Rare metal and rare earth rich peralkaline, agpaitic granitoid dykes of Siwana Ring Complex, District Barmer, Rajasthan

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Minor radial dykes trending NE–SW, N–S and NW–SE of peralkaline, agpaitic granitoids from Siwana Ring Complex record anomalous concentrations of U, Th, Nb, Sn, Pb, Y, Be, La and Ce. The dykes essentially comprise quartz, acmite, microcline and hematite with minor amounts of aegirine, riebeckite, zircon, rutile, ilmenite and betafite. Anomalous abundances of U, Th, Y and REE are attributed to betafite, acmite and aegirine besides rutile and zircon. A niobium mineral, fersmite ($CaNb_2O_6$) is also being reported for the first time from this area. The extreme iron enrichment in some of the dyke samples and their trace elemental abundances suggest that they are extreme differentiates of parental, peralkaline granites.

THE Malani Igneous Suite (MIS) represents the most voluminous, late Proterozoic intracontinental, rift-related, bimodal, rhyolite-dominated volcanic province in India[1–5]. Among the different areas of MIS, the Siwana Ring Complex (SRC), covering an area of about 1100 km^2 has been well studied and reported[1,6–8]. It represents an incomplete ring of outer rhyolite, a ring dyke of granite and a central area of about 320 km^2 comprising rhyolites preserved within the collapsed structure. Such an environment is ideally suited for uranium, rare metals and rare earths and hence the Atomic Minerals Division undertook radiometric Survey of some of these areas. Several occurrences of radioactive dykes having anomalous concentration of U, Th, Y and Nb[9–12] were discovered. The present study records a number of additional dykes from this area, which are richer in rare metal and rare earths than those reported earlier and also provides new data on mineralogy, chemistry, nature and field setting of these dykes and furthermore evaluates their genesis in brief for targeting areas for exploration. Thus Nb_2O_5 up to 12.85%, Be up to 390 ppm, Y up to 5377 ppm, Sn up to 472 ppm, La up to 3922 ppm and Ce up to > 10,000ppm have been recorded (Table 1). Detailed chemicomineralogical investigations of these dyke samples are underway.

An isolated hillock about 2.5 km NNW of Ramaniya (72°30′30″, 25°34′00″, 45 C/10; Figure 1) exposes fractured gray granites, traversed by fine grained radioactive dykes. Six prominent dykes are present (besides numerous smaller ones) with width from 10 to 65 cm and length up to 400–500 m. These dykes exhibit pinching and swelling nature and occupy NE–SW fractures, trending from N40°E–S40°W to N70°E–S70°W. A set of smaller (3–15 cm × 1–10 m) radioactive dykes is also present in this hillock, almost perpendicular to the first set.

In Mamaji Ka Wala (72°35′45″, 25°37′50″, 45 C/10),

Table 1. Spectrographic data (in ppm) of trace element content of dykes

Locality	Trend of dykes	Y	Be	Nb	La	Ce	Sn	Pb	Zr
(i) Ramaniya	NW–SE $n = 2$	2804	246	964	2589	> 10000 (max)	225	792	2311
(ii) Ramaniya	NE–SW $n = 4$	2529	86	217	1481	4101	203	1398	2641
(iii) Mamaji-Ka-Wala	N–S $n = 6$	3220	174	607	2113	> 10000 (max)	97	389	2190
(iv) Mokalsar	NE–SW $n = 7$	1593	119	414	679	1337	92	535	2229
(v) Ludhrara	NE–SW and NW–SE $n = 6$	658	43	192	232	550	66	239	3064
(vi) Ludhrara	N–S $n = 1$	492	10	> 10000 (12.85% Nb_2O_5)	2046	4692	472	219	449
Range		197–5377	10–390	70– > 10000	68–3922	249– > 10000	34–472	< 15–1880	449–4853
(vii) Siwana granites*		1967 (30)	18 (39)	220 (40)	768 (32)	1665 (28)	38 (41)	–	2948 (40)

*Analytical results of Siwana granites are after Bhushan[8].
Values rounded off to nearest integer. The figure in brackets denotes number of samples used.

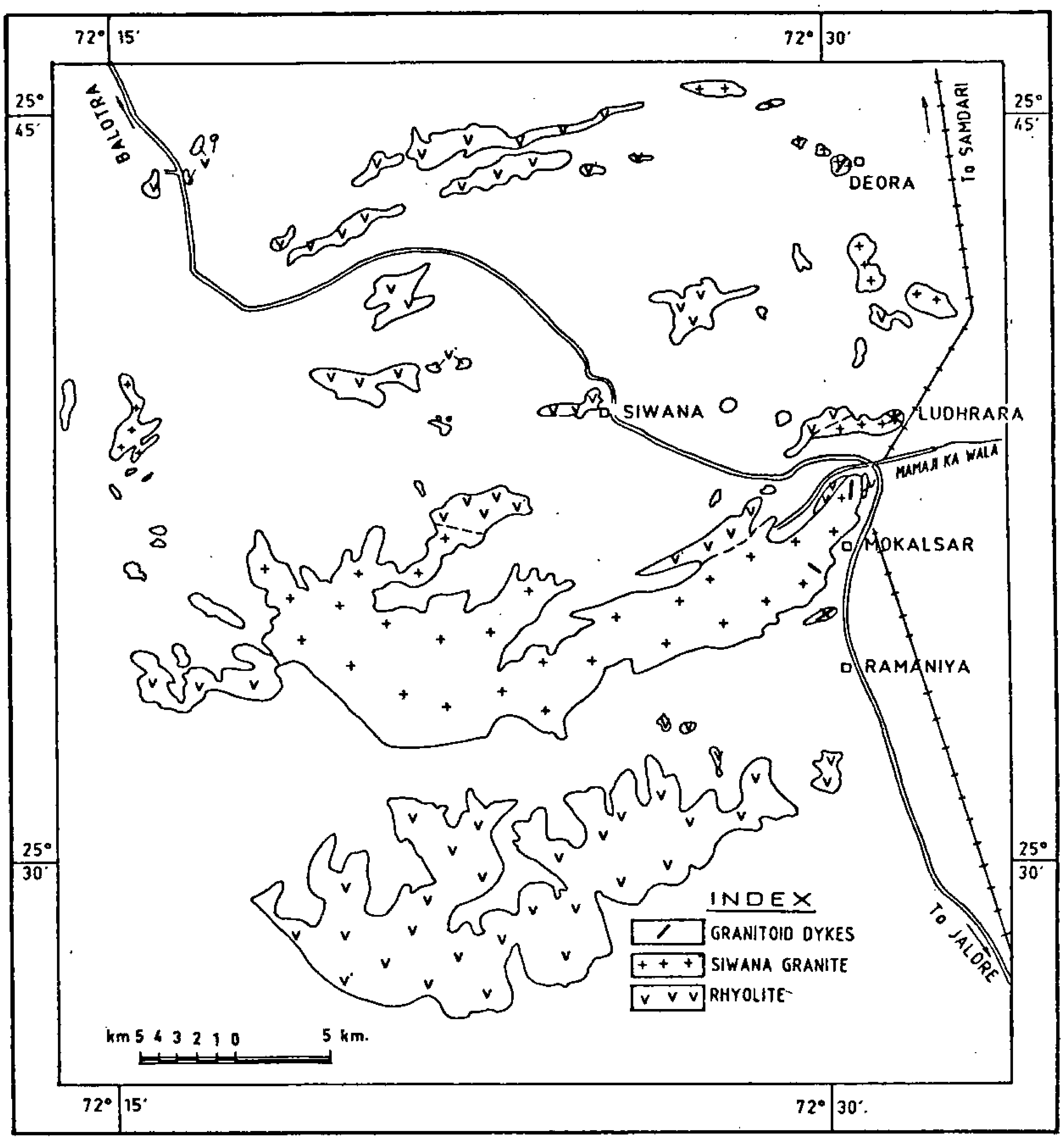

Figure 1. Geological map of Siwana Ring Complex showing location of radioactive granitoid dykes.

eight major fine grained, radioactive dykes (besides numerous minor ones) varying in width from 30 cm to 2 m and traceable for over 300–500 m intrude the pink granites along N–S fractures, adjacent to their contact with porphyritic pink rhyolite. Some of these dykes get bifurcated and later join up again. The main granite hill between Ramaniya and Mokalsar (72°30′30″, 25°36′15″) is also traversed by a major, fine grained, radioactive, NE–SW trending dyke, 1–2 m in width and about a km in length. This pinkish brown-coloured dyke has been traced up to 50 m depth on an escarpment face.

The granite hillock south of Ludhrara (72°31′40″, 25°39′00″, 45 C/10) is also traversed by numerous dykes and shows feeble radioactivity. The main dyke phase occupies NE–SW fractures and trends from N25°W–S25°W to N45°E–S45°W with subvertical northwesterly dips. They vary from 2 to 50 cm in width and are up to 200 m (approx.) in length. Some of these dykes and the host granite along or near its contact with dykes were seen to contain randomly oriented tourmaline needles (1–2 cm in length). In one of the dykes, xenoliths of host granite are also present. Another dyke phase trends NW–SE and is smaller in length (10 m–30 m). One thick dyke (about 3 m × 30 m) was seen trending randomly taking turns. These NE–SW and NW–SE trending dykes are not significantly enriched in rare metals and contain only Y (658 ppm), Be (43 ppm) and Nb (192 ppm). The vein which was found to contain 12.85% of Nb_2O_5 is a minor pegmatoid vein (only 5–8 cm in width and about 10 m in length) trending N–S.

Petromineralogical studies of Mamaji Ka Wala samples (specific gravity from 2.7 to 2.9) revealed that they are mainly composed of quartz, k-feldspar and acmite with scanty grains of aegirine and riebeckite. Zircon and hematite are the main accessory minerals. However, apatite, rutile and ilmenite are also present. Intergrowth of hematite with ilmenite and rutile is common. Coarse grained laths of hematite up to 2 mm in length and 1 mm in width have also been observed. Micrographic texture associated with eutectic intergrowth of quartz and k-feldspar is developed in one sample. Marginal alteration of hematite to goethite and of acmite to chlorite and epidote is common. However, in some of the acicular grains of acmite, partial to complete alteration to crystalline iron oxide (predominantly hematite) is very pronounced. Radiometric assay of these samples indicated up to 0.024% eU_3O_8, 0.004% U_3O_8 (beta/gamma) and up to 0.044% ThO_2. SSNTD studies using CN film, recorded moderate density alpha tracks after 3 days of exposure. These tracks cannot be clearly correlated to any mineral. However, zircon and traces of betafite have been identified by XRD as radioactive minerals and acmite, hematite and microcline as common minerals. As these dykes are significantly enriched in Y (3220 ppm), La (2133 ppm) and Ce up to > 10,000 ppm with considerable Nb (607 ppm), Be (174 ppm), Sn (97 ppm), Zr (2190 ppm), U_3O_8 up to 0.004% and ThO_2 up to 0.044% and no specific mineral phase responsible for these elements has been observed, it can be surmised that acmite, rutile and zircon along with traces of betafite must have accommodated these elements.

The hand specimen of NE–SW trending Ramaniya dykes are fine grained, melanocratic, hard with dark green to greenish gray. They are composed of orthoclase, quartz, aegirine, acmite and aegirine-augite having inequigranular, holocrystalline texture. Quartz and mafic minerals occur as segregated layers. The mafic minerals are bleached and show typical euhedral prismatic and acicular habit. The modal composition works out to be orthoclase – 35 to 40%, quartz – 30 to 35% and aegirine, acmite and aegirine–augite making 25 to 30%, others are 5% (mainly hematite with rare zircon, rutile, etc.). SSNTD studies using CN films recorded low density, dispersed tracks attributable only to disseminated ferruginous material. The NW–SE trending dykes on the other hand are coarse grained and pegmatitic in nature, containing quartz and k-feldspar in the central portion and aegirine laths on the margins, near their contact with granite. As the Ramaniya dykes are also significantly enriched in Y (2529 ppm), Sn (203 ppm), La (1481 ppm), Ce (4101 ppm), Pb (1398 ppm), U_3O_8 up to 0.031% and ThO_2 up to 0.065% and no distinct Y, Sn, Pb, REE, U and Th bearing phase has so far been identified, it can be surmised that the mafic and accessory minerals present must have accommodated these elements.

The NE–SW and NW–SE trending Ludhrara dykes are peralkaline, acmite-bearing, hornblende and biotite microgranites having phenocrysts of hornblende and/or k-feldspar. The N–S trending Nb-rich, pegmatoid vein contains a mineral assemblage different from the other Ludhrara dykes. It consists of very coarse grained quartz and orthoclase along with minor acmite and some Fersmite ($CaNb_2O_6$), identified by XRD. Samples from this vein analysed up to 0.021% U_3O_8 and 0.18% ThC which might have been accommodated by fersmite.

Whole rock analysis data of three samples fror Mamaji-Ka-Wala is presented in Table 2. Analytic data of Siwana granites, average of 8 samples of Bhushar is also given for comparison. The dyke samples contai high Fe_2O_3 and low Al_2O_3, TiO_2, FeO, MgO, Na_2O an K_2O in comparison to Siwana granites. The dyke rock and the Siwana granites have more K_2O than Na_2C The K_2O–Na_2O ratio is 1.04 for average Siwana granite and 1.33 for dyke rocks. However, as mol · Al_2O_3 < mol · ($Na_2O + K_2O$) in all the cases, the dyke rocks ar also peralkaline in line with Siwana granites. Furthe the dyke rocks and the Siwana granites are all agpaiti

Table 2. Whole rock analysis of Mamaji-Ka-Wala dykes of Siwana Ring Complex

Sample No.	(1)	(2)	(3)	(4)	(5)
SiO_2	68.65	73.50	70.04	70.73	69.79
TiO_2	00.19	00.21	00.17	00.19	00.58
Al_2O_3	04.40	06.09	05.46	05.32	08.88
Fe_2O_3	17.85	11.86	15.28	15.00	07.63
FeO	00.44	00.37	00.44	00.42	02.07
MnO	00.14	00.10	00.10	00.11	00.14
MgO	00.12	00.11	00.08	00.10	00.66
CaO	00.14	00.36	00.14	00.21	00.29
Na_2O	02.76	02.22	03.03	02.67	04.23
K_2O	03.31	03.43	03.92	03.55	04.41
P_2O_5	00.10	00.04	00.04	00.06	00.10
Moisture	00.20	00.35	00.10	00.22	–
LOI-Moist	01.21	01.27	00.88	01.12	00.85
Total	99.51	99.91	99.68	99.70	99.63
CIPW norms					
qz	44.13	48.47	41.64	44.76	30.29
or	19.56	20.27	23.17	20.98	26.06
ab	4.20	12.23	6.26	7.60	21.12
di	0.03	0.59	0.34	0.51	0.63
hy	0.28	–	0.04	0.01	1.83
wo	–	0.32	–	–	–
ac	16.87	5.78	17.07	13.21	12.92
mt	1.32	0.91	1.25	1.16	4.59
il	0.36	0.40	0.32	0.36	1.10
hem	11.11	9.24	8.52	9.63	–
ap	0.23	0.09	0.09	0.14	0.23
Ratios					
DI	67.89	80.97	71.07	73.34	77.47
FI	84.76	86.75	88.14	86.55	90.39
AI	01.86	01.21	01.69	01.59	01.32
K_2O/Na_2O	01.20	01.55	01.29	01.33	01.04

Sample nos. 1, 2 and 3: Mamaji-Ka-Wala dyke samples analysed a Chemical Laboratory, AMD, New Delhi.
Sample 4: Average of 1, 2 and 3.
Sample 5: Average of 8 Siwana granite samples of Bhushan[8], fo comparison.
DI = Differentiation index = q + or + ab + neph + leu + kal.
FI = Fractionation index = q + or + ab + ac + sodium metasilicate.
AI = Agpaitic index = Mol ($K_2O + Na_2O$)/Mol. Al_2O_3.
Method of analysis:
(i) SiO_2, MnO, TiO_2 and P_2O_5 by spectrometry
(ii) Al_2O_3, MgO and Fe_2O_3 by AAS
(iii) Na_2O and K_2O by flamephotometry and
(iv) FeO by volumetry.

In Figure 2, K_2O–Na_2O binary diagram, all the dyke samples and Siwana granites plot in the adamallite field of Harpum[13], except one dyke sample which plots in the granite field but very close to its boundary with adamallite field.

The CIPW normative values are also given in Table 2. High acmite values are conspicuous, indicating their alkaline character. High normative hematite is invariably present in all the dyke rocks. The granites contain less normative quartz, acmite and hematite and more orthoclase, albite, magnetite and ilmenite than the dyke rocks. All the rocks have low differentiation index (DI), but the dyke rocks have a tendency to enrich in Al_2O_3 and deplete in Fe_2O_3 with increasing DI. However, with the increase in Al_2O_3 content, the AI also decreases. Bhushan[8] has concluded fractionation of magma during ascent and emplacement at shallow depths due to low PH_2O. The varying trends of major oxides deciphered above are consistent with Bhushan's conclusion and suggest that the dykes are the last fractionate of the parental Siwana granite magma.

Table 1 shows average trace element abundances of dykes from SRC and of Siwana granites. The Ramaniya and Mamaji-Ka-Wala dykes contain more Y, Be, Nb, Sn, La and Ce and less Zr than the Siwana granites. High Pb content of all the dykes is also conspicuous. The Mokalsar dyke is enriched in only Be, Nb and Sn as compared to Siwana granite. The second Ludhrara dyke (Sl No. vii in Table 1) is unique in that it is significantly enriched in Nb, contains appreciably higher LREE, but is depleted in all others.

As all these elements generally get concentrated at the pegmatitic stage of fractionation, these dykes may represent the late stage injections, a view in full agreement with the conclusions drawn from major oxide analysis. The high Pb content may be due to the presence of radiogenic lead contributed by anomalous U and Th present in dykes. The lower Zr content of dykes in comparison to Siwana granites may be due to the separation of Zr as zircon during granitic stage of fractionation. Nb exhibits a positive correlation with Sn and Be. In Figure 3, Y, Nb and La have been plotted against Zr. Except second Ludhrara dyke (Sl No. vii in Table 1) all the dyke samples plot in the peralkaline field of Bowden[14] in line with Siwana granites.

The exact genesis of these peralkaline granitoid dykes of SRC has not yet been worked out. However, Srivastava[5] has provided an excellent summary of all the major theories dealing with the origin of alkaline 'A-type' magmas. According to him, the major ideas are: (i) Simple fractionation of mantle-derived alkaline magmas[15]; (ii) Reaction of mantle-derived alkaline magmas with crustal rocks[16,17]; (iii) Melting of lower crustal rocks under fluxin influence of mantle-derived volatiles[18]; and (iv) Partial melting at high temperature of depleted I-type source in lower continental crust[19–21].

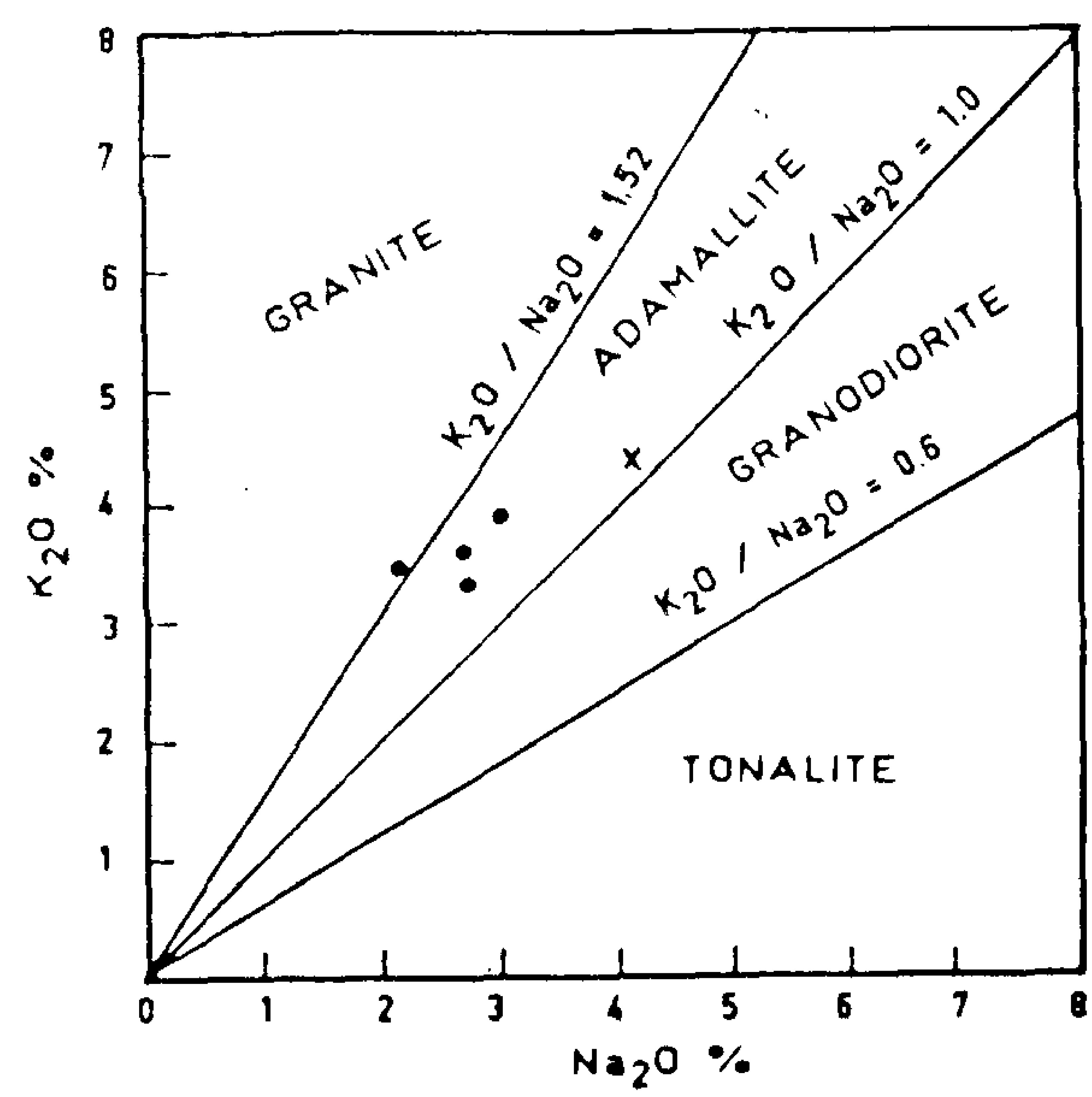

Figure 2. Na_2O–K_2O binary diagram of Harpum (1963) for the nomenclature of rocks of granitic composition [•, Dyke samples (1, 2, 3 and 4 of Table 2); ×, Siwana granite (5 of Table 2)].

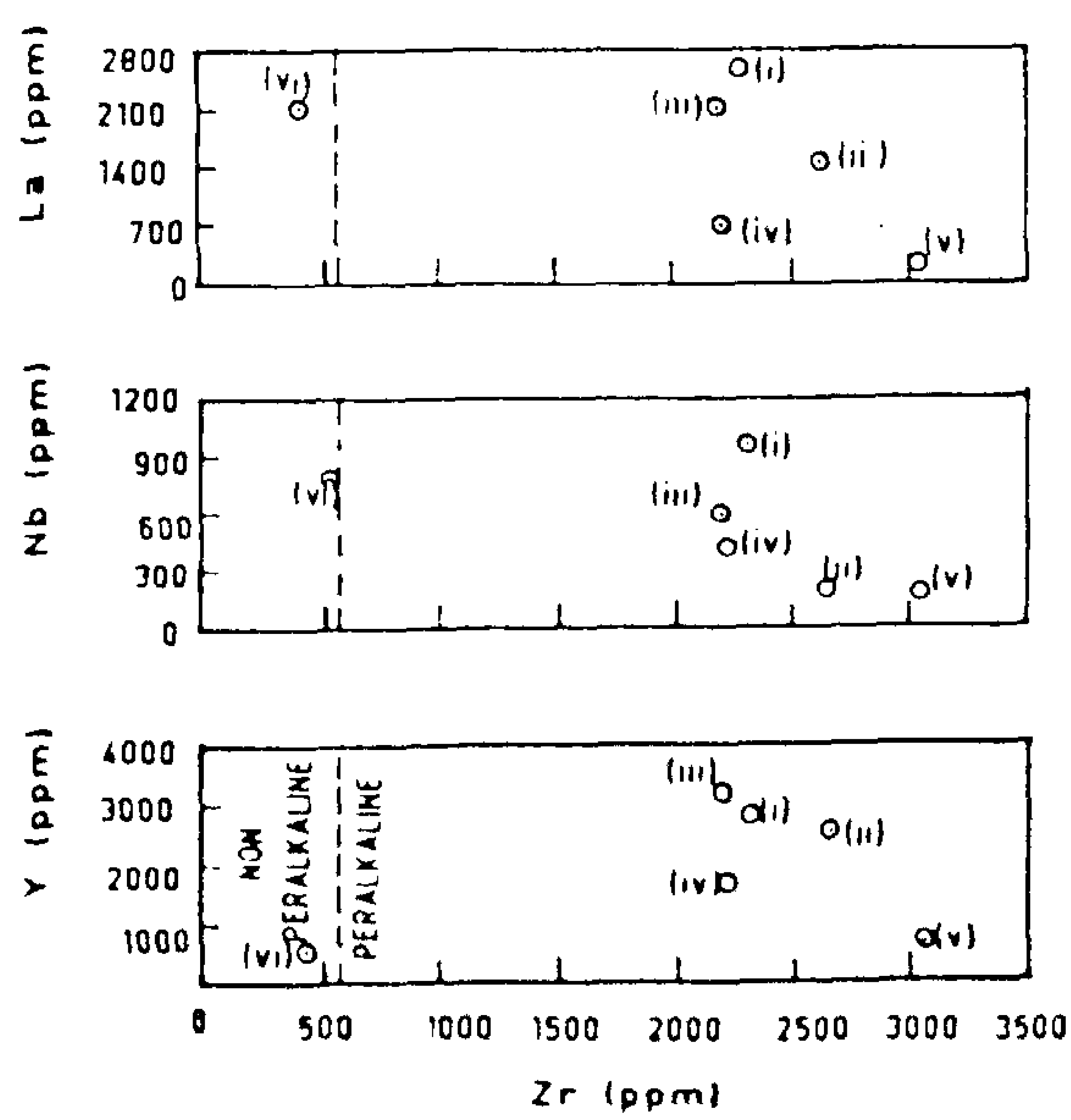

Figure 3. Zr versus Y, Nb and La of granitoid dykes of Siwana Ring Complex. The dividing line between peralkaline and nonperalkaline is after 'Bowden, 1974'. Figure in bracket against points indicates the locality Sl No. as listed in Table 1.

Srivastava[5] opines that the contamination of mantle-derived magmas must have led to the formation of alkaline magmas of SRC.

It can, therefore, be concluded that U, Th, Nb, Sn, Pb, Y, Be and LREE rich peralkaline, agpaitic granitoid dykes, so far recorded only from the eastern half of the inner granite ring of Siwana Ring Complex, represent the last pegmatitic stage fractionates of such parental alkaline magma of SRC. In view of the anomalous abundances of these strategic elements in them, these dykes and the remaining western half of the granite ring needs further detailed investigations to evaluate their trace element potential and economic feasibility for possible exploitation in future.

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Alkaline nature and taphrogenetic affinity of felsic volcanic rocks of St. Mary Islands, off Mangalore coast

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The St. Mary Islands located off the Mangalore coast is an isolated patch of volcanic rocks presumed by some of the earlier workers to be related to the Deccan Trap volcanism. Geochemical analysis of the rocks of the islands reveals their essentially felsic but alkaline nature which indicates a possible relation with continental rift. In the light of the available age-data (of 93 Ma) and their location in the reconstructed Gondwanaland, the genesis of the St. Mary Islands volcanics can be related to the crustal thinning preceeding the Indo-Madagascar rift which predates Deccan volcanism significantly. This study necessitates identifying such expressions of rift-related magmatism of pre-Deccan age from other areas of the western margin of the Indian subcontinent.

THE St. Mary Islands, situated within a distance of 4 km from the mainland, off the Mangalore coast (between 74°40′13″–74°4′ E and 13°19′30″–13°23′10′ N) is well known for the occurrence of spectacular columnar joints in the rocks of the islands. Detailed field and petrographic studies by earlier workers[1,2] indicated that the rocks of the islands are essentially felsic volcanic rocks like rhyolite, rhyodacite and dacite. Geochronological studies have indicated an age of 93 Ma for them[3]. Here we present the results of the geochemical analysis – carried out by the rapid methods of silicate analysis outlined by Shapiro and Brannock[4] – and the interpretation of the data along with the already available chemical data on these rocks. Though the data are of preliminary nature, they are sufficient enough to decipher the magmatic affinities and petrogenetic aspects and to discuss their tectonic setting in relation to Plate Tectonics. Petrographically, the rocks are fine-grained with phenocrysts of feldspar and commonly showing small xenoliths – mostly having a diameter of 1 to 2 mm – of mafic nature made up essentially of augite and plagioclase.

Table 1 presents results of the chemical analysis of the volcanic rocks. The felsic nature of the rocks is reflected by their high silica content and low magnesia content, except in samples with significant presence of mafic xenoliths. When plotted in the SiO_2 vs $(N_2O + K_2O)$ diagram for the nomenclature of volcanic rocks they fall in the fields of trachydacite, rhyolite and dacite (Figure 1). Compared to the chemistry of average rhyolite, the rhyolites of the islands possess higher TiO_2