Recognition of a new albitite zone in northern Rajasthan: its implications on uranium mineralization

A number of albitite occurrences have been reported amidst Archaean basement and the Meso-Proterozoic cover rocks of Delhi Supergroup in north-central and northern Rajasthan. These occurrences form a linear zone about 130 km in length and 5–12 km in width from Neorana in the north to Nayagaon in the south. This zone has a regional NE–SW trend and occurs about 20–40 km east of known albitite line[1]. We report here a zone of albitite and albitized rocks in the Banded Gneissic Complex (BGC) around Bichun, Nayagaon, Asalpur and Dungarwara and amidst Delhi Supergroup rocks in the East Khetri basin around Chiplata, Sirsori ki Dhani, Ghasipura, Rela and Neorana. The delineated albitite occurrences are radioactive and some of them host significant uranium and REE, Y and Sc. These albitite occurrences represent a intracontinental rift zone parallel to the one established by Ray[1] and assume significance for exploration for uranium and other polymetallic minerals (REE, Y and Sc).

Albitite, a monomineralic rock mainly consisting of albite, has drawn much attention in the former USSR for many decades. In India, Ray[1] reported several albitite occurrences along narrow and linear zones interpreted as 'albitite line' in Khetri and Kishangarh areas of northern Rajasthan. Fareeduddin and Bose[2] also reported a parallel albitite zone about 30 km west of Ray's albitite line near Arath. These are emplaced in Delhi metasediments as well as in pre-Delhi rocks with sharp intrusive contacts and interpreted as the product of deep crustal magmatic processes along intracontinental rift zone. Initially reported as cumulous segregates along deep crustal lineaments, they are now considered to have a greater spread and are increasingly interpreted as related to syn to post-tectonic hydrothermal activity[1]. Albitites in Aravalli Fold Belt in South Rajasthan and in the rocks of Mangalwar Complex in south central Rajasthan have also been reported[3,4]. The Atomic Minerals Directorate for Exploration and Research (AMD) is engaged in uranium exploration in the albitite zone, which extends on the eastern part of the Khetri sub-basin in the North Delhi Fold Belt (NDFB) and along the contact of older basement rocks with the Delhi Supergroup in the South Delhi Fold Belt (SDFB) in Rajasthan. Widespread development of alkali metasomatites has been observed in the Proterozoic cover rocks and underlying crystalline massifs of Khetri sub-basin in the

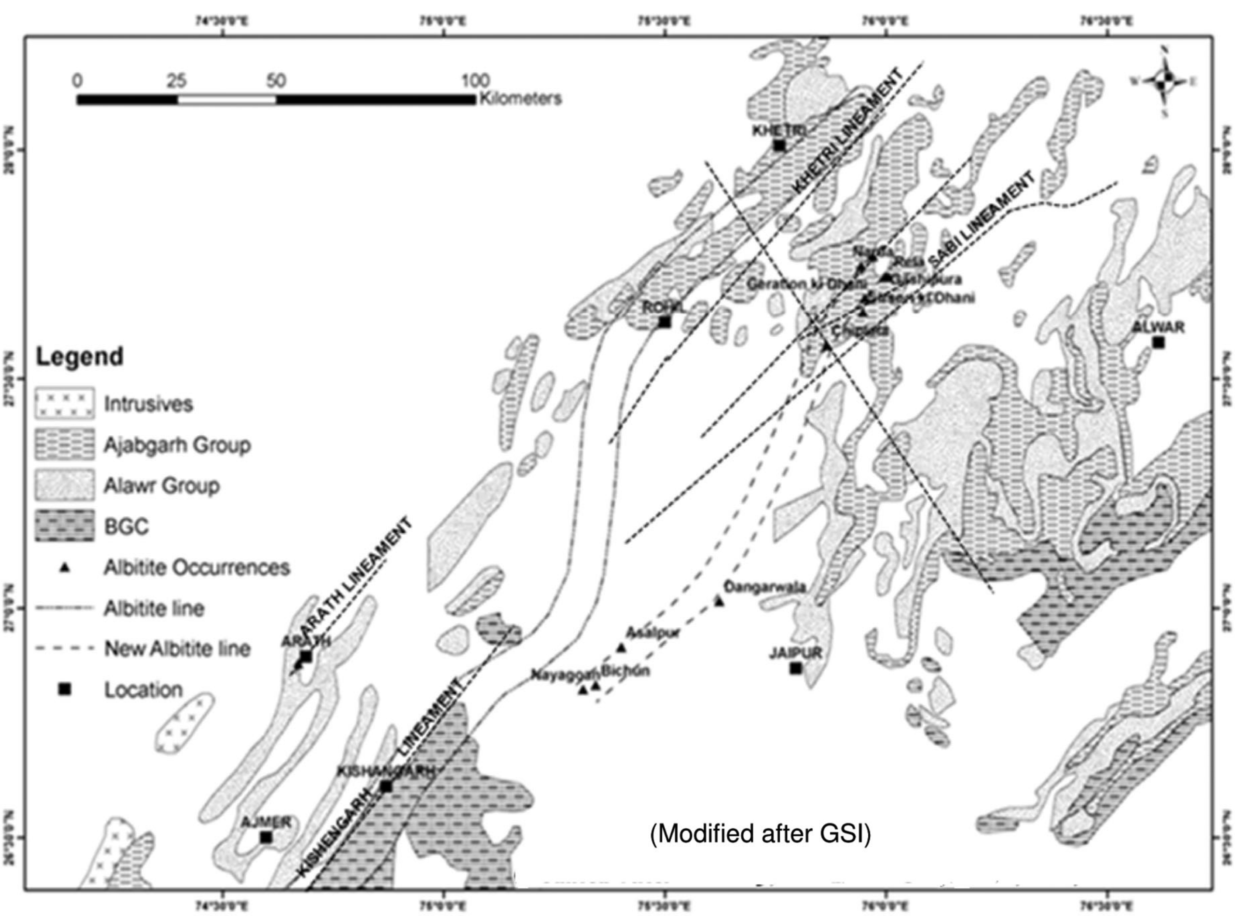

Figure 1. Geological map showing occurrence of albitite line in northern Rajasthan.

Table 1. Details of albitite occurrences

Location	Latitude/longitude	Dimension	Rock type	$\%U_3O_8$		$\%ThO_2$	
				From	To	From	To
Nayagaon	26°47′39.8″ 75°19′11.9″	1500 m × 2–50 m (n = 9)	Albitized granite gneiss	0.048	0.210	<0.010	<0.010
Bichun	26°49′41.3″ 75°20′41.6″	1700 m × 5–30 m (n = 20)	Albitite	<0.010	6.40	<0.010	0.280
Bichun village	26°47′37.3″ 75°20′47.9″	800 m × 5–50 m (n = 8)	Albitized granite gneiss	0.024	0.200	<0.010	<0.010
Asalpur	26°54′48.6″ 75°23′52.9″	1500 m × 2–5 m (n = 9)	Albitized quartzite	<0.010	0.045	0.022	0.280
Dangarwala	27°01′54.1″ 75°37′1.1″	70 m × 30 m (n = 4)	Albitite	<0.010	0.050	<0.010	0.036
Ciplata	27°34′24.6″ 75°51′52.4″	50 m × 2 m (n = 3)	Albitized pegmatite	0.100	0.200	0.015	0.150
Gashipura	27°43′28″ 75°59′56″	100 m × 2 m (n = 5)	Albitized impure marble	<0.010	0.300	<0.010	0.130
Rela	27°43′22″ 75°00′28″	450 m × 0.5–10 m (n = 6)	Albitized impure marble	0.079	0.140	<0.010	0.014

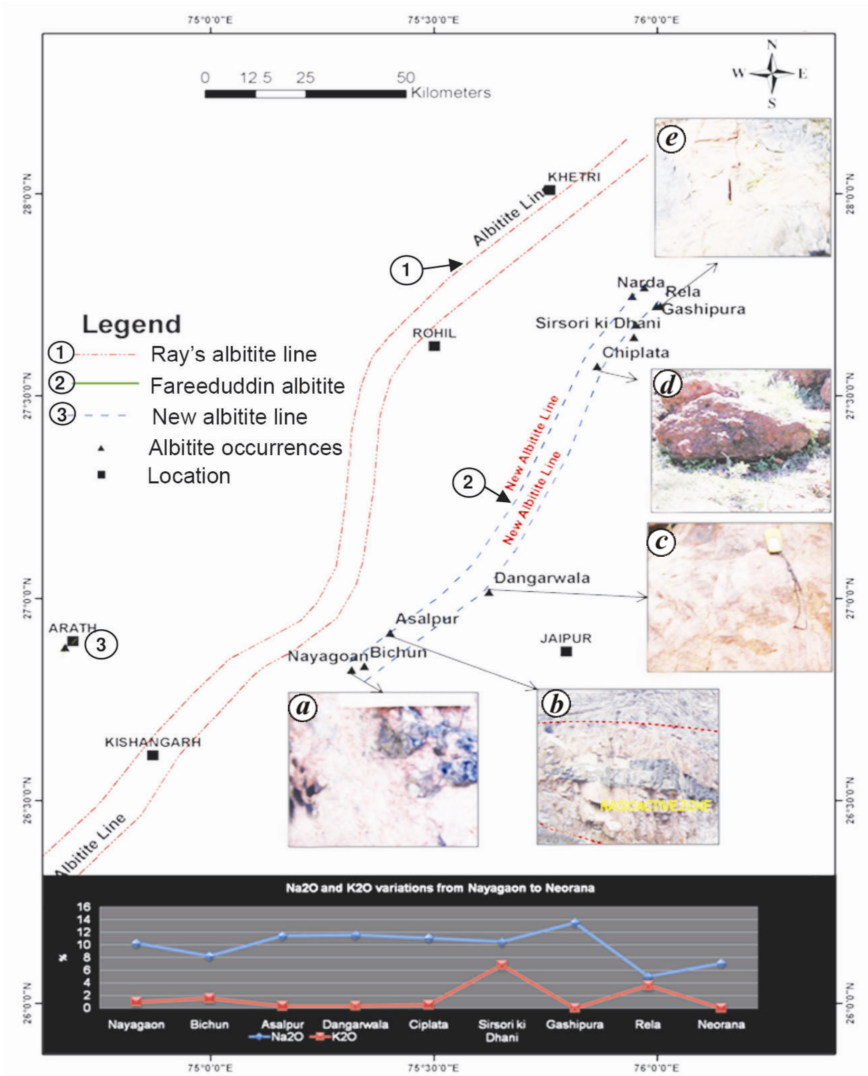

Figure 2. ***a***, Davidite-bearing albitite at Bichun. ***b***, BGC rock enclave in pink colour albitite at Asalpur. ***c***, Pink colour albitite at Dangarwada. ***d***, Brick red colour albitite at Chiplata. ***e***, Pink colour albitite intruding Delhi metasediments at Ghasipura.

NDFB[5]. Uranium investigation by AMD in the albitite zone of Khetri sub-basin has resulted in the identification of a medium-grade low-tonnage uranium deposit at Rohil[6]. In the albitite zone considered in this study, radioactive albitites have been reported earlier at Geratyon ki Dhani, where a parallel lineament was interpreted[7,8]. Albitite terrain of Rajasthan is also considered favourable for iron-ore–copper–gold (IOCG) mineralization[9].

In recent times, AMD has identified significant uraniferous albitite/albitized rocks with substantial concentrations of rare metal and rare earth elements (REE) in the BGC terrain around Bichun and Nayagaon[10] areas and elsewhere[11]. Further northeast, the albitite and albitized rocks occur around Asalpur and Dungarwara and thereafter, they are noticed around Chiplata, Sirsori ki Dhani, Ghasipura, Rela and Neorana in the Khetri basin of NDFB (Figure 1). These occurrences form a NE-SW trending zone and transgress various lithounits of the basement gneiss and Proterozoic cover rocks of Delhi Supergroup. They appear to be an ‘albitite zone’ parallel to the already known albitite line in northern Rajasthan (Figure 1). Here we elucidate geology, geochemistry, mineralogy and disposition of the albitite zone and its mineral potential in northern Rajasthan.

The study area in the southern part comprises BGC rocks consisting of granite gneiss, migmatite, amphibolite, quartzite with interlayered schist and phyllite traversed by numerous albitite/aplitic injections. The contact of Delhi

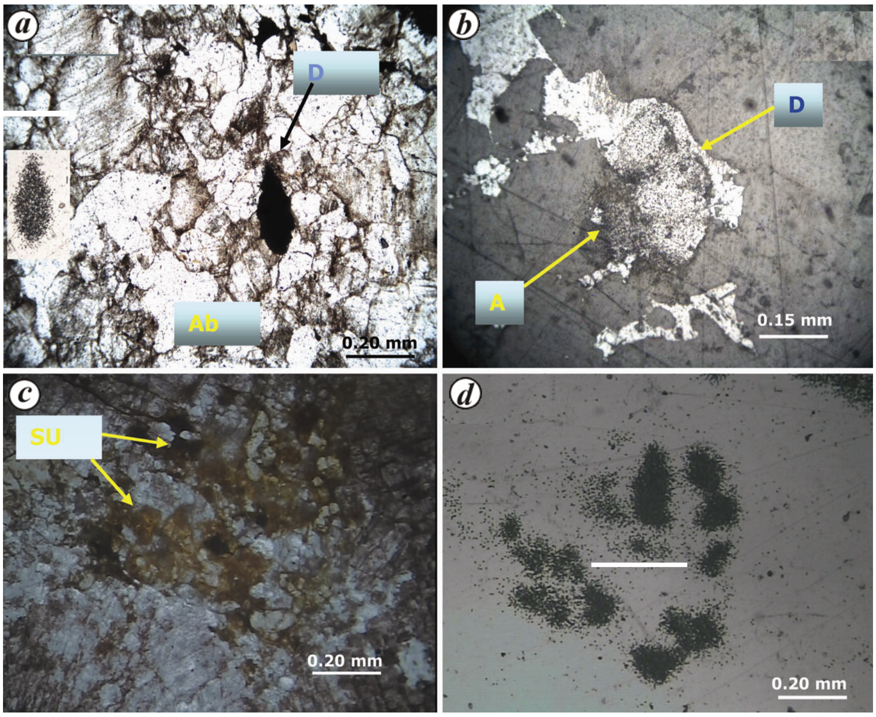

Figure 3. ***a***, Davidite (D) embedded in albite (Ab) grains in albitite of Bichun area. Note the brownish-red colour of albite. (Inset) Alpha tracks of davidite. Plane polarized under transmitted light. ***b***, Davidite (D) overlain by alpha tracks (A) on cellulose nitrate film with slight offset from Bichun area. Reflected, plane polarized light. ***c***, Secondary uranium minerals (SU) in albitite of Bichun area surrounded by aventurine albite. Transmitted plane polarized light. ***d***, High-density alpha tracks corresponding to secondary minerals of (***c***) transmitted plane polarized light.

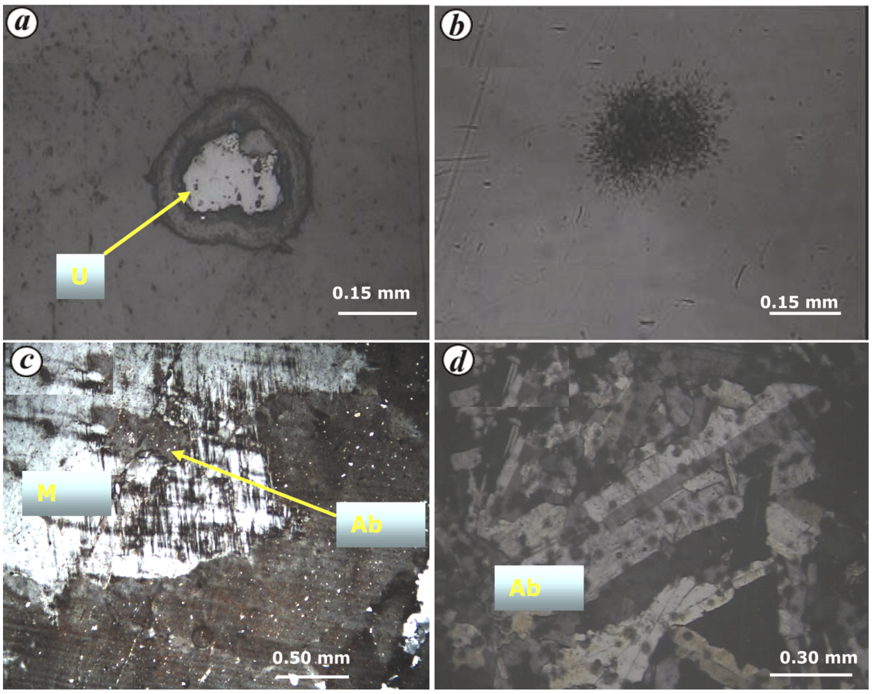

Figure 4. ***a***, Uraninite (U) as inclusion in biotite from Nayagaon area. Note the reaction rim around uraninite grain. Reflected plane polarized light. ***b***, High-density alpha tracks corresponding to uraninite of (***a***). ***c***, Microcline (M) being replaced by albite (Ab) in pegmatoid from Bichun area. Transmitted light under crossed nicols. ***d***, Randomly oriented laths of albite (Ab) in albitite of Ghasipura area transmitted light under crossed nicols.

metasediments with BGC is best exposed at Maurija, where Alwar Group overlies the basement rocks unconformably. Further north, the Mesoproterozoic cover rocks of Alwar and Ajabgarh Groups occur as linear to curvilinear ridges in the Khetri basin around Chiplata, Sirsori ki Dhani, Rela, Ghasipura, Neorana and Rayan ka Bas areas. The basin has witnessed a number of igneous activities in the form of granites, pegmatites, aplites and albitites.

Albitites in the study area occur as NNE–SSW, NE–SW and NW–SE trending bodies. These are light pink to flesh-red coloured, fine- to medium-grained intrusives parallel to or transecting the general trend of foliation of the country rocks. At places, they are pegmatitic and contain large lumps of disseminated radioactive crystals (Figure 2). The albitite and pegmatite occurrences coincide with the major lineaments such as Sabi and its parallel lineaments. The latter seems to be the northern extension of the Kaliguman lineament as deduced from the satellite imagery (Figure 1).

In the BGC terrain around Bichun, Nayagaon, Asalpur, Dangarwara albitite/albitized zones with sizeable dimensions were identified. Further NNE in the cover sequence, albitites were observed at a number of places around Chiplata, Sirsori ki Dhani, Rela, Ghasipura, Neorana and Rayan ka Bas areas in the Khetri basin. Most of these albitite occurrences are uraniferous, except the one at Asalpur where it is found to be thoriferous (Table 1). Significant uranium mineralization (up to 6.4% U_3O_8) with encouraging REE, Y and Sc were identified in association with albitized rocks of BGC terrain around Bichun, Nayagaon and Dangarwara. Apart from sodic albitites, numerous potash-rich aplitic bodies are also exposed around Ramsinghpura, Ryan ka Bas and Bhagwanpura, and some of them are found to be uraniferous.

Petrographic studies identified the uranium host rocks as albitite and albitized pegmatites in Bichun, albitized hornblende/biotite gneiss in Nayagaon, and albitite in Rela area. The albitite of Bichun area is fine-grained and is composed mainly of reddish coloured albite with minor amounts of quartz. The albite grains are subhedral to anhedral and very few of these have well-developed twin lamellae. Quartz occurs as fine to very fine-sized grains. Sphene, magnetite and ilmenite are accessory minerals.

Table 2. Major oxide analysis by XRF

Major oxide	SiO_2	TiO_2	Al_2O_3	Fe_2O_3 (T)	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
Fareeduddin	64.13	0.12	19.13	3.03	0.1	1.16	1.89	8.48	0.32	0.005
Ray's Alb. Line	65.35	0.49	17.98	3.21	0.07	0.31	1.06	7.36	3.14	0.005
Nayagaon	55.65	1.33	17.48	6.04	4.42	0.02	3.32	10.29	1.01	0.05
Bichun	65.23	1.63	17.06	3.46	1	0.01	1.58	8.26	1.56	0.05
Asalpur	66.78	<0.01	18.78	0.58	0.03	0.03	0.7	11.49	0.34	0.07
Dangarwala	65.19	0.73	18.92	0.43	0.005	0.005	1.12	11.61	0.38	0.1
Chiplata	67.61	0.005	18.8	0.45	0.06	0.005	0.03	11.11	0.54	0.2
Sirsori ki Dhani	57.87	1.23	21.23	0.45	0.11	0.01	0.25	10.5	6.83	0.22
Gashipura	60.3	0.35	19.47	4.08	0.08	0.005	0.38	13.55	0.005	0.67
Rela	39.91	0.3	12.13	3.06	6.59	0.13	10.78	5.01	3.6	0.16
Neorana	73.65	1.45	13.37	2.24	0.78	0.04	1.21	7.11	0.005	0.54

Table 3. CIPW normative minerals

Minerals	Nayagaon	Bichun	Asalpur	Dangarwara	Chiplata	Sirsori ki Dhani	Gashipura	Rela	Neorana
Q	0.00	8.53	0.00	0.00	1.05	0.00	0.00	0.00	31.15
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76
Or	5.97	9.22	2.01	2.25	3.19	40.36	0.03	19.18	0.03
Ab	56.50	69.89	93.33	89.58	93.69	29.22	77.84	0.00	60.16
An	0.00	4.86	0.00	0.00	0.00	0.00	0.00	0.00	2.48
Lc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	0.00
Ne	15.05	0.00	0.75	3.04	0.00	22.73	12.07	22.94	0.00
Ns	0.65	0.00	0.59	0.71	0.07	4.11	3.38	0.01	0.00
Di	11.43	0.05	0.27	0.03	0.00	0.00	0.00	22.81	0.00
Wo	1.38	0.34	1.12	0.98	0.00	0.00	0.00	11.16	0.00
Hy	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.10
Ol	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00
Il	2.53	2.14	0.00	0.01	0.01	0.24	0.17	0.57	1.67
Tn	0.00	1.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pf	0.00	0.00	0.00	1.23	0.00	0.00	0.00	0.00	0.00
Ru	0.00	0.00	0.00	0.00	0.00	1.11	0.26	0.00	0.57
Ap	0.12	0.12	0.17	0.24	0.05	0.45	0.68	0.38	1.28
Sum	93.63	96.40	98.22	98.07	98.18	98.23	94.44	78.70	98.19

Radioactive phases are mainly davidite, brannerite and secondary uranyl minerals. Fine-sized uraninite occurs in traces. Davidite occurs as subhedral fine-sized grains (Figure 3 *a*) and as lumps measured in centimetres. Medium-density alpha tracks are recorded on CN film over these randomly oriented grains (Figure 3 *b*). Secondary uranyl minerals occur as clusters of fine-sized flakes of greenish-yellow colour (Figure 3 *c*). High-density alpha tracks are recorded on CN film corresponding to these minerals (Figure 3 *d*). In albitized pegmatite, k-feldspar grains are being replaced by aventurine albite (Figure 4 *c*).

In Nayagaon area, partially albitized hornblende gneiss is the host. Quartz, microcline and albite–oligoclase are the major minerals, while biotite and hornblende are the minor minerals. Sphene, rutile and magnetite occur as accessory phase in these rocks. Biotite flakes are partially chloritized and some of these are kinked indicating later episode of deformation. Ferruginous and albititic material is present along interstitial grain spaces and minor fractures. The sources of radioactivity are davidite, brannerite, U–Ti–Fe complex and secondary uranyl minerals. Davidite is more abundant than brannerite. The latter occurs as anhedral, fine-sized specks and gives high-density alpha tracks on CN film. Davidite is also fine-sized and occurs as subhedral to anhedral grains. Uraninite occurs mainly as fine-sized inclusions within biotite and feldspar (Figure 4 *a* and *b*). Associated minerals are rutile, sphene and magnetite. XRD studies also confirmed that radioactivity is due to the presence of davidite with minor brannerite and uraninite.

In Rela and Ghasipura, the rocks hosting radioactivity are albitite and ferruginized impure marble. Also, marble is characterized by fine- to medium-sized calcite, secondary carbonates and minor quartz ± chert. Albitization is manifested by the presence of clusters of fine-sized albite grains along weak planes and in the interstitial grain spaces. Brannerite is the main contributor of radioactivity in these samples associated with U–Ti complex as amorphous phase. Brannerite occurs as fine to medium-sized, subhedral to anhedral grains in the micro-fractures and is surrounded by U–Ti complex. Albite occurs as fine to medium sized, randomly oriented laths exhibiting hypidiomorphic granular texture (Figure 4 *d*). Albite grains have sharp contacts and twinning is well developed in them.

Mineral composition of the albitite/albitized metasediments from Nayagaon to Neorana over a strike length of 130 km reflects enrichment of soda over potash. Representative samples from these areas ($n = 9$) indicate 5.01–13.55% Na_2O and <0.01–3.61% K_2O with Na_2O/K_2O ratio of 1.39 : 13.55. The molecular proportion of Al_2O_3 to ($Na_2O + K_2O$) and Al_2O_3 to ($CaO + Na_2O + K_2O$) indicates

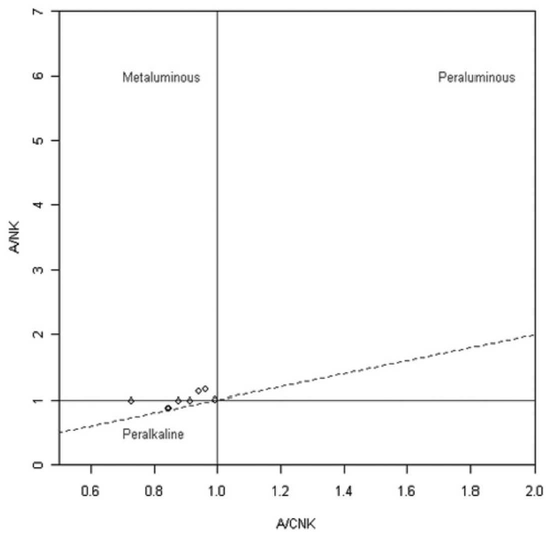

Figure 5. A/CNK–A/NK plot of albitite samples[13].

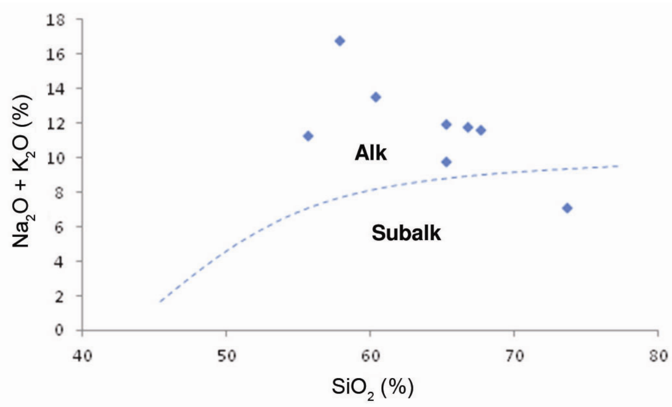

Figure 6. Alkali–silica diagram of albitite samples[14].

that the rocks are metaluminous to peralkaline in nature[12,13] (Figure 5). In the alkali–silica diagram of Miyashiro[14] (Figure 6), the albitite/albitized rocks mostly fall in the alkaline field, except one sample (Neorana) which falls in the sub-alkaline field. Despite higher silica content ranging from 59.36% to 73.65%, the albitite and related rocks show very low normative quartz. Letian[15] has observed that metasomatism of quartz-containing rocks always causes a reduction in silica content due to desilicification. One sample from Rela area indicates undersaturation (39.91% SiO_2), containing normative nepheline, leucite and diopside. In this sample, nepheline and leucite might have formed instead of albite and microcline due to the less silica availability. In general, CaO increases with decreasing Na_2O content, suggesting that soda metasomatism was accompanied by carbonate precipitation. Tables 2 and 3 list the major, minor and CIPW normative minerals of albitite and associated rocks.

Albitites are often associated with deep-seated fault systems and the sodium-rich solutions mobilized by metamorphic or anatectic process may be mixed with meteoric water or mantle-derived fluids. Many uranium deposits are known to occur in soda-rich rocks. The 'uraniferous albitite zone' defined here has geological and structural set-up akin to that of the albitite line[1], and therefore assumes significance for U–REE and other kinds of polymetallic mineralization.

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G. S. YADAV[1,*]
A. MUTHAMILSELVAN[2]
T. S. SHAJI[3]
L. K. NANDA[4]
A. K. RAI[4]

[1]*Atomic Minerals Directorate for Exploration and Research, Jamshedpur 831 002, India*
[2]*Center for Remote Sensing, Bharthidasan University, Tiruchirappalli 620 023, India*
[3]*Atomic Minerals Directorate for Exploration and Research, Thiruvananthpuram 659 012, India*
[4]*Atomic Minerals Directorate for Exploration and Research, Hyderabad 500 016, India*
**For correspondence.*
e-mail: gsyadav.amd@gov.in