Anomalous concentration of REE–Th–U in microclinite–pyroxenite–albitite in Ajmer and Nagaur districts, Rajasthan

Higher concentration of rare earth elements (REE, 153–93,085 ppm), with uranium (< 0.010–0.140% U_3O_8) and thorium (0.018–1.20% ThO_2) has been located around Bassi and Arath areas, in the southern part of the North Delhi Fold Belt (NDFB)[1] in Ajmer and Nagaur districts, Rajasthan (Figure 1). Mineralization is shear controlled within an albitite zone, which extends intermittently over 30 km length and a width of about 1–8 m. The zone is located about 30 km west of the well-known albitite line of Rajasthan in the western Indian craton[2].

Quartzite, garnetiferous mica schist, gneisses and calc-silicate metasediments belonging to Ajabgargh Group of Mesoproterozoic Delhi Supergroup resting over the Achaean basement are exposed in the study area[3]. The rock formations show N32°E–S32°W regional strike and dip towards NW. They have been deformed by three phases of folding during the Delhi orogeny. The folds of the first two phases are NE–SW trending coaxial isoclinal folds. Folds of the third phase are represented by EW to NW–SE trending cross folds. Parallel to subparallel NE–SW shears in the axial zones of NE–SW folds serve as loci for emplacement of acid and basic intrusives. Major lineaments such as Bassi–Karkeri and Luni–Sukri pass through the central and western flank of the Bassi–Kharkari synform in the study area[4].

Quartzo-feldspathic veins emplaced in garnetiferous gneiss and pyroxenite, and also pegmatites carry high abundance of REE, Th and U. The CIPW normative calculations on the samples of quartzo-feldspathic vein from Khanpura and Chinwali in the central portion of the study area ($n = 13$; major element analyses not given here) show normative albite content in the 6.14–47.47% range, and orthoclase content in the 0.77–51.41% range, indicating that both orthoclase and albite are present in the quartzo-feldspathic vein of the area. The samples from Khanpura and Chinwali respectively, indicate 5% and 15% of 'normative apatite'.

XRD studies have identified britholite ($(Ca,Ce)_5(SiO_4,PO_4)_3(OH,F)$) and chevkinite ($(Ca,Ce,Y,U,Th)_4(Fe,Mg)_2(Ti,Fe)_3Si_4O_{22}$), as the REE–Th–U minerals in

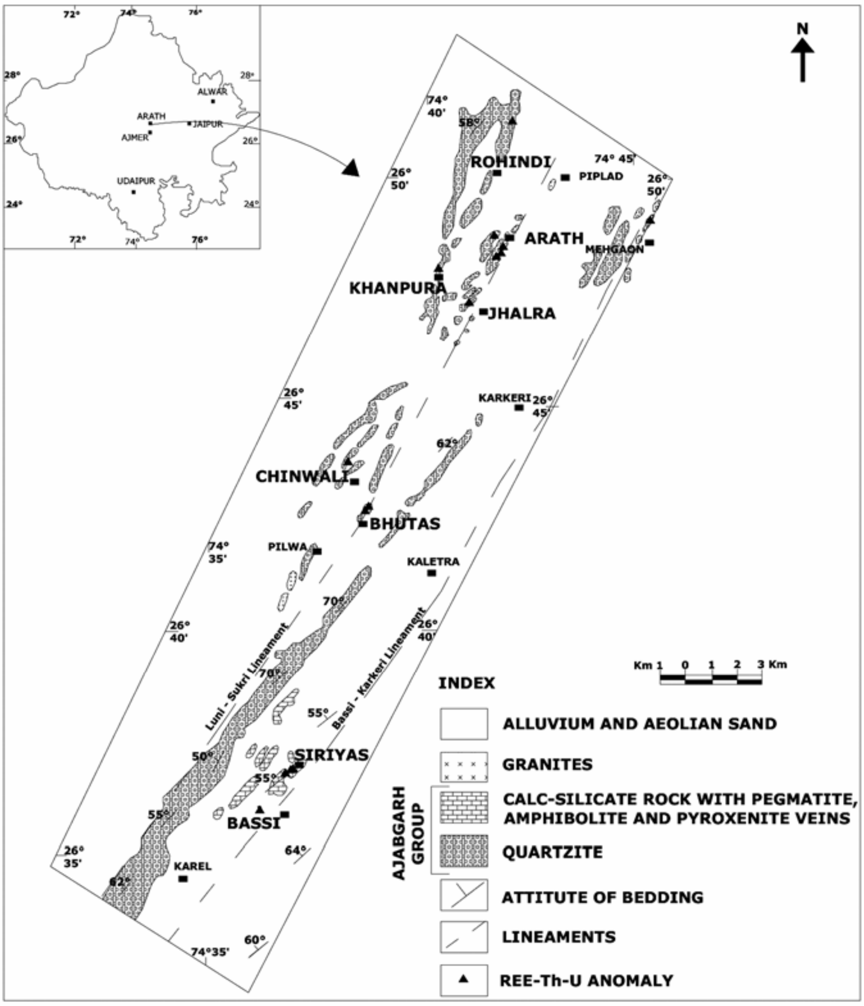

Figure 1. Geological map showing rare earth elements–Th–U occurrences in Arath–Bassi area, Ajmer and Nagaur districts, Rajasthan.

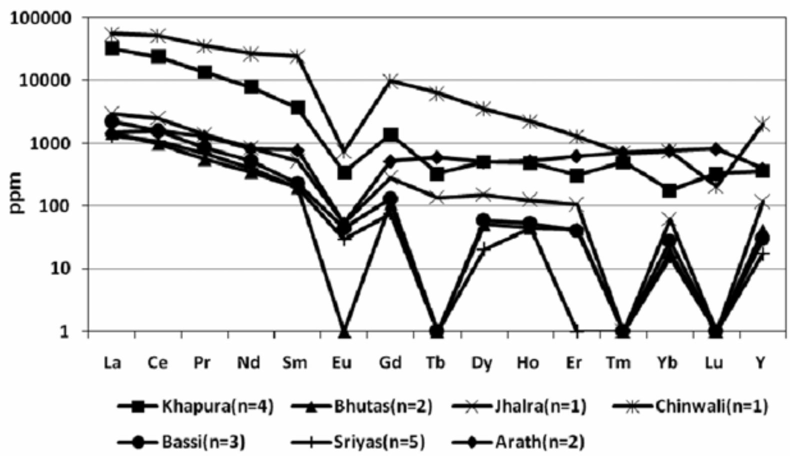

Figure 2. Plot showing rare earth elements distribution in the study area.

quartzo-feldspathic veins and pegmatites. Significant concentration of REE in the study area is probably due to abundance of these minerals in the host rock. These minerals are prone to metamictization and show large variation in their composition.

REE compositions of quartzo-feldspathic veins and pegmatites are presented in Table 1. Chondrite-normalized REE values (normalization values from Anders and Grevesses[5]) are given in Figure 2. LREE enrichment, HREE depletion and negative Eu anomaly (average 0.10) are observed in the REE patterns. LREE/$HREE_{CN}$ ratio in samples from Arath area is 1, whereas in Khanpura, Chinwali, Bassi and Siriyas samples, the ratio ranges from 7 to 21. This indicates comparatively moderate to higher degree of fractionation in the veins from the latter areas. La_{CN}/Lu_{CN} for Arath, Khanpura and Chinwali samples is 1, 100 and 274 respectively. Strong enrichment of LREE in samples from Khanpura and Chinwali is evident, whereas no such enrichment has been found in the samples from Arath[6]. La and Ce abundances in the samples from different areas are shown in Figure 3. The plot shows that the samples from Sriyas, Bassi, Jhalra, Bhutras and Arath have lower abundance of La and Ce compared to those from Khanpura and Chinwali. However, the La/Ce ratio remains fairly constant for all the samples. A plot of Y versus (La + Ce) concentrations (Figure 4) shows a significant positive correlation ($r = 0.92$) which may reflect an original substitution-induced trend between Y and REE[7]. LREE enrichment in pegmatites and quartzo-feldspathic veins is generally ascribed to fractionation of HREE into minerals such as garnet and pyroxene during partial melting of source materials or due to fractional crystallization[7]. The substitution of rare earths in britholite is considered as a function of differentiation either by direct crystallization or by post-magmatic hydrothermal alteration of pre-existing apatite[8]. Occurrence of chevkinite, which is a titano-silicate containing iron, thorium and cerium group of rare earths in a vein associated with pegmatite suggests that it was formed in a pegmatitic environment.

The uranium and thorium values in the samples of the quartzo-feldspathic veins and pegmatites range from < 0.010% to 0.140% U_3O_8, and 0.018% to 1.20% ThO_2 ($n = 18$). U/Th shows a wider range from

Table 1. Chondrite normalized rare earth elements (REE) distribution in quartzo-feldspathic veins and pegmatites of the study area

REE	Arath (*n* = 2)	Khanpura (*n* = 4)	Bhutas (*n* = 2)	Jhalra (*n* = 1)	Chinwali (*n* = 1)	Bassi (*n* = 3)	Siriyas (*n* = 5)
La	1,485	33,006	1,491	3,004	56,481	2,284	1,334
Ce	1,584	24,236	998	2,561	53,039	1,599	1,082
Pr	1,296	13,622	567	1,392	36,117	864	690
Nd	826	7,875	350	849	27,025	531	393
Sm	785	3,732	201	523	24,765	231	199
Eu	54	344	–	54	750	45	30
Gd	524	1,381	112	285	9,903	132	76
Tb	606	331	–	138	6,281	–	–
Dy	513	512	52	152	3,564	60	21
Ho	531	486	45	126	2,248	54	45
Er	632	312	44	107	1,278	41	–
Tm	723	496	–	–	702	–	–
Yb	772	177	18	62	751	28	15
Lu	823	329	–	–	206	–	–
Y	398	360	42	119	2,060	30	17
U	1,070	308	215	130	1,400	57	15
Th	1,330	2,643	505	2,000	12,000	440	518
U/TH	0.80	0.12	0.43	0.07	0.12	0.13	0.03
∑LREE	6,030	82,815	3,607	8,383	198,176	5,553	3,729
∑HREE + Y	5,522	4,383	313	988	26,993	345	175
LREE/HREE	1	19	12	8	7	16	21
∑REE	11,552	87,198	3,920	9,371	225,169	5,898	3,903
La + Ce	3,069	57,242	2,489	5,565	109,519	3,883	2,417
La/Ce	0.9	1.4	1.5	1.2	1.1	1.4	1.2
Eu/Eu*	0.1	0.1	–	0.1	–	0.2	0.2
La/Lu	2	100	–	–	274	–	–

Analytical method: REE and Th by ICP-OES; U by fluorimetry.

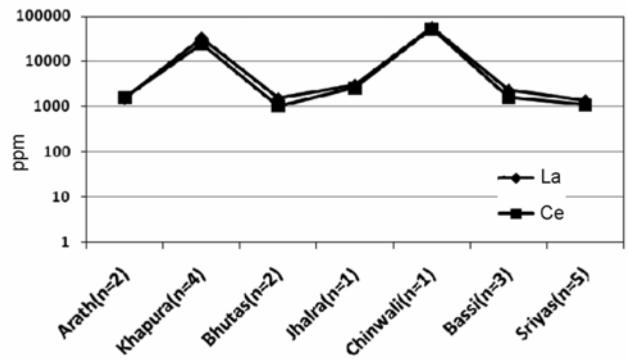

Figure 3. Plot showing relation between La and Ce.

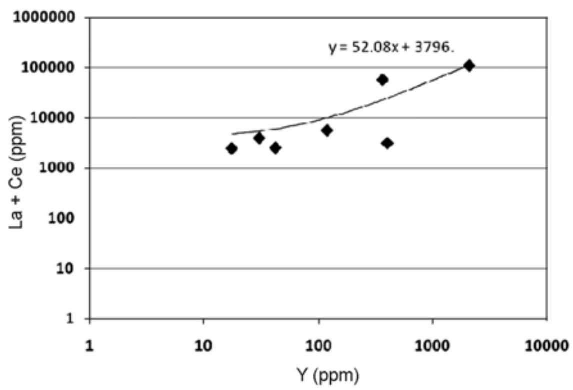

Figure 4. Plot showing Y versus (La + Ce).

0.03 to 0.80. High U/Th ratio of 0.80 for samples from Arath, indicates that U exploration may be feasible in this area.

Our studies carried out so far suggest that Karkeri–Bassi and Luni–Sukri tracts within the microclinite–pyroxenite–albitite zone may be a potential target for REE, Th and U exploration. This constitutes a new zone of REE mineralization, which is distinct from and parallel to the well-known albitite line of Rajasthan[9]. It assumes significance in suggesting that there may be other REE–Th–U mineralized zones in similar settings outside the albitite line in Rajasthan.

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Five-armed body fossil from the Ediacaran Jodhpur Sandstone, Marwar Supergroup, western Rajasthan, India: a possible precursor of phylum Echinodermata

The Jodhpur Sandstone is a prominent stratigraphic horizon of the Marwar Supergroup forming small hillocks in a desertic setting in western Rajasthan, which was earlier referred to as the Trans-Aravalli Vindhyans[1,2]. It is represented by fine to coarse-grained sandstone, pebbly sandstone, siltstone and shale, and attains a thickness of ca. 240 m. The rocks are unmetamorphosed and undeformed, and show well-preserved sedimentary structures, including cross-bedding, parallel bedding, wave and current ripple marks, and mud cracks. Argillaceous horizons occasionally show the presence of salt pseudomorph shales. These sandstones can be considered to be beach to coastal sand deposits formed in a moderate to high energy, shallow marine setting. The Jodhpur Sandstone has yielded well-preserved microbial mat structures, body fossils, microfossils and plant fossils[3–8].

The Marwar Supergroup has been subdivided into three groups; in stratigraphic order these are the Jodhpur Group, the Bilara Group and the Nagaur Group[2]. The Jodhpur Group has been further subdivided into the Pokaran Boulder Bed and the Jodhpur Sandstone (Table 1)[1]. The Jodhpur Sandstone includes both the Sonia Sandstone and the Girbhakar Sandstone[2]. The youngest of the Marwar Supergroup, the Nagaur Group, has yielded well-preserved trilobite trace fossils, *Cruziana* and *Rusophycus*[9,10] and on this basis a Lower Cambrian age has been assigned to the Nagaur Sandstone. The underlying Bilara Group, which represents basically a calcareous facies of the Marwar Supergroup, has been suggested to have the Precambrian/Cambrian boundary on the basis of carbon isotope data[11]. This implies that the Jodhpur Sandstone, which unconformably overlies the Malani Igneous Suite with radiometric age 779–681 Ma, should be younger than 681 Ma and

Table 1. Stratigraphic succession of the Marwar Supergroup (after Chauhan *et al.*[1] and Pareek[2])

Age	Supergroup	Group	Formation
Late Neoproterozoic to Early Cambrian	MARWAR SUPERGROUP	Nagaur Group (75–500 m)	Tunklian Sandstone Nagaur Sandstone
		Bilara Group (100–300 m)	Pondlo Dolomite Gotan Limestone Dhanapa Dolomite
		Jodhpur Group (125–240 m)	Jodhpur/Pokaran Sandstone Pokaran Boulder Bed
	~~ Unconformity ~~~~		
		Basement	Malani Rhyolite, Granite and Basalt