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Fenitized pre-carbonatite Deccan basalts in and around the carbonatite diatreme of Amba Dongar, Gujarat, Western India

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ABSTRACT

The late Cretaceous carbonatite-nephelinite diatreme at Amba Dongar area in western India intrude into the sedimentary Bagh beds overlain by Deccan basalt sequence. Being situated on the western periphery of the Deccan flood basalt, the thickness of basalt cover is thin. Basalt (pre-carbonatite) covers the large part of the ring complex in the outer periphery while in the central part of the ring structure thin basalt cover of the pre-doming topography has been preserved. Fragments of this basalt are caught up in the carbonatite breccia rimming central basalt. Large number of post-carbonatite basalt and dolerite dikes intrude in to central basalt, carbonatite breccia and sövite. Pre-carbonatite Deccan basalt shows widespread fenitization effects induced by the emanation from carbonatite magma which resulted into replacement of pyroxene by calcite in these basalts. As a result, the basalt has acquired a composition of 'plagioclase-calcite' rocks. Chemically the fenitized basalts show increase in Si, K, Fe, Fe and CO_2, Ba, Sr, Rb, and REE and decrease in Mg and Al. Na decreases in some fenitized basalts wherein plagioclase has been replaced by calcite. With help of major, trace and REE geochemistry the changes brought about in the pre-carbonatite basalt are presented and discussed.

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1. Introduction

The late Cretaceous Amba Dongar carbonatite-alkaline ring complex is located in the western periphery of the Deccan Basalt Province, in India. It cuts through the Precambrian basement, Cretaceous Bagh sedimentary beds (sandstone-limestone sequence) and overlying basalts. Basalts of this region have been classified as both pre-carbonatite and post-carbonatite. The pre-carbonatite Deccan basalt occupies the large part of the complex in the outer periphery and small part of the central depression of the ring structure. The different units of the ring structure are dissected by large number of post-carbonatite basic dikes (Fig. 1A, 1B).

Numerous dikes of these rocks are also encountered cutting carbonatite mass in deeper part (e.g., in boreholes up to 300 m, borehole data of GMDC). Of the total number of 16 exposed dikes in the central part of the ring, four are of basanite or olivine dolerite and the remaining are dolerites. Most of the dikes show E-W orientation. Pre-carbonatite basalt exposures have been extensively veined by thin carbonatite veins which measure from a few cm to an inch in the different parts of the outer periphery of the complex (Fig. 2).

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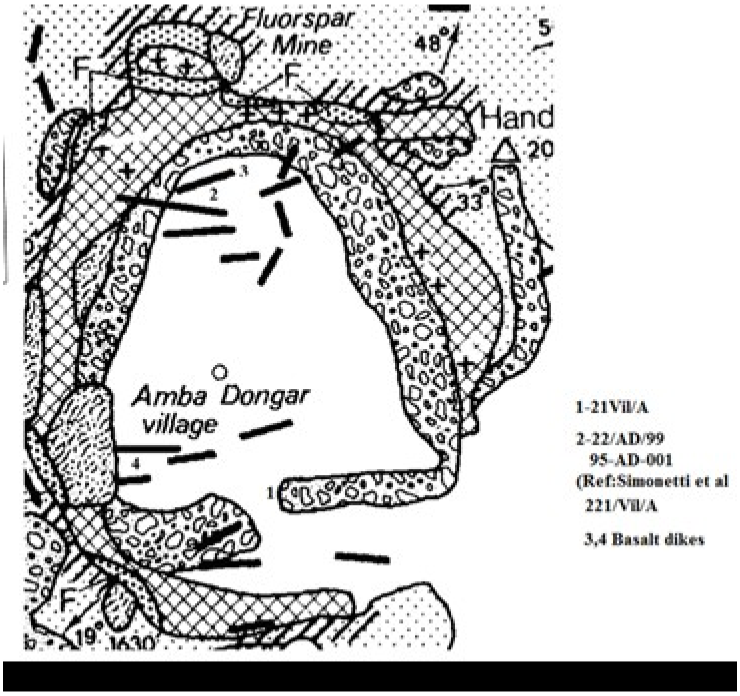

Fig. 1A. Geological map of inner ring structure of the Amba Dongar diatreme, sample numbers on right are of post-carbonatite dikes (map after Viladkar, 1981).

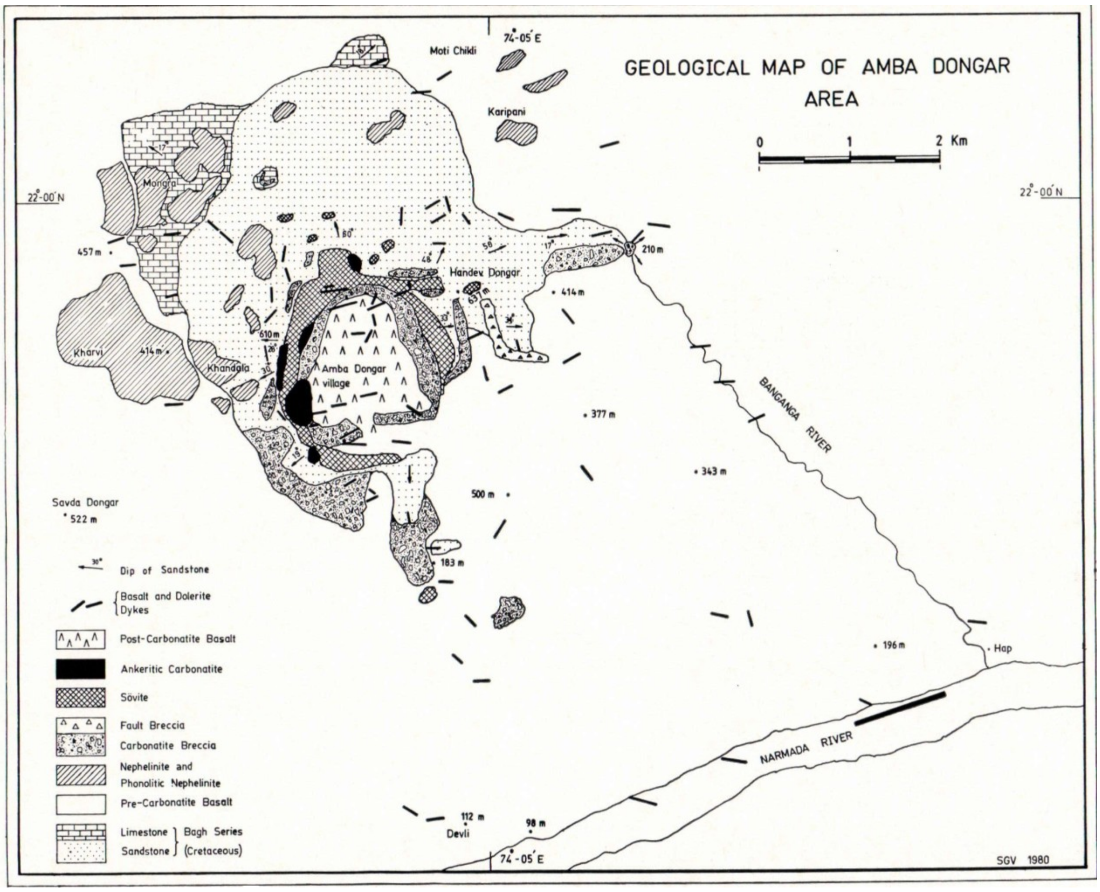

Fig. 1B. Geological map of Amba Dongar ring complex and surrounding Deccan basalt (map after Viladkar, 1981).

Fig. 2. Field photograph of carbonatite veins in pre-carbonatite basalt, Amba Dongar area, Gujarat.

In Fig. 3A, B veins cut through the pre-carbonatite basalt while Fig. 3C, D exhibit alvikite dikes cutting through the pre-carbonatite basalt.

On the basis of field, petrographic and geochemical data indisputable evidence point out that the pre-carbonatite Deccan basalt in the outer periphery of carbonatite ring structure of Amba Dongar has been extensively fenitized (mainly CO_2 and K-metasomatism). On the other hand, the young dolerite dikes in the central basalt, carbonatite breccia and sövite and the ones encountered in boreholes are very fresh.

2. Previous work, field data and petrography

This contribution is based on detailed study of basalts associated with the Amba Dongar and Panwad-Kawant (north of Amba Dongar) carbonatite complexes over the last five decades. The earliest references in this respect go to publication of Sukheswala and Udas (1963) who, reporting the first Indian occurrence of carbonatite in Amba Dongar, made very significant observations on basalts in the central depression of the ring structure. Subsequently Udas (1970), and the doctoral thesis of Viladkar (1972), respectively, studied the fenitized basalts of this region in detail. Two publications of Sukheswala and Avasia (1971) and Sukheswala et al. (1978) presented effects of fenitization on basalts in the outer periphery of Amba Dongar dome and for the first time the term 'plagioclase-calcite' was used to described these fenitized basalts.

Some pre-carbonatite basalt exposures are extensively veined by carbonatite (Fig. 2) while thin dikes of alvikite are seen intruding pre-carbonatite basalt (Fig. 3).

The part of basalt exposure in south-eastern part of Amba Dongar village where it cuts through the original complete ring of carbonatite breccia and sövite seems younger one that extruded after the main carbonatite activity (Fig. 1B). This post-carbonatite basalt and dolerite dikes seem to have been emplaced much later than the carbonatite magma activity and replaced the part of original plug of carbonatite breccia in the south-eastern part of the ring structure (Viladkar, 1972, 1996). Fig. 3C depicts the contact relation between host sövite with intruding basalt dike.

Out of the large collection of pre-carbonatite basalt samples, 123 samples from the inner part and outer part of the ring structure were selected for petrographic investigation. Out of these, 40 samples show effects of fenitization by fluids emanating from the carbonatite magma and leading to the formation of 'plagioclase-calcite' rocks (Viladkar, 1972; Sukheswala et al., 1978). Some of the basalts show a good deal of fracturing and jointing near Kadipani, east of Amba Dongar. It is possible that during the up doming of the region, the hard cover of the competent thin basalts yielded to stress and strain in

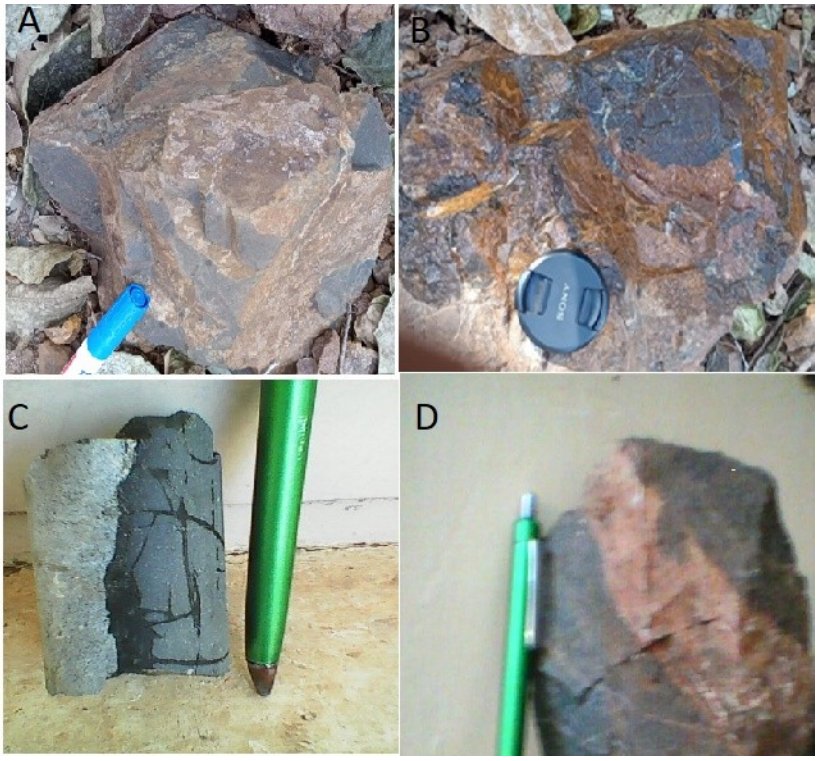

Fig. 3. A, B and D. Pre-carbonatite basalt invaded by carbonatite veins, C. post-carbonatite basalt invading sövite (drill core sample), Amba Dongar area, Gujarat (drill hole data from GMDC, drilled in the western part of the mine).

this manner. In the field the appearance of the fenitized basalts is same as that of normal dark coloured unfenitized basalts however in thin section they are composed essentially of plagioclase and calcite. They have preserved the original basaltic texture. Practically all clinopyroxene grains are completely replaced by carbonatite calcite leaving behind only mineral outline (Fig. 4B). In spite of the intense effects of carbonatization the basaltic texture is well preserved in these rocks.

Another 31 samples show presence of relict pyroxene along with plagioclase and calcite, while all basalt samples from farther away distances (more than 5 km from carbonatite diatreme) are normal plagioclase-pyroxene rocks e.g., basalts in Savda Dongar area, SW of diatreme (Fig. 1B). As against this, the post-carbonatite basalt and dolerite dikes are very fresh with no sign of any alteration. Both pyroxenes and plagioclase in them are extremely fresh and these have been analysed on EPMA (Joel Super probe JXA-8200 microprobe with accelerating voltage of 15 kV and beam current 10 nA, at the Max-Planck Institute for Chemistry, Mainz, Germany). The results are given in Table 1 and plotted in Fig. 5.

Some post-carbonatite basalt dikes show presence of pigeonite along with clinopyroxene (Table 2). Pigeonite is also reported from Deccan basalts in Bushe area and has been attributed to contamination of basaltic magma (Gangopadhyay et al., 2003).

3. Fenitization processes

The K-enrichment with consequent development of poikilitic patches of K-feldspar could easily be identified by staining test on thin sections of fenitized basalts. This process is similar to the one of K-metasomatism of nephelinites of Amba Dongar which has been detailed in an earlier publication (Viladkar, 2015). The pre-carbonatite basalt exposed in the central part of the ring structure and xenoliths of basalt fragments in carbonatite breccia are affected by this process. Basalt sample from borehole in Kadipani shows small amount of silicification along with K-metasomatism. Carbonatization and hematitization are widespread in pre-carbonatite basalts exposed in Kadipani, Moti Chikli, Mongra and Khandla. While basalt flows to farther distances e.g. SavdaDongar, SW of Amba Dongar are totally unaffected by process of fenitization. The effects of hematitization are seen as development of large patches of hematite in the groundmass while cryptocrystalline silica is seen either on rims of minerals or it also

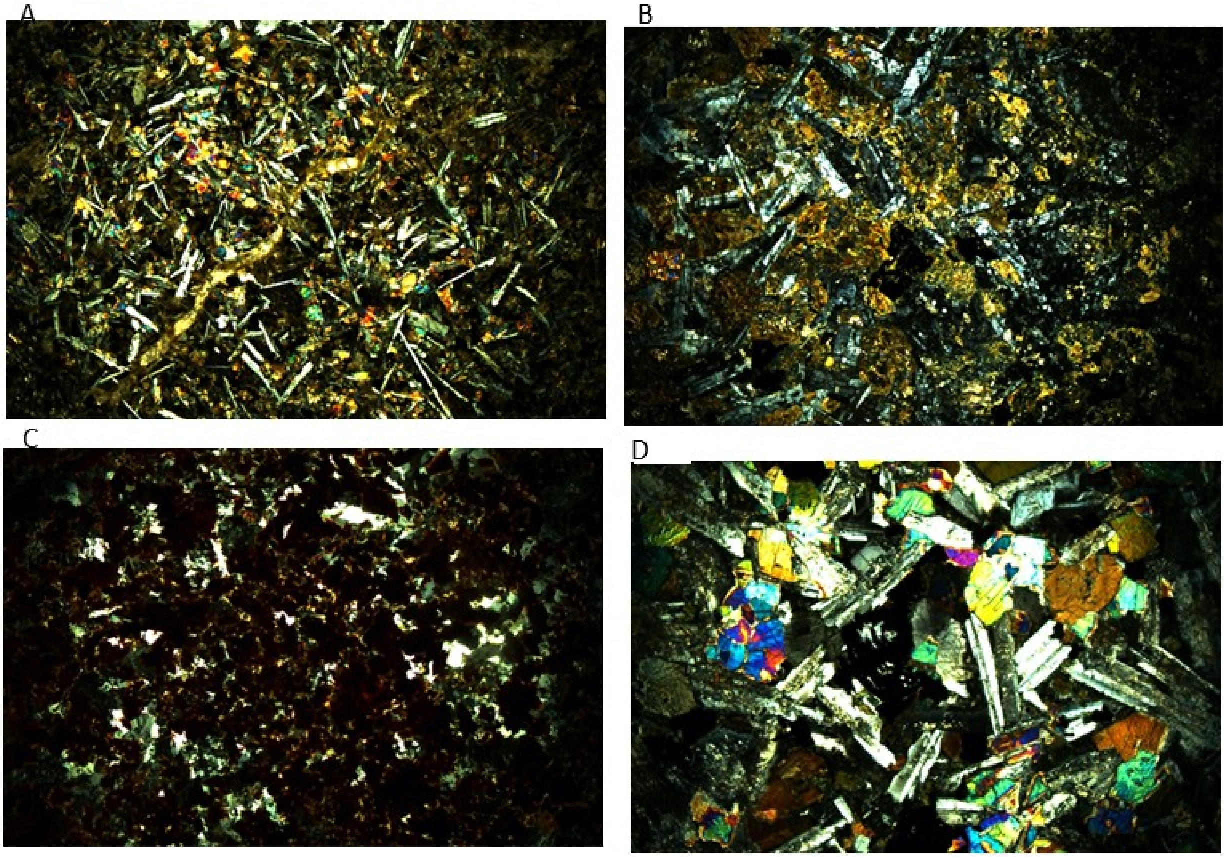

Fig. 4. Thin section photos of A. Fresh (unfenitized) pre-carbonatite basalt, B. plagioclase-calcite rock with relics of pyroxene, C. hematitization of pre-carbonatite basalt and D. post-carbonatite dolerite.

Table 1. Pyroxene from post carbonatite dolerite.

SiO_2	53.15	52.00	52.73	51.68	53.01	50.51	52.87	51.82	51.72	51.54
TiO_2	0.65	1.05	0.62	0.90	0.70	1.36	0.68	0.79	0.97	0.70
Al_2O_3	2.50	1.80	2.82	3.57	2.22	5.31	2.15	2.24	2.21	2.84
$Cr2O_3$	0.61	0.00	0.51	0.66	0.15	0.74	0.37	0.09	0.03	0.25
FeO	7.01	11.93	6.19	7.86	9.21	8.52	8.21	9.92	10.44	10.26
MnO	0.17	0.25	0.14	0.14	0.25	0.23	0.18	0.20	0.25	0.25
MgO	16.96	14.26	16.98	16.26	16.41	14.53	17.38	16.19	14.85	16.57
CaO	20.43	19.43	20.72	19.69	19.07	19.14	18.91	18.58	20.09	17.49
Na_2O	0.26	0.38	0.33	0.32	0.13	0.43	0.28	0.32	0.35	0.21
K_2O	0.00	0.02	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00
Total	101.73	101.13	101.04	101.07	101.16	100.80	101.03	100.14	100.91	100.12
Si	1.920	1.927	1.911	1.927	1.911	1.858	1.667	1.858	1.667	1.858
Ti	0.018	0.029	0.017	0.029	0.017	0.038	0.025	0.038	0.025	0.038
Al	0.106	0.079	0.120	0.079	0.120	0.230	0.243	0.230	0.243	0.230
Fe_3	0.020	0.037	0.032	0.037	0.032	0.000	0.197	0.000	0.262	-0.262
Cr_3	0.017	0.000	0.015	0.000	0.015	0.022	0.015	0.022	0.015	0.022
Fe_2	0.192	0.332	0.155	0.332	0.155	0.262	0.000	0.262	-0.262	0.524
Mn	0.005	0.008	0.004	0.008	0.004	0.007	0.005	0.007	0.005	0.007
Mg	0.913	0.788	0.917	0.788	0.917	0.797	1.066	0.797	1.066	0.797
Ca	0.791	0.771	0.805	0.771	0.805	0.754	0.725	0.754	0.725	0.754
Na	0.018	0.027	0.023	0.027	0.023	0.031	0.053	0.031	0.053	0.031
K	0.000	0.001	0.000	0.001	0.000	0.002	0.002	0.002	0.002	0.002

penetrate minerals. In some fenitized basalts large rounded globules hematite appear which seem to be due to iron released from pyroxene grains during process of fenitization.

4. Geochemical data and discussion

Representative analyses of old (pre-carbonatite) and young (post-carbonatites) basalt and dikes are

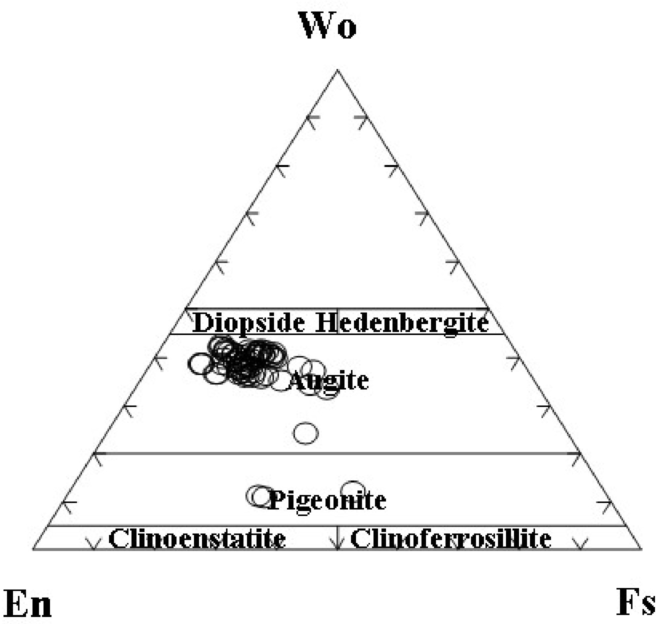

Fig. 5. Composition of clinopyroxene from post-carbonatite dolerites and basalt dikes.

Table 2. Pigeonites from post-carbonatite basalt dike.

SiO_2	53.54	51.41	53.09
TiO_2	0.27	0.35	0.29
Al_2O_3	1.19	0.78	1.17
$Cr2O_3$	0.03	0.05	0.01
FeO	19.75	28.15	20.63
MnO	0.47	0.62	0.48
MgO	20.74	14.32	20.38
CaO	5.56	5.74	5.36
Na_2O	0.03	0.13	0.09
K_2O	0.00	0.00	0.00
Total	101.57	101.54	101.50
Si	1.581	1.519	1.569
Ti	0.008	0.010	0.009
Al	0.047	0.031	0.046
Al_4	0.047	0.031	0.046
Al_6	0.000	0.000	0.000
Cr	0.001	0.002	0.001
Fe	1.167	1.663	1.220
Mn	0.028	0.037	0.028
Mg	1.225	0.846	1.205
Ca	0.328	0.339	0.317
Na	0.003	0.015	0.011
K	0.000	0.000	0.000
Sum	4.388	4.462	4.404

presented in Table 3A and 4 respectively. The pre-carbonatite basalts distinctly show higher K_2O, CO_2, Fe_2O_3 and TiO_2 which may have been added during fenitization due to emanations from the carbonatite magma intruding them. Two of the pre-carbonatite basalts (analyses 2 and 5 in Table 3B) which show good deal of K-metasomatism fall in the field of trachy-basalts on classification diagram (Fig. 6, both have normative Or 13% and 15% respectively), while the bore-hole basalt sample from Kadipani that shows good deal of carbonatization and secondary silica, falls in the field of basaltic andesite on this diagram (Fig. 6).

MgO and CaO contents in fenitized basalts are lower than post-carbonatite basalts. This could be attributed to replacement of pyroxene by calcite and albitization of plagioclase. On the other hand the post-carbonatite basalts are fresh with low K_2O, CO_2 and TiO_2. On plot of SiO_2 vs. Na_2O+K_2O (Fig. 6) three samples of 'basanite' fall in the field of normal basalt along with other post-carbonatite basalt and dolerite dikes. In addition to present geochemical analyses data, data published by Sukheswala and Avasia (1971), on samples of pre-carbonatite plagioclase-calcite rocks in the outer periphery of Amba Dongar dome has been given in Table 3B for comparison.

Chondrite-normalized trace elements patterns (Spidergram, Fig. 7) of the different fenitized basalts show large spread in their trace elements depending on the degree of fenitization. Accordingly, fenitized basalt show elevated values of K, Rb, Th, Nb, Zr. Ti and LREE. All these elements have been added from fluids emanating from carbonatite magma. In Fig. 7 pre-carbonatite basalt samples show much wider spread of different elements and this is attributed to the different degree of alteration suffered during fenitization of these samples. This is well reflected in pattern of Rb and K.

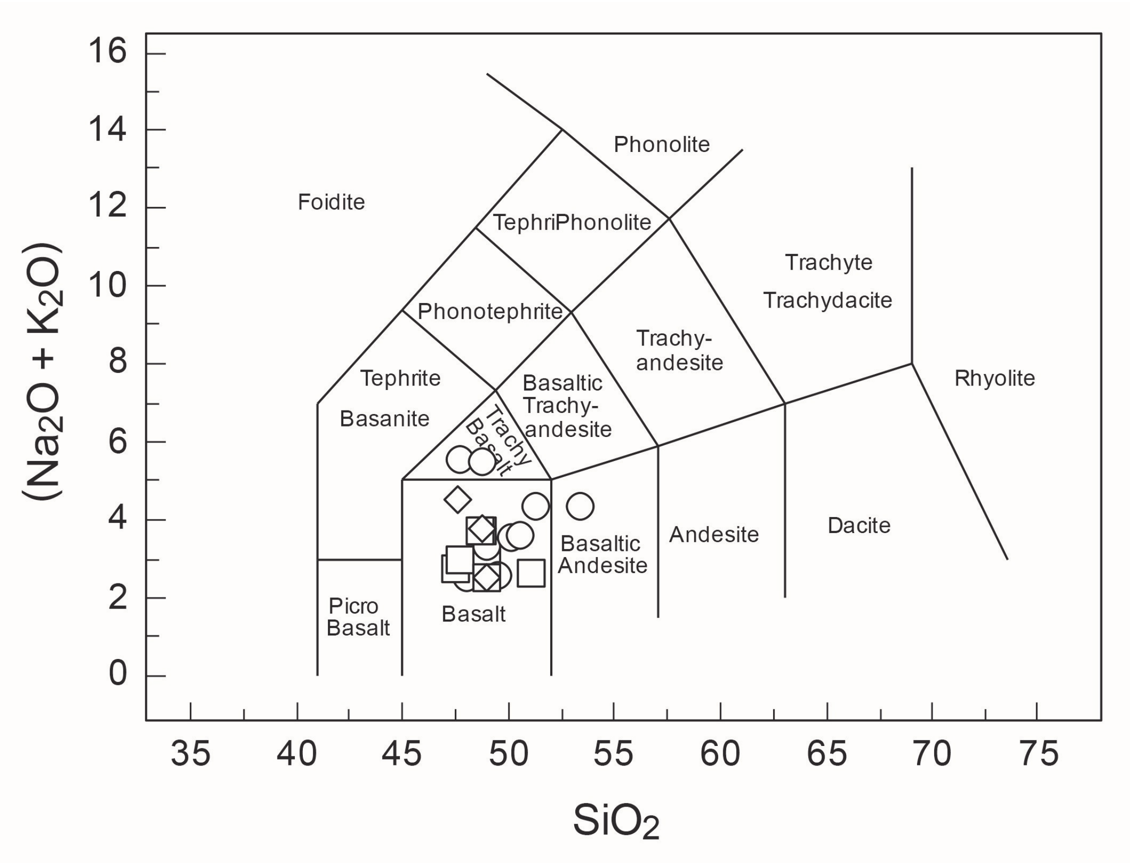

Fig. 6. Plot of pre- and post-carbonatite basalts on TAS diagram (after Le Bas et al., 1986). Circle: Pre-carbonatite basalt. Square: Post-carbonatite dolerite dikes, Diamond: post-carbonatite olivine-dolerite dikes in centre of Amba Dongar ring structure.

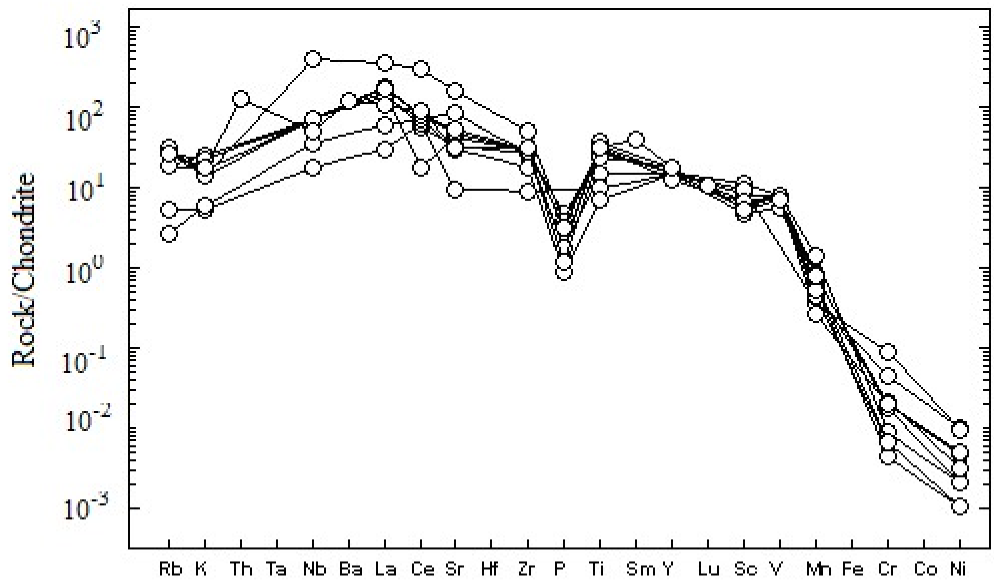

Fig. 7. Spidergram of finitized basalts from the different parts of the basalt exposures around carbonatite, large spread depends on degree of fenitization.

On the other hand, a pre-carbonatite and post-carbonatite dolerite dike show marked differences in some element patterns (Fig. 8).

The core sample (from borehole) of the pre-carbonatite basalt shows much higher values of trace elements as compared to the one from

Table 3A. Represnetative analyses of pre-carbonatite fenitized basalts.

	1	2	3	4	5
SiO_2	51.54	45.20	46.68	48.54	43.72
TiO_2	3.15	2.74	2.48	3.16	3.83
Al_2O_3	12.65	12.79	16.67	12.82	12.25
Fe_2O_3T	13.74	15.27	11.83	14.73	14.12
MnO	0.18	0.10	0.15	0.12	0.06
MgO	3.68	3.06	4.02	3.77	2.12
CaO	7.06	8.23	7.35	8.97	10.22
Na_2O	2.38	2.79	1.85	2.00	2.50
K_2O	1.81	2.25	1.43	1.43	2.54
P_2O_5	0.36	0.14	0.54	0.44	0.20
H_2Op	-	-	-	-	-
H_2Om	2.63	3.54	2.36	1.44	4.43
CO_2	-	4.96	5.00	3.70	4.87
Total	99.18	96.11	100.36	101.12	100.80
Ba	436.00	-	-	-	
Rb	51.00	50.00	50.00	60.00	35.00
Sr	333.00	560.00	560.00	1635.00	865.00
Y	36.00	35.00	35.00	25.00	35.00
Zr	283.00	260.00	260.00	450.00	255.00
Nb	28.00	40.00	40.00	220.00	40.00
Pb	8.00	-	-	10.00	20.00
Ga	22.00	-	-	-	-
Zn	116.00	-	-	-	-
Cu	82.00	-	-	-	-
Ni	48.00	10.00	10.00	30.00	45.00
V	355.00	340.00	340.00	345.00	395.00
Cr	45.00	15.00	15.00	50.00	45.00
Sc	27.00	35.00	35.00	35.00	35.00
CO	39.00	35.00	35.00	35.00	35.00
La	35.00	55.00	55.00	115.00	45.00
Ce	78.00	70.00	70.00	260.00	60.00
Nd	-	50.00	50.00	90.00	45.00
Sm	8.00	-	-	-	
Eu	2.40	-	-	-	
Gd	-	-	-	-	
Tb	1.57	-	-	-	
Di	-	-	-	-	
Ho	-	-	-	-	
Er	-	-	-	-	
Tm	-	-	-	-	
Yb	3.69	-	-	-	
Lu	0.36	-	-	-	

1-From borehole in Kadipani mine office E of Amba Dongar
2-565/Vil flow basalt in outer periphery W of Amba Dongar
3-590/Vil flow basalt in outer periphery SW of Amba Dongar
4-610/Vil flow basalt in outer periphery South of Amba Dongar
5-511/Vil flow basalt in outer periphery SW of Amba Dongar

post-carbonatite dike sample (Fig. 8). The post-carbonatite basalts show much lower concentrations of all trace elements except Ni and Cr whose concentration is much higher in the post-carbonatite basalt.

Similarly, chondrite-normalized Rare Earth Element patterns of pre- and post-carbonatites basalts show different concentration patterns (Fig. 8 to 11).

Both the post-carbonatite basanite have almost similar REE concentrations in contrast to the post-carbonatite basalts, the pre-carbonatite fenitized Deccan basalt shows much elevated concentrations of these elements. All these are affected by CO_2 and K emanations from carbonatite magma.

Table 3B. Plagiocase-calcite rocks described by Sukheswala and Avasia (1971).

	31.00	466.00
SiO_2	41.34	44.20
TiO_2	2.11	2.10
Al_2O_3	14.31	14.47
Fe_2O_3	5.43	3.16
FeO	7.07	7.21
MnO	0.54	0.27
MgO	5.09	5.39
CaO	12.29	10.94
Na_2O	1.30	1.58
K_2O	0.48	0.24
P_2O_5	0.22	0.22
H_2O	0.90	4.31
CO_2	9.46	6.16
Total	100.54	100.25

Examples of the fenitization of basic igneous rocks are not so common in literature. Verwoerd (1966) studied fenitization effects on basic igneous rocks in Goudini complex. South Africa. He observed that both acid and basic igneous rocks undergo same chemical changes during fenitization with increase alkaline (more sodium than potassium), depletion in silica, iron and magnesium from the mafic igneous rocks.

Similar observations are made by Currie and Ferguson (1972) on the basis of studies of fenitization of basic igneous rocks.

In case of Amba Dongar fenitized basalts however, K enrichment is observed due to K-metasomatism, Fe-enrichment due to hematitization of original pyroxene, silica is increased due to silicification as also by removal silica from pyroxene during replacement by calcite while there is depletion in Mg (Table 4).

5. Post-carbonatite dikes

Simonetti et al. (1998) analysed one sample of olivine-dolerite (termed basanite by them) from the central part of Amba Dongar for Nd and Sr isotopes. Their plot shows that the basanite samples plots away from Amba Dongar carbonatite but closer to the Reunion field. They further comment that 'the isotope systematics for carbonatite and adjacent basanite at Amba Dongar are not uniform'. Similarly eNd-Sr data for central basalt (unpublished data of Viladkar and Graue) also plots away from Amba Dongar carbonatite and the Deccan basalt. However, this central basalt sample is slightly enriched in Sr.

Table 4. Chemical analyses post-carbonatite basalt and dolerite dikes in Amba Dongar.

	1	2	3	4	5	6	7	8
SiO_2	47.41	45.43	45.74	49.10	48.90	49.56	49.44	46.99
TiO_2	2.00	1.98	1.95	1.05	3.00	1.52	1.50	1.45
Al_2O_3	13.37	13.34	14.14	14.36	13.65	12.63	13.56	15.26
Fe_2O_3	13.34	13.07	12.31	12.96	16.27	12.51	12.63	11.84
MnO	0.20	0.19	0.18	0.19	0.09	0.17	0.15	0.17
MgO	6.82	6.90	6.37	5.85	4.93	8.15	7.35	5.69
CaO	10.25	11.83	12.03	10.75	8.06	10.50	10.17	11.25
Na_2O	2.76	2.21	2.38	2.07	2.69	1.86	2.08	2.98
K_2O	0.81	0.39	0.43	0.45	0.78	0.45	0.68	0.61
P_2O_5	0.20	0.23	0.28	0.11	0.30	1.73	0.16	0.12
LOI	1.77	4.03	3.91	2.00	2.36	0.20	1.19	3.33
Total	98.93	99.60	99.72	99.70	101.30	99.28	98.91	99.69
Ba	258.00	279.00	310.00	133.00	-	380.2	112.00	216.00
Rb	33.00	10.00	11.00	14.00	40.00	63.5	9.45	23.10
Sr	1770.00	384.00	424.00	106.00	540.00	2552	148.70	1660.00
Y	28.00	25.00	28.00	25.00	40.00	23.24	23.65	19.00
Zr	155.00	127.00	136.00	84.00	255.00	74.75	51.00	6.98
Nb	10.00	26.00	29.00	6.00	35.00	15.02	6.00	31.71
Th	4.00	2.00	3.00	-	-	1.564	1.41	1.41
Pb	-	2.00	4.00	-	10.00	1.684	1.26	9.51
Ga	21.00	24.00	22.00	18.00	40.00		0.00	22.00
Zn	97.00	102.00	98.00	102.00	373.00		0.00	87.94
Cu	100.00	131.00	131.00	103.00	0.00		0.00	133.62
Ni	134.00	117.00	120.00	88.00	40.00	70.85	72.00	93.39
V	320.00	365.00	313.00	315.00	373.00	324	351.00	325.00
Cr	265.00	221.00	233.00	152.00	40.00	95.07	114.00	125.00
Hf	-	-	-	-			1.54	2.09
Sc	40.00	34.00	34.00	40.00	50.00	38.02	42.00	
CO	52.00	42.00	43.00	43.00	36.00	47.33	50.00	98.00
U	-	-	-	-			0.25	0.32
La	24.50	33.00	45.00	9.60	50.00	4.646	6.71	9.97
Ce	42.00	56.00	68.00	20.00	75.00	10.64	15.32	23.32
Pr	-	-	-	-	-	1.465	2.14	2.80
Nd	-	-	-	-	50.00	7.091	10.09	12.31
Sm	3.20	4.00	5.10	2.60	-	0.823	1.11	3.32
Eu	0.70	1.31	1.84	1.00	-	2.354	3.07	1.20
Gd	-	-	-	-	-	2.853	3.69	3.77
Tb	0.32	0.86	0.90	0.64	-	0.49	0.54	0.68
Di	-	-	-	-	-	3.293	4.13	3.88
Ho	-	-	-	-	-	0.711	0.88	0.76
Er	-	-	-	-		1.947	2.36	2.31
Tm	-	-	-	-		0.29	0.34	0.33
Yb	2.19	2.24	2.31	3.23		1.842	2.18	1.90
Lu	0.26	0.23	0.26	0.39		0.275	0.31	0.27

1 dolerite - AD/05/10A
2 basalt - AD/2005/2
3 basalt - AD/2005/3
4 dolerite - AD/2005/5
5 basalt 21/Vil/A
6 ol-dole
7 basalt from drill core in mining area
8 Basanite -22/AD/99 Analysis courtesy Mukul Sharma

Though the Nd and Sr isotope data is very limited (only one sample of basanite and one sample of central basalt) it shows that the isotopic systematics of both central and basalt and the carbonatite differ. More data is needed to arrive at definite conclusion.

Post-Deccan intrusive activity is not uncommon and according to Collier et al. (2008) who opined that '... after Seychelles began to rift away from India a third post-Deccan pulse of magmatism (63–58 Ma) produced offshore mafic volcanic and intrusive rocks on the northern margin of Seychelles plateau and alkaline volcanism in India'. Similar evidence of rejuvenated volcanism is also found in Hawaiian Plume (Garcia et al., 2010) and in Mauritius Island (Paul et al., 2005). In Amba Dongar this post-carbonatite basic intrusive activity is first mentioned

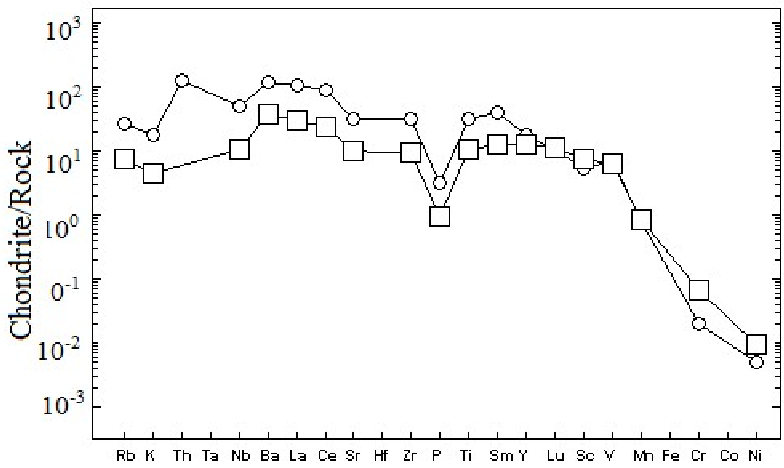

Fig. 8. Spider diagram for pre-carbonatite basalt Kadipani borehole (circle) and post-carbonatite dolerite dike AD/2005/12 (square).

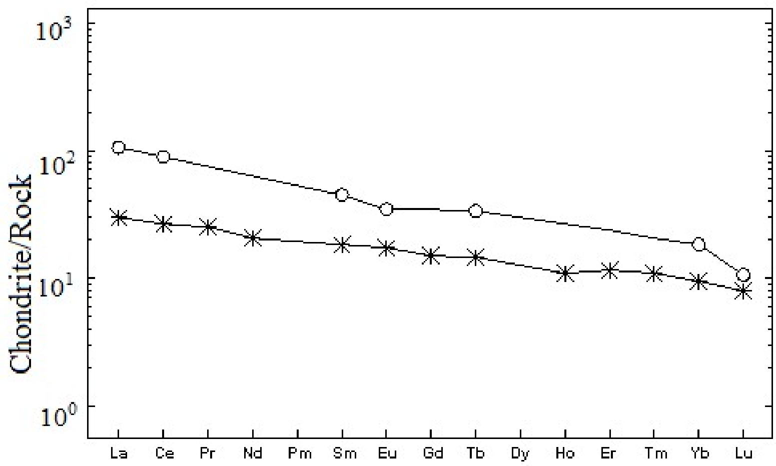

Fig. 9. Chondrite-normalized REE distribution patterns in pre-carbonatite basalt (circle) and olivine-dolerite dike (star).

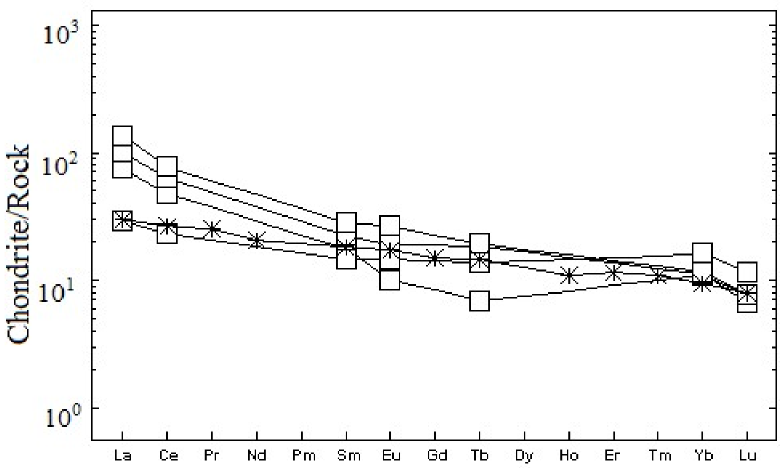

Fig. 10. Chondrite-normalized REE patterns in post-carbonatite dolerite (sqaure) and olivine-dolerite dike (star).

by Sukheswala and Udas (1963). Detailed mapping (Viladkar, 1972) proved this by the large number dolerite and olivine-dolerite dikes cutting carbonatite breccia and sövite on the surface while the presence

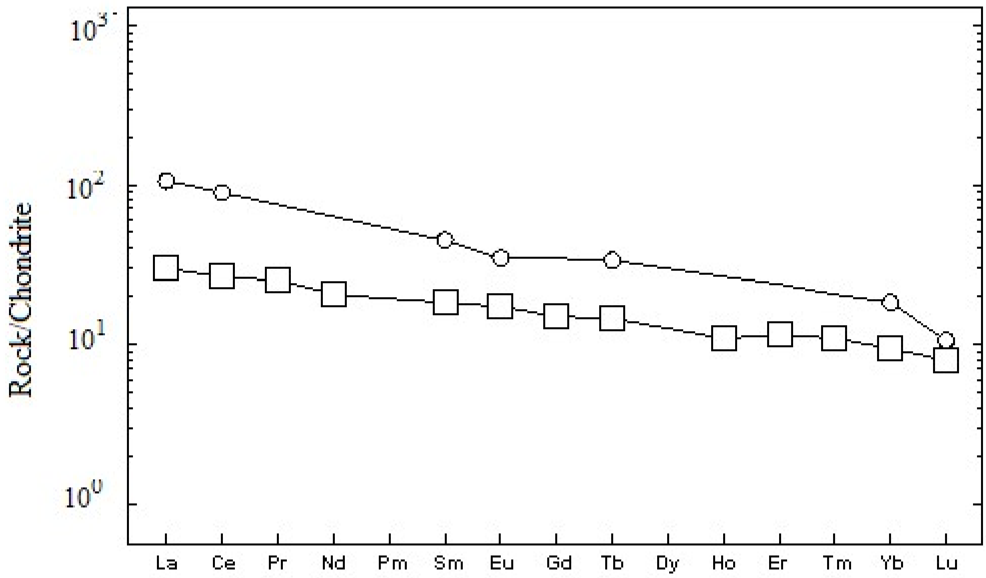

Fig. 11. Chondrite-normalized REE patterns in post-carbonatite dolerite (square) and pre-carbonatite fenitized basalt (circle).

of widespread network of dolerite dikes in deeper level distinctly cutting through the hidden carbonatite mass is further supported by drilling carried out by the GMDC and AMD. The mass of this hidden carbonatite must be enormous which caused widespread fenitization of country rocks in Amba Dongar.

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