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Ecandrewsite and zincian manganoan ilmenite from albitite veins of South Khetri Fold Belt, Rajasthan – implications in mineral search for basemetal-gold-uranium

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Ecandrewsite mineral occurs within albitite vein intruded within the Udaipurwati granite gneiss from South Khetri Belt (SKB), Rajasthan, India. Microprobe analysis of the ecandrewsite gave compositional range from $(\text{Zn}_{0.47}\text{Fe}_{0.34}\text{Mn}_{0.14})\text{Ti}_{1.01}\text{O}_3$ to $(\text{Zn}_{0.02}\text{Fe}_{0.78}\text{Mn}_{0.15})\text{Ti}_{1.01}\text{O}_3$ and is classified as ferroan manganoan ecandrewsite to zincian manganoan ilmenite. EPMA study reveals that the host rock consists of albite as major mineral constituent with some K-feldspar and chlorite as minor mineral constituents. The accessory minerals are sphene and ilmenite. On the basis of whole rock data, the albitite is classified as granite to syenite. The compositional variability within individual grains of ecandrewsite and other zinc bearing ilmenite suggests a replacement origin of the earlier formed magmatic mineral ilmenite. Core to rim enrichment of Zn content within ecandrewsite suggest that migration of Zn along the grain boundaries of ilmenite occurred through mantle derived alkaline fluids from outside the system along the deep seated fracture zones and micro-shears; thus, precipitating many other metals (Cu, Au, U, REE) along with Zn. This association of ecandrewsite within albitite may be used as an indicator mineral for search of copper, gold, uranium and REE in cratonic parts of India and elsewhere in a similar geological set up.

Introduction

Ecandrewsite is a zinc bearing ilmenite and the mineral was first described from the Broken Hill lode in 1970 (New South Wales; Brown et al., 1970). Birch et al. (1988) studied the mineralogical details through EPMA, petrography and X-ray diffraction studies of the type samples of ecandrewsite and associated minerals from Broken Hill. Mitchell and Liforovich (2004) reported this unusual zincian manganoan ilmenite mineral from agpaitic nepheline syenites of South Africa and described paragenesis of this rare ilmenite structured titanates. Modification in chemistry of primary ilmenite is reported from many areas where the original magmatic ilmenite is replaced by Mn-Zn

bearing ilmenite during later processes (Sakoma and Martin, 2002).

The host rock containing the herein reported ecandrewsite and zincian manganoan ilmenite is predominantly albitite having mainly Fe-Ti oxide studded albite (aventurine feldspar) with K-feldspar and chlorite as minor mineral constituents. Other accessory minerals are sphene and ilmenite. The occurrence of ecandrewsite and zincian manganoan ilmenite is not reported from the Khetri fold belt so far. The presence of this mineral is of importance because of its genetic implications with Cu-Au-U mineralisation in albitite as this mineral is found within undersaturated albitite associated with deep seated fracture zones within the ultramafic-mafic dominated basement in NW Indian craton. We report a new occurrence of ecandrewsite and zincian manganoan ilmenite from albitite veins intruded within Udaipurwati granite gneiss (Fig. 1) from South Khetri Fold Belt (SKB) having a variable empirical composition from $(\text{Zn}_{0.47}\text{Fe}_{0.34}\text{Mn}_{0.14})\text{Ti}_{1.01}\text{O}_3$ to $(\text{Zn}_{0.02}\text{Fe}_{0.78}\text{Mn}_{0.15})\text{Ti}_{1.01}\text{O}_3$, and its significance in mineral search in similar geological set up elsewhere.

Geological Setting

The Proterozoic Khetri fold Belt containing copper deposit in northern Rajasthan is cut across by a NW-SE trending Kantli fault into two halves; the North Khetri fold Belt and the South Khetri fold Belt. Both the belts show separate basement-cover relationship. The North Khetri fold belt is dominated by argillaceous-arenaceous facies rocks intruded by several granitic bodies, whereas the South Khetri fold Belt is dominated by felsic volcano-sedimentary rocks with plutonic granitic bodies such as Udaipurwati granite gneiss, Chhapoli granite, Seoli granite, etc. (Gupta et al., 1998). Occurrence of albitite in the Khetri fold Belt (Northern Rajasthan) defines a prominent crustal-scale linear petro-tectonic feature (Fig. 1), known as 'Albitite Line' which was first reported by Ray (1987, 1989 and 1990). The NNE-SSW trending albitite zone cuts across the Delhi and pre-Delhi rocks in the Khetri fold belt (KFB) (also known as Khetri copper belt (KCB) because of it containing known deposits of copper) and south of it, and broadly lies parallel to the trend of the Delhi orogeny. Before Ray (1987) it was called as aplite by Dasgupta, S.P. (1968). Ray (1990) further described this 'Albitite Line' as a fossil intracontinental

Figure 1.

Figure 2.

Figures 1 (left) and 2 (right). Generalised geological map of the Khetri Fold Belt (KFB; after Dasgupta, 1968), showing location of albitite vein containing ecandrewsite. Dashed lines containing dots represent 'albitite line' of Ray (1990). 1 – albitite, 2 – granite gneiss, 3 – Ajabgarh Group, 4 – Alwar Group. Field photograph of pink coloured albitite veins containing ecandrewsite, within Udaipurwati granite gneiss.

tal rift zone. The majority of albitite occurrence was reported in the South Khetri fold belt where it occurs as vein, dykes and medium sized plugs associated with mafic, ultramafic and pelitic rocks along shear zones and deep seated fractures. During present work, we found small veins of albitite intruded within the Udaipurwati granite gneiss (Fig. 2) which lies 6 km west of 'Albitite line' in the SKB. Such albitite bodies 30 km west of the 'Albitite line' of Ray (op. cit.) are also reported from Arath area (Nagaur district) of NW Indian craton by Fareeduddin and Bose (1992) possibly indicating that the albitites do occur within the cratonic terrane away from the known 'Albitite line'. Occurrence of magnetite, ilmenite, chalcopyrite, pyrite and uraninite is reported from albitite by many other workers (Yadav et al., 2015) from KCB and the basement rocks (Banded gneissic complex, BGC) of Rajasthan. Guha and Mohanty (1994) reported albitite intruded within gneisses of the Mangalwar Complex (Bhilwara Supergroup, BSG) from Siana-Kajiwara area, farther away in this craton. Albitite is deep pink to brick red colour, composed of iron studded albite as major mineral, orthoclase and quartz as minor mineral and associated minerals are sphene, magnetite and ilmenite.

Dataset and Sample Collection

Total 21 samples were collected from different albitite bodies of SKB for major oxide, trace elements and REE analysis. 9 samples of albitite were collected from large dykes of the major albitite zone between Saladipura and Guhala (Fig. 1), and 12 samples were collected from the thin veins of albitite rock intruded within the Udaipurwati granite (Fig. 1). All the 21 samples were collected from fresh albitite rocks as grab samples which were not altered by weathering or later metasomatic alterations. For petrography 6 thin sections were studied from out of these 21 samples, and out of 6 samples studied by petrography, electron microprobe analysis were carried out for two samples which contained bigger grains of ilmenite as seen through petrographical study. For petrochemical studies, all samples thus collected have been analysed through XRF (for major oxides and trace elements) and ICPMS (for REE).

Analytical Methods

Electron microprobe analyses were carried out with a CAMECA, SX-100 microprobe at EPMA lab., Faridabad, GSI using an accelerating voltage of 15 kV and a sample current of 10 nA. The beam size is 1 μ and PIP correction factor was applied. X-ray fluorescence analyses for major oxide, trace elements and ICPMS analyses for rare earth elements (REE) were performed at Chemical laboratory GSI, WR, Jaipur, Rajasthan. The whole rock analysis through XRF was carried out to determine petrochemical variations in respect of samples collected from different bodies as explained earlier. The REE analysis through ICPMS was carried out to know anomalous values of REE for their petrogenetic correlations as the samples were collected from different bodies. EPMA of two samples were carried out to know the specific mineral composition of silicate and oxide minerals present in albitite rock of the area studied. XRD analysis was done to validate the EPMA data and also to know whether any other ilmenite bearing albitite sample also con-

tained zirconian ilmenite.

Petrography and Mineral Chemistry

In hand specimen albitite, containing ecandrewsite, is dark red to brick red in colour with dirty appearance. Under microscope it looks like a stained rock in the plane as well as cross polarised light and very difficult to identify the silicate minerals. However, albite the main constituent of this rock is iron studded albite with brown, cloudy appearance.

Ecandrewsite is brown to yellowish brown in colour (Fig. 3) in transmitted light and in reflected light, it is greyish white in colour (Fig. 4). Reflection pleochroism is weak but the mineral is strongly anisotropic with colours changing from greenish grey to dark brownish grey. Neither cleavage nor twinning is observed in thin polished section. Mineral phase analysis through Electron probe micro analyser (EPMA) study reveals that the albitite consists of albite as major mineral constituent with some K-feldspar and chlorite as minor min-

Figure 3. Photomicrograph of ecandrewsite in transmitted plane polarised light.

Figure 4. Photomicrograph of ecandrewsite in reflected plane polarised light.

Table 1. Electron microprobe analysis data of Ecandrewsite and Zincian manganian ilmenite (wt%)

Point no.	TiO ₂	FeO	ZnO	MnO	Total
1	51.052	15.489	24.318	6.622	97.481
2	49.584	17.94	19.38	6.249	93.153
3	51.165	35.518	1.383	6.743	94.809
4	60.036	18.714	6.638	1.095	86.483
5	50.491	21.869	16.663	5.913	94.936
6	47.306	21.293	16.051	6.015	90.665
7	56.875	19.057	6.435	1.309	83.676
8	49.852	15.714	22.485	6.248	94.299
9	49.952	37.401	5.17	3.14	95.663
Cations calculated on the basis of 3 oxygen atoms					
	Ti	Fe	Zn	Mn	
1	1.01	0.34	0.47	0.14	
2	1.02	0.41	0.49	0.14	
3	1.01	0.78	0.02	0.15	
4	1.2	0.41	0.13	0.02	
5	1.02	0.49	0.33	0.13	
6	1.007	0.5	0.33	0.14	
7	1.19	0.44	0.13	0.03	
8	1.02	0.35	0.45	0.14	
9	0.99	0.83	0.1	0.07	

Formula on the basis of 3 oxygen atoms are as follows:

Figure 5. BSE image of ecandrewsite, the numbers in the image are the points which were analysed.

Figure 6. BSE image of zincian manganian ilmenite, the numbers in the image are the points which were analysed.

Figure 7. Classification of ecandrewsite and zinc bearing ilmenite in triangular diagram with three end members ZnTiO₃-FeTiO₃-MnTiO₃ after Mitchell and Liferovich (2004).

Figure 8. Classification of feldspars after calculating cations of albitite.

Table 2. Major oxide (wt%), trace elements (ppm), REE data (ppm) and normative minerals of albitite dykes from Saladipura-Guhala area

	BRS-12	BRS-13	BRS-14	BRS-18	BRS-25	BRS-26	BRS-27	BRS-28	BRS-29
SiO ₂	70.88	62.07	76.96	71.44	72.89	74.96	63.58	76.26	75.84
Al ₂ O ₃	10.94	14.49	10.75	12.63	11.61	11.6	14.83	11.44	9.77
Fe ₂ O ₃	2.96	8.62	0.86	1.18	2.18	1.3	4.7	2.17	1.8
MnO	0.02	0.04	0.01	0.06	0.01	0.01	0.07	0.01	0.01
MgO	0.44	0.91	0.25	0.29	0.11	0.28	2.63	0.37	0.11
CaO	2.43	1.71	1.08	1.39	2.37	0.34	2.25	0.35	0.92
Na ₂ O	6.56	1.7	5.81	7.66	8.43	8.79	8.91	7.38	6.43
K ₂ O	0.05	4.19	0.35	0.03	0.01	0.01	0.04	0.01	0.01
TiO ₂	0.49	0.88	0.07	0.56	0.33	0.17	1.14	0.39	0.33
P ₂ O ₅	0.26	0.27	0.25	0.34	0.02	0.09	0.05	0.1	0.11
Ba	2169	942	< 50	133	116	< 50	163	230	180
Ga	13	14	2	20	17	21	21	11	6
Sc	10	17	6	16	12	6	22	12	12
V	33	83	14	25	24	17	70	27	23
Th	139	76	12	34	32	27	27	42	36
Pb	7	8	< 5	4	< 5	8	14	< 5	< 5
Ni	14	11	7	12	8	7	132	6	6
Co	8	16	8	5	14	< 5	76	9	7
Rb	17	181	35	16	12	11	15	15	15
Cr	42	10	< 5	5	13	11	172	22	6
Sr	59	107	110	37	22	23	38	21	22
Zr	485	740	40	415	493	446	180	169	220
Nb	5	39	< 5	15	14	< 5	19	6	5
Cu	2	28	20	13	18	35	459	34	26
Zn	19	36	16	39	34	34	418	37	31
Y	86.97	135.38	9.61	69.04	35.10	10.24	40.58	24.60	27.71
U	5.45	4.72	2.98	3.46	6.40	7.99	8.98	15.73	13.32
La	1977.74	233.04	48.13	167.00	123.80	53.73	69.67	114.20	143.30
Ce	2593.74	421.36	56.48	193.30	209.00	94.86	138.20	313.20	242.10
Pr	237.29	51.16	4.69	28.76	19.50	8.61	11.64	17.74	20.83
Nd	878.01	190.32	15.95	107.40	66.90	28.43	41.82	56.57	67.49
Sm	87.02	33.04	2.48	17.10	8.90	3.65	7.17	8.37	8.77
Eu	9.07	4.56	0.94	2.44	1.80	0.67	1.25	1.23	1.16
Gd	60.94	28.29	2.40	15.08	7.59	3.11	7.07	7.57	7.71
Tb	5.45	4.91	0.39	2.42	1.11	0.38	1.20	1.04	1.05
Dy	14.26	25.74	1.98	12.48	5.47	1.82	6.92	5.08	5.25
Ho	2.30	5.52	0.39	2.69	1.26	0.38	1.50	1.03	1.11
Er	7.10	15.32	1.07	7.33	3.57	1.14	4.23	2.79	3.05
Tm	0.70	2.30	0.17	1.12	0.56	0.18	0.65	0.43	0.44
Yb	4.42	14.64	1.19	6.96	3.61	1.19	3.97	2.70	2.82
Lu	0.64	2.07	0.16	0.98	0.52	0.20	0.55	0.37	0.40

Table 2. (continued)

Normative minerals									
	BRS-12	BRS-13	BRS-14	BRS-18	BRS-25	BRS-26	BRS-27	BRS-28	BRS-29
Q	29.583	31.886	40.170	25.332	25.367	30.131	5.264	33.348	38.371
C	0.000	4.695	0	0	0	0	0	0	0
Or	0.295	24.762	2.068	0.177	0.059	0.059	0.236	0.059	0.059
Ab	55.509	14.385	49.163	64.797	59.662	59.610	75.394	58.787	50.197
An	0.257	6.720	2.219	0	0	0	0.352	0	0
Ne	0	0	0	0	0	0	0	0	0
Ac	0	0	0	0.018	6.307	3.761	0	3.225	3.710
Ns	0	0	0	0	1.050	2.444	0	0	0
Di	2.364	0	1.013	1.558	0.591	0.425	5.283	0	0.591
Wo	2.269	0	0	0.400	4.074	0	0	0	0.825
Hy	0	2.267	0.153	0	0	0.500	4.102	0.922	0
Ol	0	0	0	0	0	0	0	0	0
Il	0.043	0.086	0.021	0.128	0.021	0.021	0.150	0.021	0.021
Hm	2.960	8.620	0.860	1.174	0	0	4.700	1.055	0.518
Tn	1.148	0	0.144	1.209	0.782	0.390	2.605	0.763	0.782
Pf	0	0	0	0	0	0	0	0	0
Ru	0	0.835	0	0	0	0	0	0.068	0
Ap	0.616	0.640	0.592	0.805	0.047	0.213	0.118	0.237	0.261
Sum	95.044	94.895	96.403	95.599	97.961	97.555	98.204	98.485	95.336

eral constituents. The accessory minerals are sphene and ilmenite. Ecanndrewsite present in albitite is associated with zincian manganian ilmenite and they both are surrounded by sphene. EPMA results of ecanndrewsite are given in the (Table 1). Zinc contents (Table 1, Figs. 5 and 6) are variable with maximum record being 24%. The empirical formulae, based on 3 oxygen atoms, are also shown in Table 1. After calculating mineral formula, the minerals are classified in triangular diagram with three end members (Fig. 7). Considering the ideal formula for ecanndrewsite as ZnTiO_3 , the composition ranges from $(\text{Zn}_{0.47} \text{Fe}_{0.34} \text{Mn}_{0.14}) \text{Ti}_{1.01}\text{O}_3$ to $(\text{Zn}_{0.02} \text{Fe}_{0.78} \text{Mn}_{0.15}) \text{Ti}_{1.01}\text{O}_3$, and hence, they are ferroan manganian ecanndrewsite to zincian manganian ilmenite. The EPMA analyses of the other silicate minerals are given in the Table 2. The analyzed feldspar and chlorites were plotted in mineral classification diagrams. Majority of the feldspar are albite (Fig. 8) having compositional ranges $\text{Ab}_{99.6} \text{An}_{0.1} \text{Or}_{0.3}$ to $\text{Ab}_{95.6} \text{An}_{3.9} \text{Or}_{0.5}$ with very minor orthoclase. Chlorites are classified as pseudothuringite (Fig. 9).

Figure 9. Classification of chlorite as pseudothuringite after calculating cations.

Table 3. Major oxide (wt%), trace elements (ppm), REE data (ppm) normative minerals of thin veins of albitite intruded within Udaipurwati granite

	BRS-4	BRS-46	BRS-47	BRS-86	BRS-90	BRS-91	BRS-92	BRS-100	BRS-101	BRS-102	BRS-103	BRS-84
SiO ₂	77.64	71.25	68.4	72.1	67.53	60.61	74.36	72.95	60.23	64.55	56.13	72.12
Al ₂ O ₃	11.43	11.68	13.92	14.21	16.11	18.34	13.34	13.37	14.47	13.88	21.59	14.41
Fe ₂ O ₃	0.86	3.99	4.48	1.24	2.12	4.56	0.47	1.88	2.62	2.08	2.62	1.3
MnO	0.03	0.03	0.05	0.02	0.03	0.04	0	0.02	0.03	0.03	0.1	0.02
MgO	0.11	0.4	0.44	0.19	0.16	0.37	0.03	0.33	3.35	2.38	0.31	0.2
CaO	0.48	0.84	1.09	0.43	0.56	0.38	0.18	0.36	4.92	4.56	0.74	0.44
Na ₂ O	5.33	2.83	3.60	7.26	7.26	9.46	8.44	4.39	9.3	8.88	11.28	7.44
K ₂ O	1.03	5.85	5.33	2.29	3.87	2.62	1.39	3.92	0.25	0.27	1.13	2.34
TiO ₂	0.27	0.38	0.46	0.08	0.33	0.48	0.25	0.43	0.67	0.66	0.49	0.08
P ₂ O ₅	0.08	0.08	0.13	0.04	0.11	0.03	0.03	0.09	0.12	0.11	0.17	0.04
Ba	50	350	367	24	383	157	42	410	17	67	238	26
Ga	23	30	34	24	6	5	7	5	19	12	31	26
Sc	5	6	7	3	3	7	5	6	20	14	10	4
V	14	34	40	15	24	39	17	25	34	32	29	15
Th	92	92	116	77	96	81	102	85	21	18	92	77
Pb	< 2	37	53	31	35	30	5	13	7	5	31	37
Ni	8	16	17	12	14	13	5	13	40	32	14	12
Co	17	26	26	19	19	14	8	15	17	16	13	20
Rb	47	311	322	92	231	118	38	168	18	19	56	94
Cr	< 5	< 15	< 15	< 5	< 5	< 5	< 5	< 5	70	62	< 5	< 5
Sr	34	27	36	14	87	56	14	73	8	14	77	16
Zr	395	353	444	378	660	410	290	457	197	193	706	387
Nb	15	27	38	47	13	8	< 5	10	8	6	18	51
Cu	18	13	10	23	1129	846	7	21	9	14	20	25
Zn	13	20	42	30	59	147	12	11	20	23	19	30
Y	47.3315	83.7505	129.8468	64.9064	35.4044	35.0653	13.8892	64.7955	26.496	29.6307	22.5875	80.5626
U	13.5019	23.8973	13.9364	78.6425	12.4444	12.7403	4.5164	14.9985	3.0552	3.0754	2.1289	88.1412
La	333.8817	104.9958	101.6811	13.3387	26.9023	11.904	9.0593	79.9325	43.3793	80.5753	33.0515	14.8409
Ce	473.6367	199.3189	206.1465	16.2868	60.0364	29.0596	26.2992	153.6767	110.1687	159.8011	93.3079	17.3756
Pr	48.707	21.3463	23.0739	2.7204	4.7093	2.204	1.9055	14.2569	9.4158	17.1025	7.9974	3.7371
Nd	166.8479	79.2532	89.2223	11.9451	17.202	8.5812	6.852	52.1876	34.5522	64.0502	29.4054	16.4185
Sm	25.2098	14.7661	18.5844	4.296	3.6908	2.2036	1.3487	10.5229	5.8968	10.2616	4.8465	5.8315
Eu	4.0533	1.5973	1.6408	0.3865	0.9967	0.7759	0.165	2.1375	1.2861	2.1799	1.0912	0.5541
Gd	20.6259	14.0402	18.0641	4.9456	3.7047	2.4328	1.4351	9.8418	5.0251	8.0105	4.2661	6.6073
Tb	2.6457	2.6076	3.6578	1.4937	0.8093	0.618	0.3098	1.9034	0.8338	1.1667	0.7001	2.1645
Dy	9.8925	14.7567	21.7941	11.3967	5.1267	4.4818	2.1491	11.6517	4.6862	5.5034	3.8848	14.7296
Ho	1.8306	3.1761	5.015	2.8856	1.2444	1.2275	0.5184	2.6671	1.0024	1.1548	0.8597	3.6338
Er	5.1167	9.2247	14.4437	9.1647	3.6718	3.9102	1.4793	7.4372	2.8293	3.2394	2.4406	10.2959
Tm	0.7312	1.4615	2.4292	1.84	0.6495	0.7454	0.2478	1.2708	0.4323	0.4815	0.3839	2.3585
Yb	4.5178	9.1866	15.1304	13.1375	4.1781	4.9339	1.5258	7.8969	2.722	2.9932	2.3231	17.6225
Lu	0.6294	1.2832	2.1148	1.9331	0.5725	0.7076	0.2284	1.0741	0.38	0.3909	0.3197	2.5427

Table 3. (continued)

Normative mineralogy												
	BRS-04	BRS-46	BRS-47	BRS-86	BRS-90	BRS-91	BRS-92	BRS-100	BRS-101	BRS-102	BRS-103	BRS-84
Q	41.728	30.608	24.436	20.669	9.833	0	25.260	31.403	0	4.789	0	19.602
C	0.866	0.000	0.558	0	0	0	0	1.466	0	0	0.872	0
Or	6.087	34.572	31.499	13.533	22.870	15.483	8.214	23.166	1.477	1.596	6.678	13.829
Ab	45.101	23.947	30.462	60.341	61.317	69.478	60.877	37.147	66.582	69.890	62.403	61.091
An	1.859	1.888	4.558	0	0	0	0	1.198	0	0	2.561	0
Ne	0	0	0	0	0	5.563	0	0	3.496	0	17.901	0
Ac	0	0	0	0.961	0.102	0.266	1.360	0	4.984	4.625	0	1.642
Ns	0	0	0	0	0	0	2.094	0	0	0	0	0
Di	0	0.428	0	1.021	0.800	0.135	0	0	16.664	12.788	0	1.075
Wo	0	0	0	0.150	0	0	0	0	0	1.376	0	0.142
Hy	0.274	0.798	1.096	0	0.028	0	0.075	0.822	0	0	0	0
Ol	0	0	0	0	0	0.602	0	0	0.434	0	0.541	0
Il	0.064	0.064	0.107	0.043	0.064	0.086	0	0.043	0.064	0.064	0.214	0.043
Hm	0.860	3.990	4.480	0.908	2.085	4.468	0	1.880	0.897	0.481	2.620	0.732
Tn	0	0.850	0	0.141	0.727	0	0.491	0	0	1.537	0	0.141
Pf	0	0	0	0	0	0.741	0	0	1.083	0	0	0
Ru	0.236	0	0.404	0	0	0	0.050	0.408	0	0	0.378	0
Ap	0.189	0.189	0.308	0.095	0.261	0.071	0.071	0.213	0.284	0.261	0.403	0.095
Sum	97.265	97.335	97.908	97.862	98.086	96.892	98.492	97.745	95.967	94.406	94.570	98.392

Figure 10. Total alkali vs. silica (TAS) diagram of selected samples of albitite. Red squares are samples from Udaipurwati granite gneiss and black dots are samples from Saladipura-Guhala area.

Geochemistry

Whole rock chemistry data reveals (Tables 2 and 3) that the albitite samples have variable silica and CaO content, low MgO, TiO_2 , very low MnO and P_2O_5 . Average $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio is 0.01 indicating that soda content is higher than potash. In CIPW norm, normative acmite appears in maximum numbers of samples which also indicate hypersodic nature of the albitite. The chemical data also reveals that the albitite veins intruded within Udaipurwati granite gneiss is relatively silica poor than the albitites of Saladipura-Guhala area. In some samples from the veins of Udaipurwati granite gneiss, normative nepheline and olivine appears, indicating silica undersaturated nature. High K_2O content in some samples of the Udaipurwati granite gneiss, compared to the general low-K nature of the majority of the samples of both the areas is possibly due to contamination by host granite country rock during emplacement of albitite within Udaipurwati granite gneiss. Molar proportion of Al_2O_3 to $\text{K}_2\text{O} + \text{Na}_2\text{O}$ indicates the albitites are metaluminous to peralkaline. In SiO_2 vs. $\text{K}_2\text{O} + \text{Na}_2\text{O}$ diagram (Fig. 10; after Cox et al., 1979) the majority of the samples from the Udaipurwati granite gneiss falls in alkaline

Figure 11. Chondrite normalised REE pattern of albitite (after Nakamura, 1974).

field and classified as syenite to granite whereas the samples from the Saladipura–Guhala area falls in the subalkaline field and classified as granite to diorite.

The REE data (Tables 2 and 3) of the albitite and their chondrite normalized pattern (Fig. 11) show variable degree of REE fractionation, indicated by the ratio $La_N/Yb_N = 0.56$ to 298.30. Both LREE and HREE fractionation are more and variable, indicated by the ratios of $La_N/Sm_N = 1.57$ to 13.98 and $Ce_N/Sm_N = 0.70$ to 8.78. Out of twenty one samples, nineteen samples show negative Eu (Eu/Eu^* value ranging from 0.26 to 0.83) anomaly, indicating plagioclase fractionation at source which is further supported by less amount of CaO and crystallisation in reducing environment. The geochemical data of albitites of both the areas (Saladipura-Guhala and Udaipurwati granite gneiss) indicate that they are cogenetic in nature.

Discussion and Conclusions

Compositional variability of ecandrewsite from ferroan manganous ecandrewsite to zincian manganous ilmenite and their mineral association suggests that they were formed due to replacement of primary magmatic minerals of ilmenite group. The compositional variability within individual mineral grains probably reflects the changes in the alkalinity of the fluid involved. The variations of the soda content shown by appearance of normative acmite, but absence of any sodic amphibole or sodic pyroxene within the albitite indicate involvement

of soda rich fluid from outside the system. Core to rim enrichment of Zn content within ecandrewsite grains also indicate replacement of zinc in later stage. Tables 2 and 3 indicate enrichment of Cu, U and REE in the samples of albitite, and the KFB is an established copper producing area in Rajasthan (Ray, 2004). Therefore, it may be possible that along with soda and Zn, many other metals (Cu, Au, U, REE) migrated through mantle derived fluids from outside the system along the deep seated fracture zones ('intracontinental rift' of Ray, 1990) envisaged for the emplacement of the albitites. Zn specially migrated along the grain boundaries of ilmenite through an alkaline fluid along micro-shear zones in the rock and precipitated the element along the grain boundary towards core part by replacing the already existing ilmenite grains in the albitite. This is reflected in core to rim enrichment of Zn content (Table 1, Figs. 5 and 6) within ecandrewsite grains. Occurrence of ecandrewsite, thus, suggest a petrotectonic significance wherein the migration of elements (Zn, Cu-Au-U, REE) took place through the major deep seated fractures and associated micro-shears generated during the Proterozoic Khetri fold belt development and emplacement of the Udaipurwati granite pluton. Introduction of Zn from outside ilmenite also indicate possibility of accumulation of other compatible metals associated with Zn, like Cu, Pb, Au and also U and REE. This unusual mineral found in the albitite within Udaipurwati granite gneiss may also be an indicator mineral for search of Cu-Au-U and REE metals within the granite gneiss country and possibly diamond within the ultramafic–mafic rock dominated basement part of the KFB. This unusual mineral association of ecandrewsite with ilmenite

may also be looked into other areas of similar geological set up within NW Indian craton and elsewhere in the world for search of base metals, gold, Uranium and REE of importance.

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