	RS1	RS
SiO ₂	69.81	73.25	72.83	71.35	74.18	72.53	73.09	68.75	72.27
TiO ₂	0.17	0.20	0.08	0.66	0.67	0.45	0.07	0.47	0.31
Al ₂ O ₃	11.48	10.63	11.20	12.15	11.91	13.76	12.78	13.71	11.31
Fe ₂ O ₃	4.62	4.58	1.33	0.72	1.13	1.37	1.31	3.25	2.25
FeO	1.96	2.23	2.19	3.24	1.54	1.23	0.78	1.73	1.31
MnO	0.01	0.05	0.09	0.07	0.09	0.03	0.05	0.04	0.01
MgO	0.62	0.38	0.46	1.34	1.45	0.15	0.31	0.64	0.97
CaO	0.60	0.30	0.06	0.09	0.01	0.43	0.38	0.37	0.51
Na ₂ O	4.20	3.47	3.81	3.29	3.54	3.71	3.51	4.11	4.05
K ₂ O	5.20	3.46	5.53	4.15	3.53	4.72	5.21	5.36	5.13
P ₂ O ₅	0.09	0.05	0.16	0.01	0.01	0.03	0.80	0.03	0.02
H ₂ O+	1.58	1.68	2.34	1.84	1.67	1.68	1.94	1.86	1.97
Total	100.34	100.27	100.08	99.92	99.84	100.09	100.23	100.33	100.11
	CIPW NORMS								
qu	24.87	44.54	28.73	30.93	51.42	31.62	33.57	22.61	27.62
or	30.73	2.54	32.68	24.53	20.86	27.89	30.79	31.68	30.32
ab	30.10	20.90	26.82	27.84	13.03	31.39	29.70	34.86	29.62
an	-	1.17	-	3.21	-	1.94	-	1.63	-
ne	-	-	-	-	-	-	-	-	-
cor	-	2.39	-	1.06	5.81	1.84	2.59	0.53	-
ac	4.79	-	3.85	-	-	-	-	-	4.10
wo	-	-	-	-	-	-	-	-	-
en	1.96	-	-	-	-	-	-	-	1.95
fs	-	-	-	-	-	-	-	-	-
wo	-	-	-	-	-	-	-	-	-
en	1.48	1.01	5.20	7.74	4.57	0.81	1.10	1.59	2.70
fs	-	-	-	-	-	-	-	-	-
fo	-	-	-	-	-	-	-	-	-
fa	-	-	-	-	-	-	-	-	-
mt	4.30	6.64	0.46	1.04	1.64	1.99	1.90	4.35	1.21
hm	-	-	-	-	-	-	-	0.25	-
il	0.32	0.38	0.16	1.25	1.27	0.85	0.13	0.89	0.59
ap	0.20	0.11	0.36	0.45	0.27	0.07	1.85	0.07	0.04
D.I	85.70	85.98	88.23	83.30	85.31	90.90	94.06	89.15	87.56
A.I	1.07	0.88	1.09	0.82	0.81	0.82	0.88	0.91	1.08
O.R	69.56	75.30	36.12	16.66	40.34	50.34	62.92	92.30	61.12

Table III. Trace Element Data (in ppm) for Jalor rocks, W. Rajasthan

Rock	Biotite granite (subsolvus)										Alkali granite (hypersolvus)								Rhyolite				
	Sample No	J16	J117	J117	J10	J18	K11	K33	K35	K1	J110	J111	J19	J13	J14B	J112	J119	J119	K8				
Ba	88	119	78	138	141	265	108	164	145	108	113	126	61	56	126	60	60	90					
Sr	44	121	88	182	332	315	136	100	96	92	70	98	143	92	70	88	88	46					
Th	20	21	19	10	28	25	23	13	21	24	20	13	1	1	1	4	4	3					
U	5	1	3	4	5	5	6	3	7	7	6	5	1	1	1	1	1	1					
Zr	537	637	630	660	610	618	612	530	535	612	612	560	456	337	932	421	412	412					
Y	50	77	98	71	72	61	65	75	57	61	51	57	81	63	50	3	25	25					
Hf	1	-	-	-	2	1	2	-	-	2	-	-	9	1	9	1	1	1					
Ta	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-					
Sc	2	1	4	3	3	2	3	1	4	3	5	3	6	5	4	3	3	3					
Li	22	12	7	7	9	8	9	7	25	7	16	24	7	1	7	8	8	5					
Zn	8	60	16	10	10	8	13	9	10	50	7	60	8	8	9	11	13	13					
Ga	25	22	22	12	18	16	16	25	24	24	24	24	25	12	20	17	21	21					
Mo	6	6	6	6	7	8	7	4	7	7	6	7	1	2	2	2	5	5					
Sn	6	6	4	8	7	7	7	6	8	7	5	9	1	2	4	5	5	5					

RATIOS

Th/U	4.01	14.51	6.35	2.46	5.45	4.89	3.79	4.28	2.92	3.37	3.33	3.38	0.61	6.50	3.24	7.83	21.83
Zr/TiO	0.15	0.14	0.16	0.42	0.27	0.36	0.19	0.40	0.08	0.24	0.21	0.38	0.44	0.28	1.94	0.10	0.10
Ba/Sr	1.97	0.97	0.88	0.75	0.42	0.83	0.78	1.64	1.18	1.16	1.61	1.27	0.42	0.60	1.80	0.67	1.95
Ga/Al	3.26	3.64	3.29	1.74	2.93	2.31	2.34	3.30	3.78	3.76	4.07	4.46	4.17	2.16	3.39	2.60	3.33

Table. IV: Rare Earth Elements data (in ppm) for Jalor rocks, W.Rajasthan

Sample No	J116	J18	K35	K1	J110	J111	J19
ROCK	Biotite Hornblende Granite Biotite Granite (subsolvus)			--- Alkali Granite --- (hypersolvus)			
La	59	72	46	57	86	55	48
Ce	107	117	165	155	197	130	123
Pr	16	20	16	20	29	11	15
Nd	77	97	64	105	118	92	55
Sm	13	15	22	20	19	11	9
Eu	1	.27	1	.27	2	2	2
Gd	14	20	21	13	23	15	20
Ho	2	3	4	4	5	3	2
Yb	17	17	18	22	12	11	11
RATIOS							
La/Yb	2.14	2.55	1.52	1.59	4.27	2.91	2.61
Ce/Yb	1.46	2.26	2.05	1.64	3.85	2.60	2.51
Eu/Sm	0.19	0.04	0.13	0.03	0.22	0.48	0.56

trend. The granites of the Jalor area when plotted on log 10 K O/MgO diagram proposed by Rogers and Greenberg (1981), straddle the fields of alkali granite and calc-alkali batholiths. The hypersolvus granites are restricted to the alkali granite field. In the adjacent Mokalsar area, the hypersolvus granites fall in the alkali granite field of the same diagram. In the Batchelor and Bowden (1985) $R1 = 4 Si - 11 (Na + K) - 2(Fe + Ti)$ and $R2 = 6Ca + 2Mg + Al$ plot, based on the multicationic parameters devised by de la Roche et al. (1980), the Jalor granites show an anorogenic trend. Some samples plot on the Lata orogenic field boundaries (Fig. 8). For comparison the field of the adjacent Siwana granite is also shown (Vallinayagam, 1988).

The ternary plot of normative Oz-Or-Ab components for the Jalor granites show that, compared to the subsolvus granites, the hypersolvus granites are potash-rich and were emplaced at comparatively greater depths. In the peralkaline system the low temperature melt composition would become more sodic (Thompson and Mackenzie, 1967). However, the presence of fluorine or chlorine in the volatile phase will shift the ternary minimum into the region of the peralkaline granite

(Von Platen, 1965). Subsolvus granites of the Jalor area are albite-rich relative to the hypersolvus granites. Such a shift could be caused by the lack of fluorine during crystallisation but could also be caused by the activity of calcium in the magma (Harris and Marriner, 1980). A compilation in the form of grid for all existing minimum melt compositions over a range of pressures and Ab/An ratios has been utilized by Anderson and Cullers (1978) and is reproduced in Figure 9. The scatter of data may also be due to hydrothermal alteration and/or differing degree of differentiation at the same water pressure (B. Bonin, personal communication). The values for the Jalor granites are consistent with magma generation from a crustal source at an average of 4 to 8 Kb (16 to 27 Kms). The hypersolvus granites represent water-poor magmas and the two-feldspar (subsolvus) granites may have developed at lower temperature, through depression of the solidus to levels below the crest of the alkali feldspar solvus (Tuttle and Bowen, 1958). It has also been suggested that the relatively high water content of the magmas yielding subsolvus granites may well be responsible for the conditions of alumina oversaturation through removal of alkalis in an aqueous

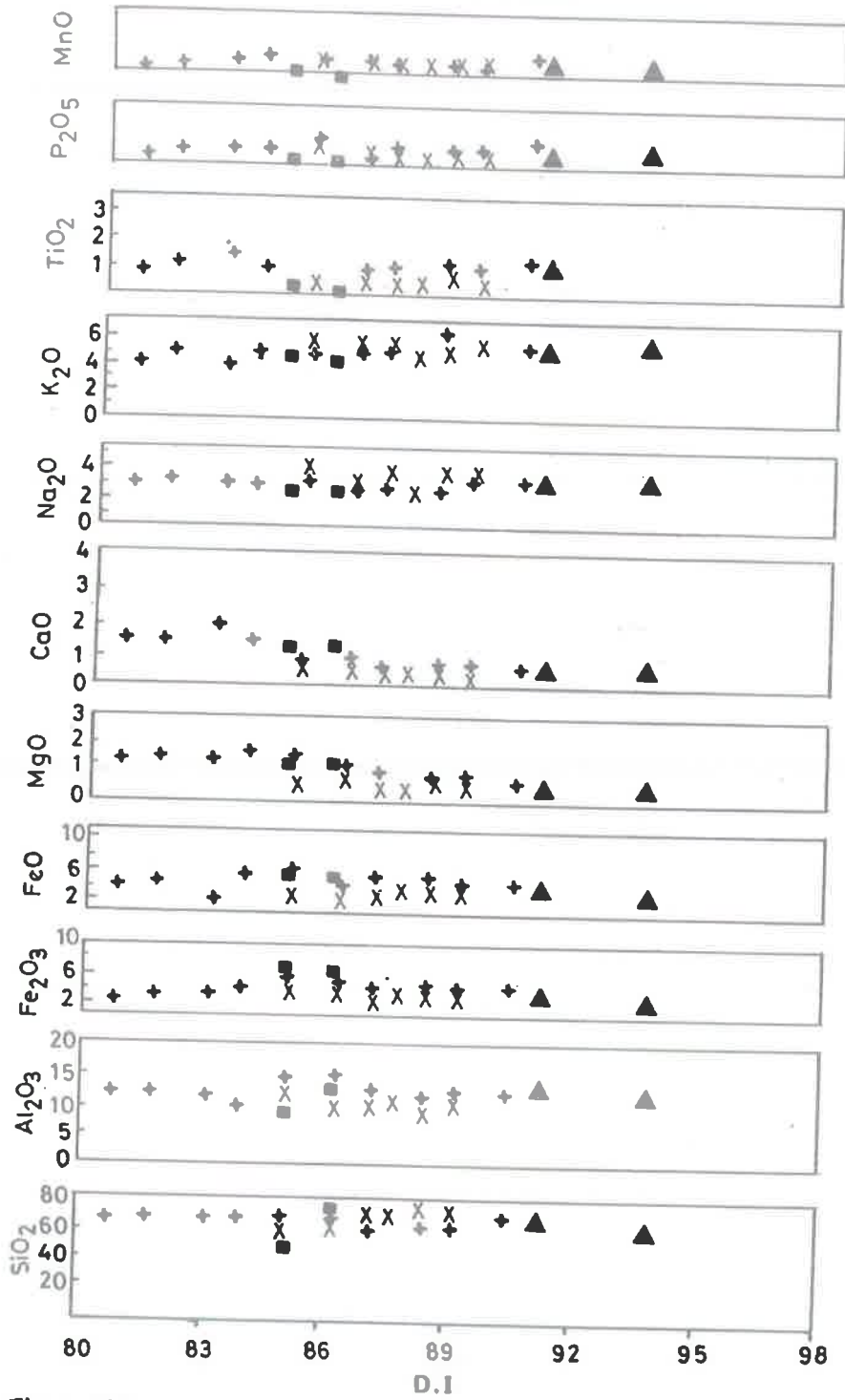


Fig. 7 Differentiation index variation diagram. Symbols: + Subsolvus granite x Hypersolvus granite, ▲ Peraluminous rhyolite, ■ Peralkaline rhyolite.

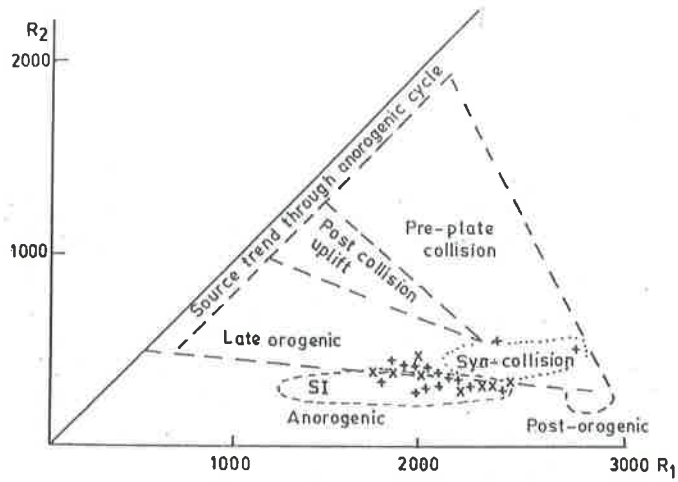


Fig.8. The de la Roche R1-R2 diagram of the major granitoid associations. The Jalor granites fall in anorogenic and Late-Orogenic field. Symbols same as in Fig.7. ---- Field of the adjacent Sivana (SI) granites (Vallinayagam, 1988).

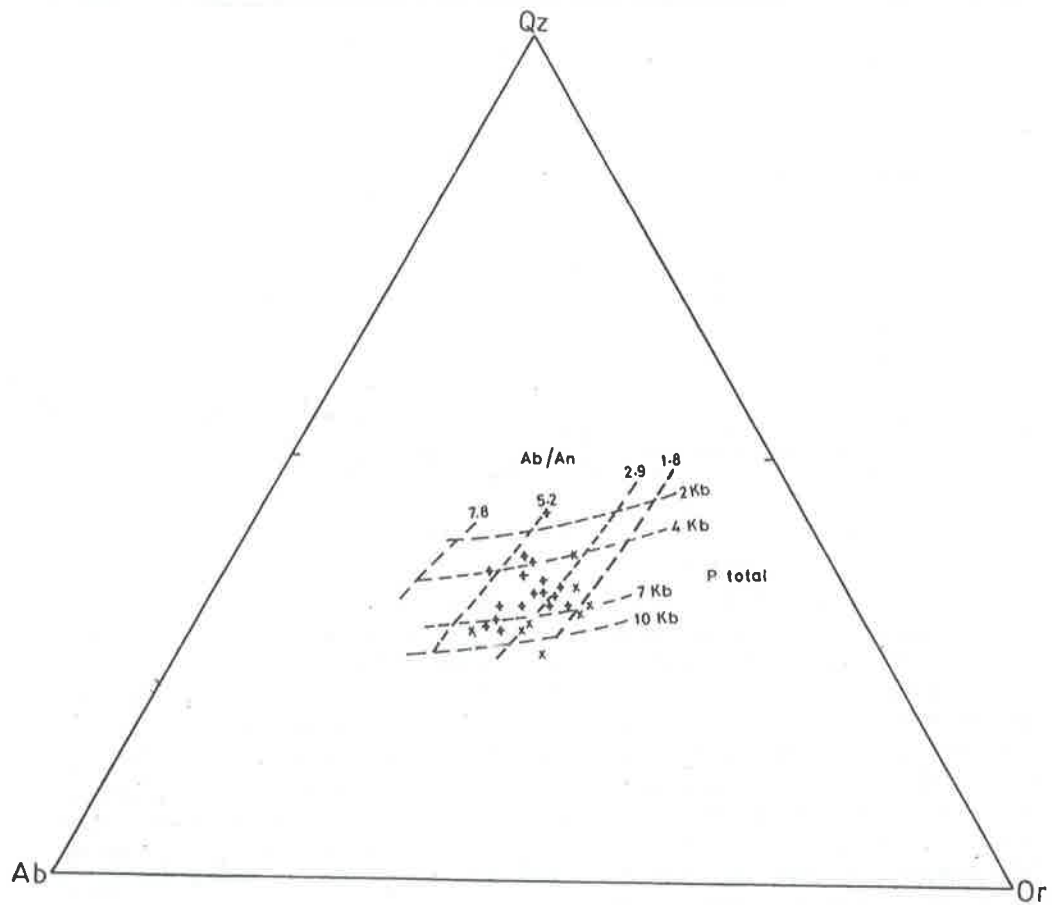


Fig.9. Normative Quartz-Albite-Orthoclase diagram of Jalor granites and comparison to experimental minimum melt composition. Minimum melt experimental grid after Anderson & Cullers, 1978.

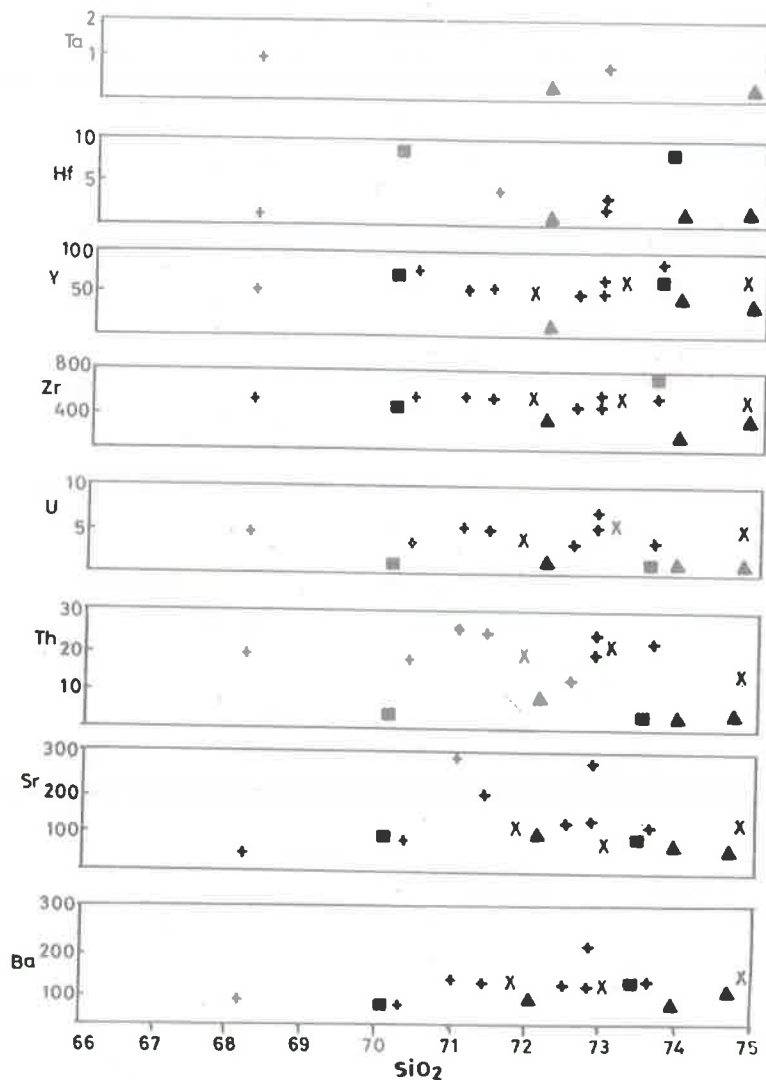


Fig.10 Trace elements versus SiO_2 plot. Symbols same as in Fig 7.

fluid phase during cooling (Luth *et al*, 1964).

Table III suggests that the granites of the Jalor area show high abundances of highly charged cations like Zr, Y, U, Th including Ga. The average values of Ga, Y, Zr, Th and U for the Jalor subsolvus granites are 20, 70, 596, 20, 5 and for the hypersolvus granites the values are 24, 56, 595, 19, 6 respectively. Similarly for the peralkaline rhyolites (sample nos. J112 and J13) the contents of Zr, Y and Ga (694, 66, 23 respectively) are comparable to the granites.

The Jalor granites are enriched in Th, U, Zr, Y, Ga and Li relative to the rhyolites as is evident in the Harker variation diagram (Figs. 10, 11). These elements including Ba define a constant linear trend and do not vary as a function of SiO_2 . However for Th in the granite, a scatter of data can be seen. For Sn a hint of positive correlation in both granites as well as rhyolites can be seen. Mo and Sc do not define any trend for granites and rhyolites. Zn is enriched in the hypersolvus granites relative to

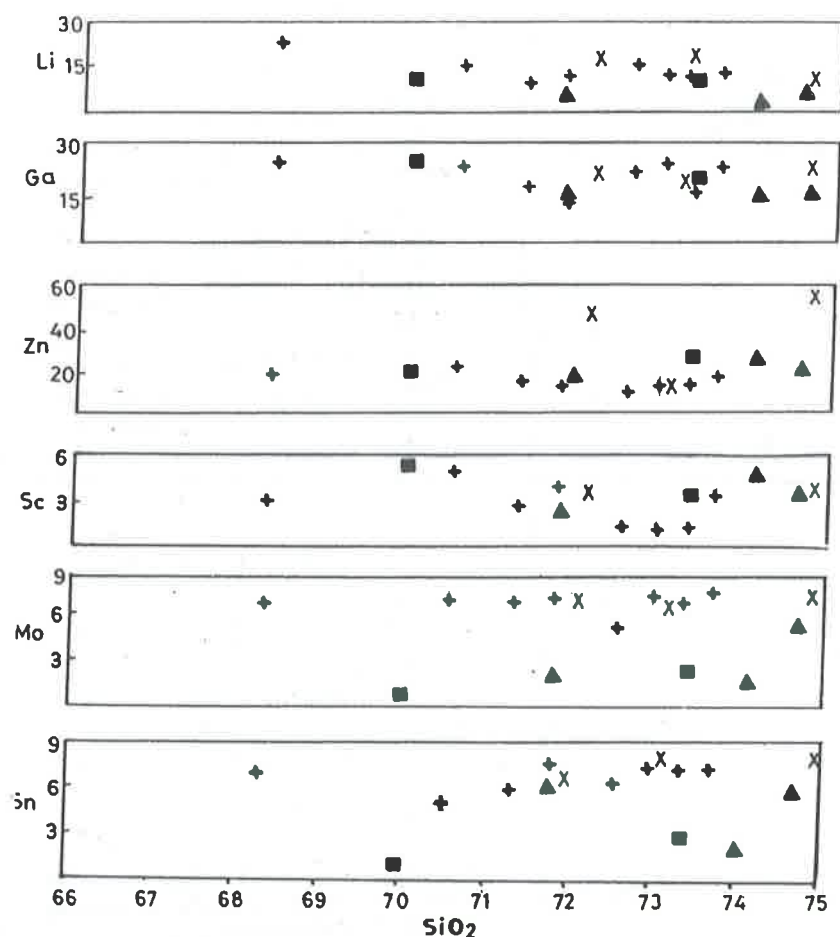


Fig.11. Trace elements versus SiO₂ plot. Symbols same as in Fig.7.

subsolvus granites and rhyolites. Hf and Ta show lower values and were not detected in all of the samples probably because they were below the detection limits of our analytical methods.

Jalor granites plot in the A-type field of Collins *et al* (1982). All the hypersolvus granites plot in the A-type field whereas some samples of subsolvus granite plot outside the A-type field (Dhar, 1990). According to Collins *et al*, (1982) high Ga/Al ratios

are diagnostic features of A-type granites. Whalen *et al.* (1987) have suggested that by utilizing plots of Ga/Al versus certain trace elements, it is possible to distinguish A-type granites from I-S- and M-type granites. Although subalkaline compositions in some suites tend to give values which overlap with compositions of other granite types, the presence of more alkaline compositions in many suites clearly identifies them as A-type. The Ga/Al values for the hypersolvus

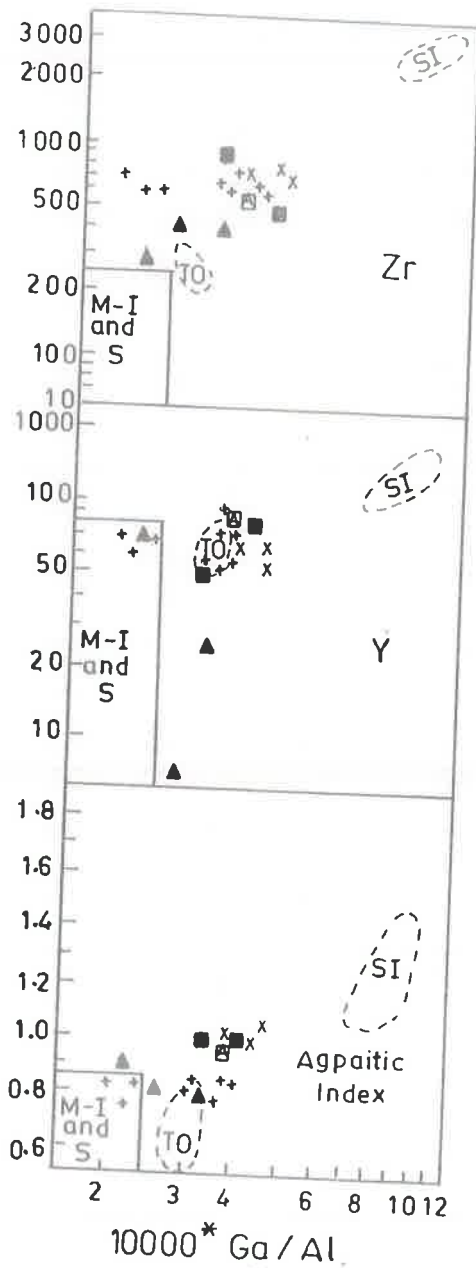


Fig.12. $10000^* Ga/Al$ versus Zr, Y and apatitic index discrimination diagram (Whalen *et al.*, 1987). M-I and S-type granite fields shown A: average A type granite. Symbols same as in Fig.7. SI and TO fields of A-type Siwana & Tosham granites. (Iby & Kochhar, 1990).

granites are higher (3.76 - 4.6) than those for the subsolvus granites (1.74 - 3.78). Likewise Ga/Al values for the peralkaline rhyolites are higher (3.39 - 4.17) than their peraluminous equivalents (2.16 - 3.33). $10,000^* Ga/Al$ versus Zr, Y and apatitic index diagrams (Fig. 12) show that most of the Jalor granites and acid volcanics plot outside the fields formed by I-S and M-type granites, but some subsolvus granites (J10, K11, K33) and one rhyolite (J14B) overlap with the I-M- and S-types. Rhyolites of peralkaline nature (J13 and J12) show more proximity to the A-type composition in the same diagram. Fields of peraluminous Tosham and adjacent peralkaline Siwana granites are also shown for comparison.

REE CHEMISTRY

The Jalor granites are characterised by high total REE abundances (subsolvus granites = 962 ppm and hypersolvus granites = 949 ppm). La/Yb_N ratio for subsolvus granites and hypersolvus granites are 1.52 - 2.55 and 2.61 - 4.27 respectively. For the Jalor granites moderate LREE enrichment and a mild upward curvature of the HREE portion of the chondrite normalised curves can be seen (Figs. 13, 14). The hypersolvus granites show enrichment of LREE as compared to subsolvus granites whereas subsolvus granites have higher values of HREE when compared with hypersolvus granites. In the Jalor granites Eu depletion is more pronounced in the subsolvus granites. Normally peralkaline granites show more pronounced negative Eu anomalies compared to peraluminous granites (c.f. Bowden and Kinnaird, 1984; Vallinayagam, 1988). The more pronounced negative Eu anomaly in the subsolvus granites as compared to hypersolvus granites could be due to the interaction of a fluid phase with the former, and also could be due to the fractionation of plagioclase (c.f. Bowden and Kinnaird, 1984). Like the Jalor granites the peralkaline granites of the Midian Mountains, Saudi Arabia (Harris & Marriner, 1980) show enrichment of LREE, with less marked Eu anomaly as compared to the

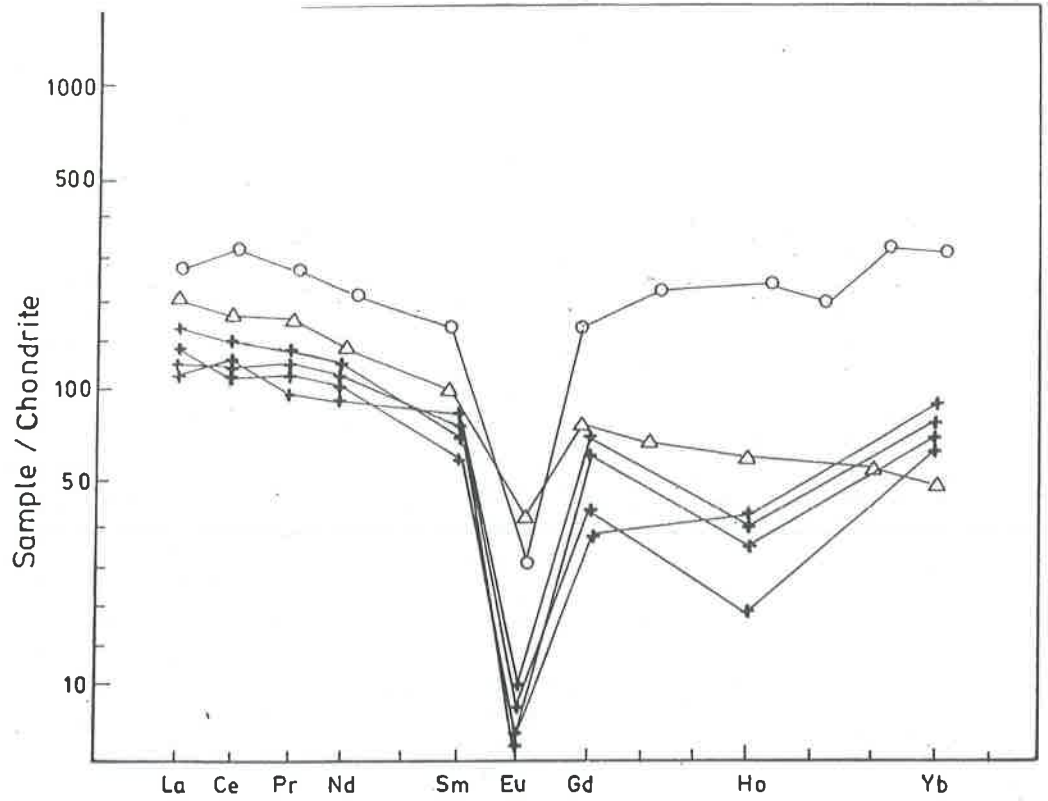


Fig.13. Chondrite normalised REE plot for the + Jalor subsolvus granite. (O) A-type granite SE Australia and (O) Nigerian Younger Granites.

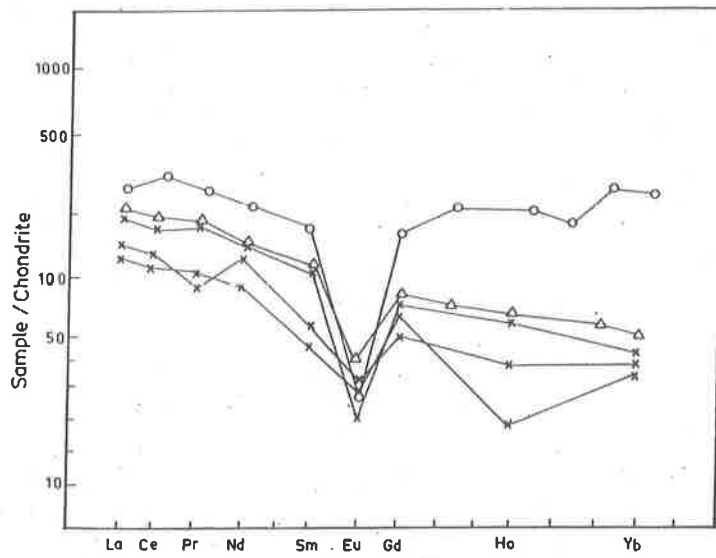


Fig.14. Chondrite normalised REE plot for the X Jalor hypersolvus granite Symbols same as in Fig.13.

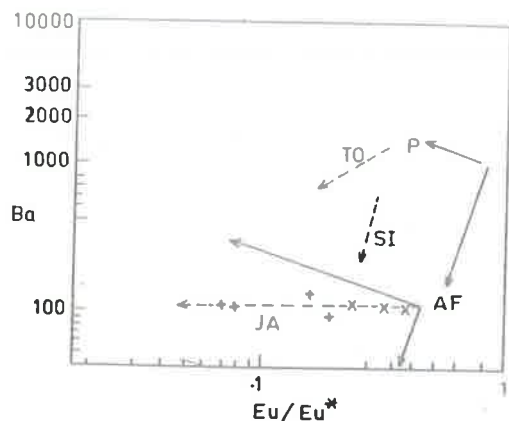


Fig. 15. Ba versus Eu/Eu^* variation diagram for Jalor granites. Symbols same as in Fig. 7. AF and PI are Rayleigh Fractionation trends calculated for the removal of alkali feldspars (AF) or plagioclase (PI). JA, SI and TO are the Jalor, Siwana & Tosham trends respectively. TO (Tosham) and (SI) Siwana trends after Eby & Kochhar (1990).

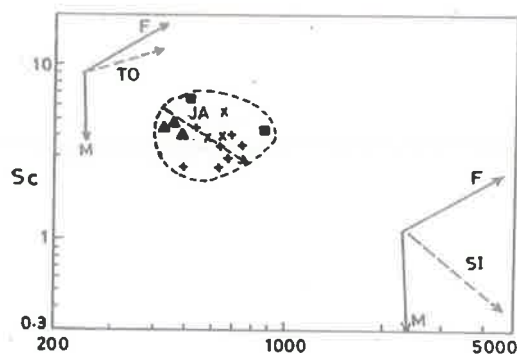


Fig. 16. Sc versus Zr variation diagram for Jalor rocks. Symbols same as in Fig. 7. F (Feldspar) and M (amphibole/pyroxene) Rayleigh fractionation trend. JA, SI and TO are the Jalor, Siwana & Tosham trends respectively. TO (Tosham) and SI (Siwana) trends after Eby and Kochhar (1990).

peraluminous/metaluminous granites. The effect of feldspar fractionation on the evolution of Jalor granites can be investigated by the plot Ba - Eu/Eu^* (Fig. 15). AF and PI are Rayleigh fractionation trends calculated for the removal of alkali feldspar (AF) or plagioclase (PI). For the Jalor granites the linear trend is indicative of fractionation involving both plagioclase and alkali feldspar for subsolvus and hypersolvus granites. For comparison fields of Siwana and Tosham are also shown. Evolution of the adjoining

Siwana granite is largely controlled by alkali feldspar fractionation which is in agreement with its hypersolvus character. In the plot of Zr-Sc (Fig. 16), showing feldspar (F) and amphibole/pyroxene (M) Rayleigh fractionation trends, variations in Zr-Sc ratios are almost totally controlled by alkali feldspar fractionation. The evolution of the Jalor rocks was largely controlled by alkali feldspar fractionation. For comparison Tosham and Siwana trends are also shown. The trend for Jalor rocks appears to be parallel to that of the Siwana rocks. However in comparison to Siwana the higher values for Sc suggest that the Jalor magma is a differentiate of a more mafic parental magma (Eby and Kochhar, 1990). The variable nature of the Eu/Eu^* ratio for the subsolvus (0.15) and hypersolvus granites (0.41) may be due to late stage hydrothermal solutions. This is consistent with the wider spread in Ba/Sr ratios, and the apparent mobility of U in the rhyolite and some of the granite samples. Moreover the alteration of orthoclase to sericite and plagioclase to kaolinite also attests to late stage hydrothermal activity (Dhar, 1990). Therefore, in view of the role of late stage hydrothermal fluids the magmatic trend of the Jalor samples (Fig. 15) may not be strictly followed (c.f. Eby and Kochhar 1990). According to Bowden and Whiteley (1974) the Eu depletion in the rocks could not just be related to magmatic processes but also to hydrothermal processes. Significant REE variation in the Nigerian granites have been attributed to post-magmatic hydrothermal fluids (Bowden, 1985). Keeping in view the role of migrating hydrothermal fluids in controlling the REE distribution in the A-type granites of Nigeria and Saudi Arabia, a similar interpretation seems to be credible for the REE variation in the hypersolvus-subolvus granites of Jalor. The granites of the Jalor area are A-type with enhanced proportions of SiO_2 , Na_2O+K_2O , Fe/Mg, Ga, Zr, Y, U, Th and REE (except Eu), and low in CaO, MgO, Sr and Sc (Dhar, 1990).

DISCUSSION AND CONCLUSION

The relationship between the peralkaline and the peraluminous components of the Jalor complex is not fully understood. However the comparable contents of such trace elements as Ba, Th, U, Ga, Y, Zr of both components suggests that both magmas have a common source. Harris and Marriner (1980) have suggested that high level emplacement, associated with volcanic activity of a volatile-rich peralkaline magma, could result in a pressure drop in the crust underlying the granite. The pressure drop would allow partial melting to occur at depth if $P(H_2O)$ were less than P (total) (Cann, 1970), a condition likely to be satisfied since the available volatiles have been lost to the peralkaline magma. The melting would produce a metaluminous granite which is subsequently emplaced as core to a peralkaline granite. It is suggested that a similar mechanism probably took place in Jalor area. The volatiles associated with the eruption of the rhyolite dyke in Jalor and the acid volcanics in the adjoining Siwana area, contributed to the trace element pattern shown by the hypersolvus granites. It is pertinent to mention here that some of the subsolvus granites of the Jalor area have fayalite which may represent pristine (original) composition. According to Martin and Bowden (1981) interaction of magnetite and fayalite might have contributed to the peralkaline overprints. In this case the peralkaline granite represents a younger phase. At the present stage of knowledge it is difficult to propose a petrogenetic model and suggest which of the granites is younger. According to Creaser *et al.* (1991), limited plagioclase fractionation of an A-type magma results in derivative hypersolvus granites which may be peralkaline. Notably the last crystallisation product of some metaaluminous A-type granites include alkali-amphiboles (Collins *et al.*, 1982).

According to Srivastava (1989) the peralkaline sodatrachytes, rhyolites of Barmer and granites of Siwana, Western Rajasthan belong to younger ring complexes marking an event at ca. 500 Ma and thus are younger than the Malani rhyolites which have an

Rb-Sr isochron age of 745 ± 10 Ma. Further he concludes that the Jalor and Siwana granites represent a Palaeozoic event related to a period of crustal upwarping before the commencement of Gondwana rifting. These interpretations of Srivastava (1988, 1989) are based on the results of Crawford and Compston (1970, p. 364) on samples Ga1711 of Jalor granite and Ga1734 rhyolite from Barmer, which give younger ages of 428 and 526 Ma by the Rb/Sr method. Ga1711 is a museum sample and may have been mistakenly attributed, and Ga1734 a weathered sample and the results may not be reliable. These younger ages have led to the postulation of an erroneous thermal event at 500 Ma. The present work shows that the Jalor magmatism, is not exclusively peraluminous as was believed by Srivastava (1988), but has a peralkaline component closely associated in space and time. This is at variance with Chandrasekaran and Srivastava (1992), who suggest that the Jalor and Siwana granites are distinct. This is significant since peraluminous rhyolites are also associated with the peralkaline granite of Siwana in the adjoining Mokalsar area (Vallinayagam, 1988). According to Currie, (1989), mildly peralkaline siliceous ash flow sheets occur world wide and are associated with non-peralkaline material. Thus the contentions of Murthy *et al.* (1961), Venkataraman *et al.* (1968), Kochhar (1984) and Bhushan (1985, 1989) that the peralkaline rhyolites and granites are cogenetic with normal peraluminous granites and rhyolites are substantiated. The Jalor and Siwana granites may represent the parent stock of the peraluminous and peralkaline rhyolite. Recent Rb/Sr age determinations of the Jalor and Siwana granites by Rathore *et al.* (1991) have also shown the Jalor and Siwana granites are coeval at 731 ± 14 Ma and are age equivalent to the Tosham granites (Kochhar *et al.*, 1985). The Siwana, Jalor and Tosham ring complexes mark a period of anorogenic magmatism in the northern part of the Indian shield.

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