

Appraisal of Crustal Contamination in Southern Bastar Mafic Dykes in Chattisgarh, India

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Abstract

The present work is an attempt to assess the effect of crustal contamination through the Granitoids host rock, within the southern Bastar mafic dykes of Chhattisgarh, India, in the light of geochemical characteristics. Petrographically, these dykes are classified as Amphibolite, Dolerite/Meta-Dolerite and Diorite. Geochemically, all dyke samples have been classified as “high iron sub-alkaline Tholeiites”. On account of overlapping magnesium and iron concentration in Amphibolite and Dolerite dykes, distinctly higher High-Field Strength Element (HFSE), higher Rare-Earth Element (REE) concentrations in the Dolerite dykes than in the Amphibolite dykes, it is inferred that both dyke swarms are fed from two different Tholeiitic magmas. Conclusively, these dykes are recognized as belonging to two different swarms, BD1 and BD2 respectively. This is also corroborated by differences in the LREE patterns *i.e.* BD2 dykes have relatively enriched LREE pattern than that of BD1 dykes. It is evident from higher La^N/Lu^N ratio in the BD2 swarm, than in BD1 dyke swarm. These dykes intrude in the coarse-grained leucocratic Bastar Granitoids/Granite Gneisses, which are the host for these dykes. The comparative study of the Primordial mantle-normalized multi-element spidergrams, and Chondrite-normalized rare-earth element patterns for the average of BD1 and BD2 dykes and the average of Bastar Granitoids, clearly reflect that the great degree of variation in LIL elements, observed in the Bastar dykes, is either due to metamorphism or due to secondary alteration, and not due to crustal contamination. This is further supported by much higher average “Nb”/“La” ratios in Bastar Mafic Dykes, than in the Bastar Granitoids. Crustal assimilation plays almost no role in the petrogenesis of the Bastar mafic dykes. The Bastar mafic dykes owe their incompatible element characteristics, certainly mantle derived.

Keywords

Crustal Contamination, Dolerite, Amphibolite, Granite, Spidergram, REE

1. Introduction

Mafic dykes constitute a crustal expression of crustal extension in both oceanic and continental environments, and represent major avenues by which basaltic magma is transferred from mantle to upper crust. Dykes are an integral part of the feeder systems for many volcanic islands, whether they represent intra-plate activity as in Hawaii or are subduction-related as along the Aleutian [1] [2] [3].

The chemistry of Proterozoic dykes mostly reflects the composition of the sub-continental lithosphere. The effects of crustal contamination are minimal. Detailed studies of the mafic dykes in space and time, yield valuable information on the growth and development of the sub-continental lithosphere throughout the Proterozoic [2] [4] [5]. The present work is an attempt to assess the effect of crustal contamination, within the southern Bastar mafic dykes, in the light of geochemical characteristics.

2. Location, Extent and Accessibility

The study area is a part of Bastar District, Chhattisgarh. Jagadalpur is the district headquarters of the Bastar district. The area under investigation, *i.e.* in and around Dantewara, Katekalyan, and Bastnar, falls in the southern Bastar region. It lies between the latitudes 18°45' and 19°N and longitudes 81°30' and 82°E, covering about 425 sq.km. It forms a part of the Survey of India Topographic sheet nos. 65 F/5 and 65 F/9 (scale 1:50,000), published in 1982. Boundaries with Orissa and Andhra Pradesh lie only a few kilometers away due east and south respectively. The area is approachable through rail, road and air. The shortest and easiest route to reach southern Bastar region is via Raipur. One can reach Raipur (the Capital of Chhattisgarh) by direct trains or flights. The location and google image map is shown in **Figure 1**.

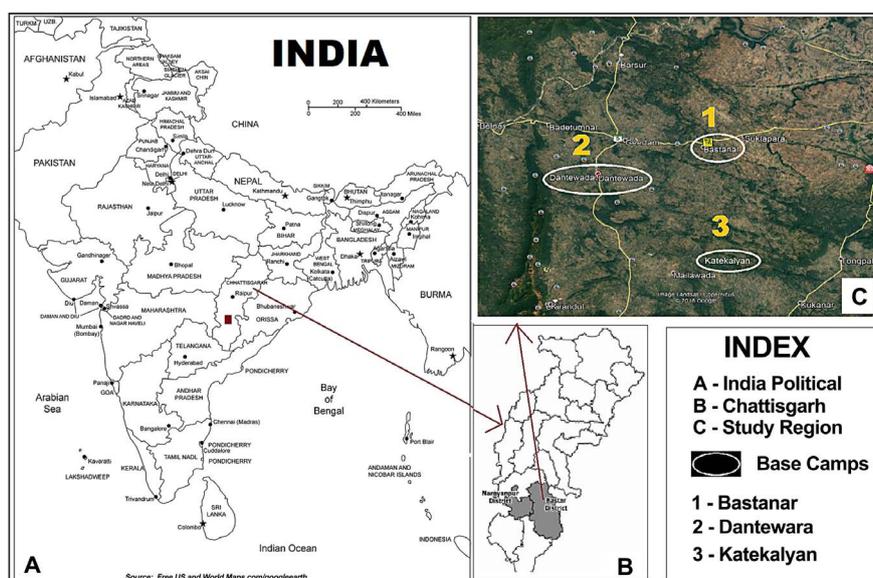


Figure 1. Location & google image map.

3. Regional Geology

The regional geology of Bastar has been most authentically explained by [6]. He has geologically mapped the Southern Bastar and Jaypore area from Bailadila Hill Range to Eastern Ghats. The geological succession as given by [6] reveals that sedimentary rocks of Cuddapahs Super group, unconformably overlie the older Archean members which include various acidic and basic intrusives igneous rocks and metamorphites. Soils and Laterites/ferruginous Laterites form the upper most formation which overlies the Cuddapahs. The metamorphites are divided into three successively younger series viz. Sukma, Bengal and Bailadila Series. The three-fold division, is purely on local basis and no definite boundaries between these units have been demarcated yet.

The region contains a very vast tract of granites and granite-gneisses with engulfed and overlying supracrustal rocks of Dongargarh, Sakoli, Sausar, Bengal, Sukma, and Bailadila Groups. These older rocks are overlain by several unmetamorphosed Late Proterozoic sedimentary basins. The region also consists of several economic deposits such as Banded Iron Formation, corundum deposits, and heavy metal deposits such as “Sn”-“Nb”-“Ta” mineralization etc.

Generalized Geological Succession of the Region

The generalized geological succession in the study area of the South Bastar Region is presented in **Table 1**.

The region is a vast granitic terrain, intruded by numerous mafic dykes. These dykes vary in length from about 500 meters to a few kilometers. The width of these dykes varies from few meters to about 100 meters. Dykes regionally trend in NW-SE to WNW-ESE direction, mostly following the trends of Mahanadi and Godavari rifts and few other major lineaments.

The study area was defined by the objective of systematic sampling of mafic dykes. For this objective, the field study was concentrated in three sub areas namely Bastanar, Dantewara and Katekelyan. The modified Geological Map of the study region, combined with regional tectonic set up, is shown in **Figure 2**.

Clear contacts and Cross cut relations, between the mafic dykes and the granites have been authentically reported from various field exposures (**Figure 3(A)** & **Figure 3(B)**). No dyke is reported to cut Late Proterozoic sedimentary basins. Amphibolite dykes are reported to cut only granite gneisses (age varies between 2.5 and 3.0 Ga), whereas, Dolerite/Meta-Dolerite dykes cut Granite Gneisses as well as Granites (Granite age varies between 2.0 and 2.5 Ga).

In the absence of direct age data for these mafic dykes of the southern Bastar Craton, ages of these dykes have been established on the basis of field relationships, overlapping Granitoids age data, petrological and geochemical results and previous work. Mostly, on the basis of cross cut relationship, it is suggested that the BD1 swarm is emplaced in the Archean time (age > 2.3 Ga) and BD2 swarm is emplaced in the Proterozoic time (age < 2.3 Ga).

Table 1. Geological succession of the study area (Verma, 1998).

RECENT		Soils and alluvium Laterite
----- <i>Unconformity</i> -----		
P R O T E R O Z O I C	CUDDAPAH	Quartzites and Grits
	----- <i>Unconformity</i> -----	
	CHANDENAR GROUP	(Dolerite Dykes Amphibolite Dykes) BD2 DYKES Undifferentiated Granite Greenstones
----- <i>Unconformity</i> -----		
A R C H E A N	BAILADILA GROUP	Rocks of this group are not exposed in the study area
	----- <i>Unconformity</i> -----	
	BENGPAL GROUP	Basalts and Tuffs Schists and Gneisses Schists and Gneisses with Andalusite Sericite-Schist and coarse Quartzite
S U K M A	SUKMA SUPRACRUSTAL SUITE	(Amphibolite Dykes) ⇒ BD1 Dykes Diopside Gneisses
	----- <i>Unconformity</i> -----	
Ca. 3000 and Ca. 3400 M Yrs.		

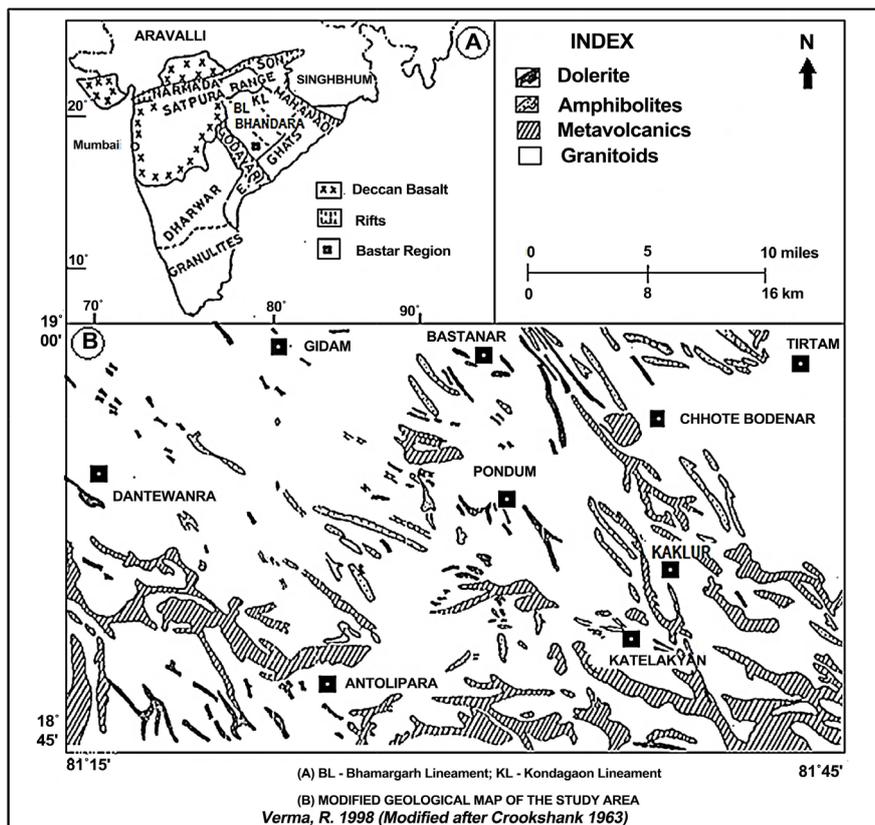


Figure 2. Geological succession of study region (Source: Verma, R., 1998).

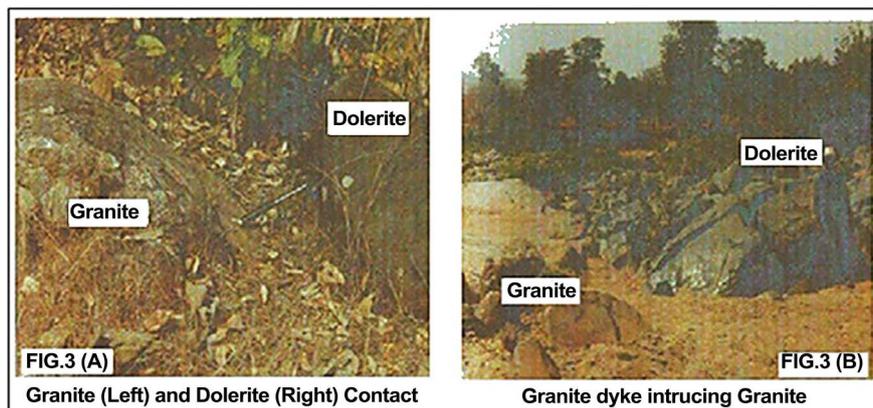


Figure 3. Contact of granite and dolerite (Source: Verma, R., 1998).

4. Petrology and Geochemistry of Mafic Dykes

4.1. Petrography and Petrology

The study region is a vast granitic terrain which is intruded by three types of mafic dykes namely Amphibolites, Dolerites and few Diorites. The representative hand specimen of these rocks are shown in **Figure 4** [7].

Petrographically, these dykes are classified as Amphibolite, Dolerite/Meta-Dolerite and Diorite. Amphibolite rocks are medium-to coarse-grained and consist essentially of Amphibolite facies mineral assemblages. Hornblende is the chief constituent of amphibolites with the average being 44.93%. Plagioclase is another major constituent (mostly calcic Plagioclase) *i.e.* Labradorite to Anorthite. Plagioclase content varies in mode from 20.06% and 34.24%. The accessory minerals include Quartz, Biotite, Magnetite, Sphene and Chlorite. Most of the Amphibolite rocks show equigranular granoblastic texture (**Figure 5(A)**).

Pyroxene, mostly Augite is the major mineral of the Dolerites which range from 38.96% - 58.80% averaging 47.22% in the mode. Calcic plagioclase of Labradoritic and Bytownitic composition is the second most dominant mineral present, ranging from 20.75% - 32.50% in mode and 24.43% on average. Hornblende constitutes 11.58% ranging from 6.54% to 17.45 % in mode. Among the accessories, Magnetite, Ilmenite, Apatite, Sphene and Zircon are present. Dolerite/Meta-dolerites essentially exhibit ophitic and sub-ophitic textures (**Figure 5(B)**). In addition, meta-dolerites also exhibit corona texture in which Augite crystals are mantled by hornblende. These dolerites consist of Augite/Titano-Augite, plagioclase feldspar (Labradorite and Bytownite) and iron oxide as main mineral constituents. In some Dolerite rocks, pyroxenes are entirely replaced by Hornblende but the original ophitic texture is still retained [7]. The average modal composition of these mafic dykes is shown in **Table 2**.

4.2. Geochemistry

In the Amphibolites, SiO_2 averages 50.60%. A very wide variation is observed in TiO_2 , and P_2O_5 . They show variation from 0.86% to 2.58% (av. 1.26%) and

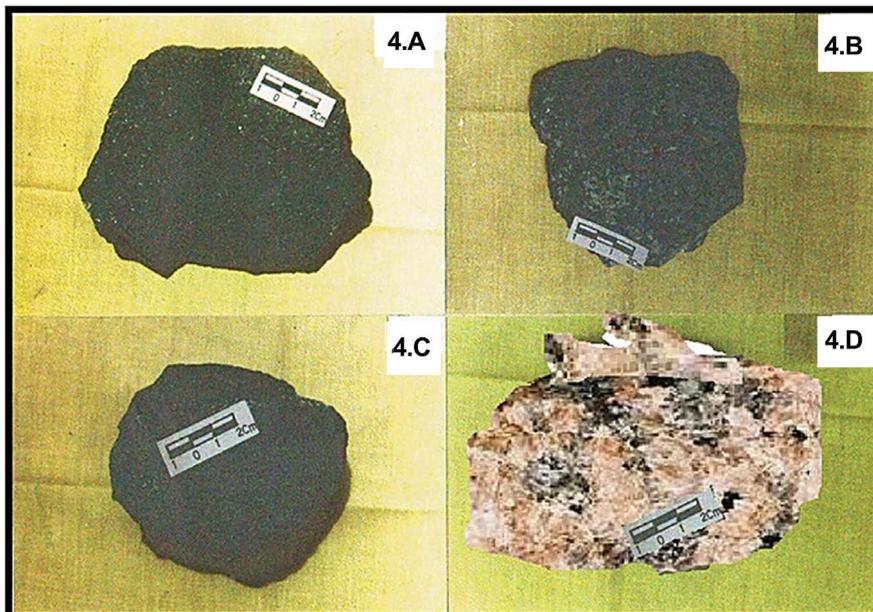


Figure 4. Hand specimens of representative rocks (Source: Verma, R., 1998).

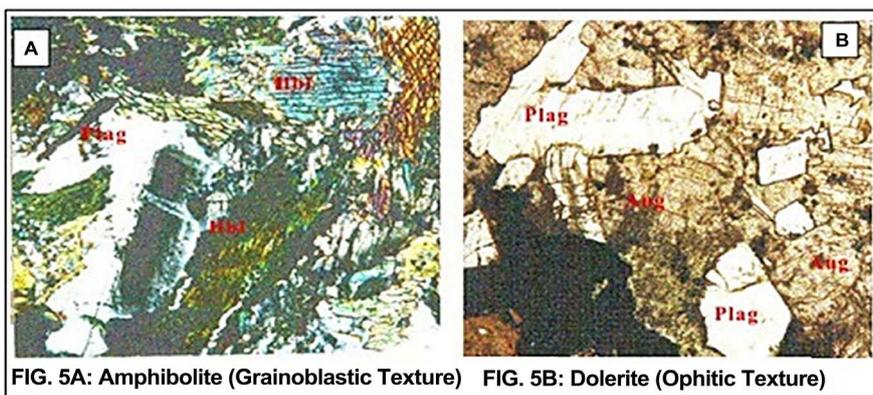


Figure 5. Photomicrographs (source: Verma, R., 1998).

Table 2. Average modal composition of southern bastar mafic dykes (Source: Verma, R. 1998).

S.N.	MINERAL	AVERAVE MODAL COMPOSITION
1	Quartz	0.56
2	K-Feldspar	0.75
3	Plagioclase Feldspar	39.86
4	Hornblende	42.70
5	Chlorite	03.58
6	Augite	06.86
7	Micas	0.15
8	Iron Oxides	3.97
9	Others	1.14
TOTAL		99.57
COLOUR INDEX		57.82

0.08% to 0.75% (av. 0.16%) respectively. Al_2O_3 averages 14.07%, whereas Fe_2O_3 averages 14.83%. MnO averages 0.20%. Average value of MgO concentrations in amphibolites is 6.04%. CaO averages 9.88%. Alkalis (Na_2O and K_2O) have average values 2.54% and 0.57% respectively. Wide ranges of oxides are probably due to the metamorphism of these rocks.

Dolerites/meta-dolerites show limited range of oxide (wt. %) variations. In Dolerite/meta-dolerite SiO_2 averages 49.49%. TiO_2 shows wide variation and ranges from 0.60% to 2.61%, with average value of 2.14%. Al_2O_3 averages 13.04%. Fe_2O_3 shows variation from 14.15% to 18.75% (av. 17.20%) and MnO averages 0.21%. MgO range is very high, *i.e.* 2.55% - 9.92%, and has an average value of 5.07%. CaO is present with an average of 9.10%. Average value of Na_2O is 2.42% and that of K_2O is 0.87%. P_2O_5 shows wide variation (0.06% - 0.58%) and has average values of 0.29%.

Geochemically, all dyke samples have been classified as high iron sub-alkaline Tholeiites. Incompatible trace element (including rare-earth elements) data, clearly divide them into two distinct swarms. Older set of dykes is recognized as BD1 swarm and the younger set is recognized as BD2 swarm. BD1 set consists mainly of Amphibolite dykes, whereas, the BD2 set comprises Amphibolite dykes, dolerite/meta-dolerite dykes and minor diorite dykes. BD1 dykes are low-Ti, Fe-rich olivine to quartz Tholeiites, whereas, the BD2 dykes are predominantly quartz Tholeiites with higher "Ti" and "Fe" contents (Figure 6).

Most of the southern Bastar mafic dykes have overlapping magnesium and iron concentration range but high-field strength and rare-earth element concentrations are distinctly higher in the in BD2 dykes than in the BD1 dykes. This inference suggests that both swarms are fed from two different tholeiitic magmas. This is also corroborated by differences in the LREE patterns. BD2 dykes have relatively enriched LREE pattern than that of BD1 dykes (Figure 7). It is evident from higher La^N/Lu^N ratio in the BD2 swarm too. Average geochemical analyses of representative samples of Amphibolites, Dolerites and Diorite of both dyke swarms BD1 and BD2, is presented in Table 3.

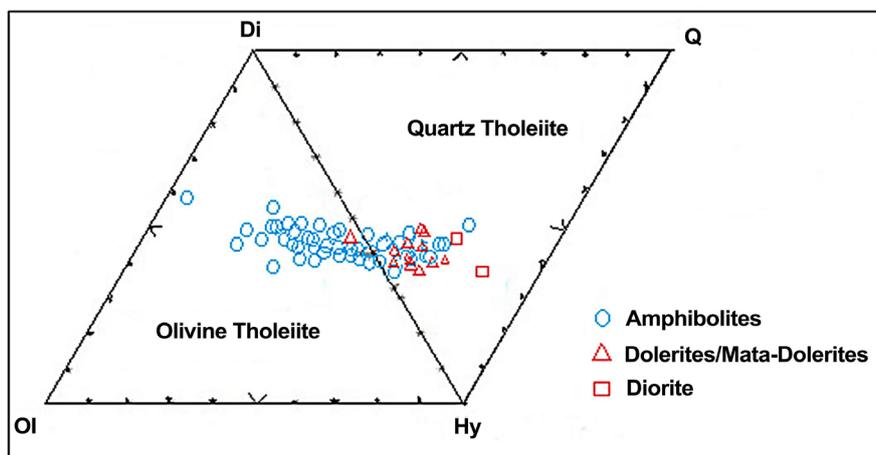


Figure 6. classification of bastar dykes (Source: Verma, R., 1998).

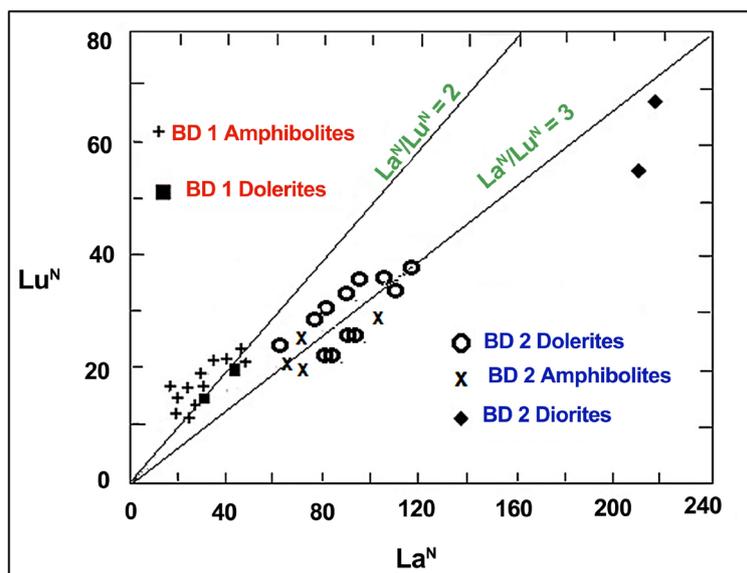


Figure 7. La^N/Lu^N DIAGRAM (Source: Verma, R., 1998).

5. Petrology and Geochemistry of Bastar Granitoids

5.1. Petrology and Petrography

The Bastar Granitoids/Granite Gneisses are coarse-grained grey coloured leucocratic rocks. The chief constituents are Quartz (27% - 45%), Microcline (13% - 31%) and Plagioclase (3% - 12%). Biotite content is as low as 3% in Granites while it is as high as 17% in the Granite Gneisses. Other accessory minerals are Apatite, Muscovite and Sphene. The Granite Gneisses possess the crude foliation due to the presence of ferromagnesian mineral Biotite. These granites show porphyritic and granoblastic texture while the Granite Gneisses show gneissose texture [8].

5.2. Geochemistry

The chemical analyses of the Bastar Granitoids representatives, are presented in Table 4. The major contents are SiO_2 (av. 70.80%), Al_2O_3 (av. 13.55%), Na_2O (av. 3.66%), K_2O (3.41%) and Fe_2O_3 (av. 2.51) and CaO (av. 1.32%). Among the trace elements, the prominent ones are "Cr" (52 - 598 ppm), "Sr" (55 - 419 ppm), "Zr" (138 - 501 ppm), "Th" (15 - 81 ppm) and "U" (4 - 28 ppm). "La" (52 - 70 ppm), "Ce" (102 - 181 ppm) and "Nd" (42 - 91 ppm) are the most numerous REE. Most of the other Rare Earth Elements were not detected in all the representative samples.

6. Crustal Contamination

Mantle derived magmas have been subjected to some degree of contamination [9]. Crustal contamination has been defined as "the contamination of mantle derived melts by continental crust after they have left the source region" [10].

Crustal contamination is very common to occur in the continental flood basalts and is often invoked to explain the high concentrations of large ion

Table 3. Average geochemistry of southern bastar mafic dykes (Source: Verma, R. 1998).

MAJOR OXIDES (wt. %)								
OXIDE	1	2	3	4	5	6	7	8
SiO ₂	50.69	51.20	49.31	49.92	53.17	50.40	51.18	50.36
TiO ₂	1.13	0.87	2.27	2.20	1.79	1.36	1.69	3.62
Al ₂ O ₃	14.17	13.46	13.00	13.38	13.56	15.91	16.01	13.41
Fe ₂ O ₃	14.51	14.38	17.50	17.16	16.53	10.01	9.40	13.63
MnO	0.19	0.19	0.21	0.22	0.20	0.18	0.16	0.18
MgO	6.17	7.50	4.81	5.10	2.18	8.96	6.90	5.52
CaO	10.03	9.90	9.02	8.82	6.91	11.43	11.49	9.60
Na ₂ O	2.58	1.94	2.47	2.21	2.97	2.30	2.74	2.80
K ₂ O	0.53	0.88	0.87	0.86	1.35	0.09	0.43	0.77
P ₂ O ₅	0.14	0.10	0.31	0.27	0.80	0.14	0.15	0.42
TRACE ELEMENTS (ppm)								
Cr	133	295	80	76	8	346	225	81
Ni	101	120	68	69	8	177	132	78
Rb	25	41	47	43	47	2.3	10.3	15.4
Ba	166	154	286	264	490	20	86	191
Sr	135	144	145	159	168	98	155	395
Nb	5	4	14	11	27	2.1	8.6	21.5
Zr	77	68	184	153	485	97	121	227
Y	27	24	50	41	108	37	39	42S
RARE EARTH ELEMENTS (ppm)								
La	6.86	7.69	20.16	17.46	47.90	2.95	6.92	24.00
Ce	16.47	17.91	47.64	39.00	113.11	12.00	17.60	53.00
Pr	2.10	2.17	6.03	4.96	14.22	--	--	6.00
Nd	9.53	8.85	23.67	20.55	57.95	9.90	13.60	35.10
Sm	2.67	2.37	6.68	5.33	14.90	3.91	4.64	8.90
Eu	1.01	0.80	2.18	1.80	3.92	1.41	1.55	2.98
Gd	3.70	3.26	8.50	6.81	18.30	6.40	6.00	9.10
Dy	3.90	3.32	8.11	6.52	16.95	5.60	--	7.58
Ho	0.90	0.78	1.84	1.50	3.84	--	--	1.41
Er	2.58	2.22	4.99	4.09	10.33	--	--	3.64
Yb	2.61	2.30	4.88	4.06	10.03	3.61	3.46	3.04
Lu	0.40	0.36	0.75	0.63	1.56	0.50	0.46	0.42

Lithophile elements (LILE) in these basalts [11] [12] [13] [14]. Assimilation and enrichment of LILE from the wall rock may be expected to occur if the magma was flowing turbulently—a condition thought to exist in the basic dykes over 3 m in width [15]. Evidence for the nature of contaminants of Deccan Traps magmas may be provided by crustal xenoliths in Lamprophyre and Tholeiitic dykes that intruded the Deccan lava pile towards the end of volcanic activity. The potential

Table 4. Geochemical analyses of bastar granitoids (Source: Hsean 1994).

MAJOR ELEMENTS		SAMPLE				
OXIDE Wt. %	BG1	BG 2	BG 3	BG 4	BG 5	BG 6
SiO ₂	71.36	74.49	71.76	64.5	72.57	70.16
TiO ₂	0.38	0.09	0.24	0.42	0.13	0.38
Al ₂ O ₃	13.99	12.6	13.05	12.7	13.58	15.42
Fe ₂ O ₃ (T)	1.76	1.62	2.53	4.72	1.76	2.67
MgO	0.29	0.30	0.52	1.55	0.044	0.6
MnO	0.04	0.04	0.05	0.25	0.06	0.07
CaO	1.85	0.48	3.9	4.04	0.57	0.73
Na ₂ O	4.53	3.44	4.59	3.21	3.81	2.39
K ₂ O	4	5.3	1.88	3.49	4.54	3.85
P ₂ O ₅	0.07	0.04	0.05	0.81	0.21	0.07
LOI	1.01	0.46	1.25	1.48	1.21	1.86
TOTAL	99.28	98.86	99.82	97.17	98.484	98.2
TRACE ELEMENTS						
Cu	14	6	4	14	16	15
Ni	11	18	13	59	17	49
Co	ND	66	6	62	ND	ND
Sc	2	21	9	9	5	8
Zn	29	39	35	80	28	48
Ga	24	22	19	19	22	21
Pb	48	121	24	28	44	64
Cr	300	100	361	52	362	598
Th	15	81	21	23	72	49
Rb	131	352	55	123	291	192
U	10	28	4	9	18	12
Sr	271	55	419	799	92	240
Y	11	99	31	37	32	29
Zr	169	501	321	333	138	392
Nb	10	29	15	39	28	23
Ba	15	17	82	741	567	262
V	ND	4	22	ND	ND	ND
Hf	ND	ND	ND	ND	ND	ND
Ta	ND	ND	ND	ND	ND	ND
La	ND	52	56	70	ND	ND
Ce	ND	111	102	181	ND	ND
Pr	ND	18	14	33	ND	ND
Nd	ND	47	42.4	91	ND	ND
Sm	ND	11	8	15.1	ND	ND
Eu	ND	4.2	2.1	3.2	ND	ND
Gd	ND	9.2	5.6	9.1	ND	ND
Tb	ND	2.3	1.1	2.2	ND	ND
Dy	ND	11.3	4.1	6.2	ND	ND
Ho	ND	2.4	1.1	1.8	ND	ND
Er	ND	10	3.3	1	ND	ND
Tm	ND	2	1	1	ND	ND
Yb	ND	11	4	11	ND	ND
Lu	ND	2	1	1	0.8	ND

contaminants are represented by xenoliths that include mafic (plagioclase-poor) Granulites and felsic (plagioclase-rich) Granulites [16]. Crustal contamination of mafic magmas has been reported from Proterozoic Isortoq Dyke Swarm, South Greenland [17]. Incompatible trace element data of mafic dykes in part of Chotanagpur Gneissic Complex, suggest enriched source characteristics and influence of crustal contamination in their genesis [18].

Crustal contamination has been reported within Picritic Magmas during Transport through Dykes: the Expo Intrusive Suite, Cape Smith Fold Belt, New Quebec [19]. Contrasting mechanisms for crustal sulphur contamination of mafic dyke and sill complexes from the British Palaeogene Igneous Province has also been reported [20].

Metasomatic mantle source and crustal contamination have been reported for the formation of the Neoproterozoic mafic dike swarm in the northern Yangtze Block, South China [21].

A reported on the Geochemistry and Tectonic Setting of the Eshan Granites in the Southwestern Margin of the Yangtze Plate, Yunnan. Major and trace element analyses suggest that the magmas of the Pojiao Unit Granites, was derived by partial melting of a clay-poor source from the upper crust; the magmas of the Lüzcun Unit granites derived by partial melting of upper crust with a small proportion of middle crust accompanied by crystallization of Albite which triggered strength reduction [22].

[23] has evaluated the Geochemistry and Petrogenesis of Mafic Doleritic Dykes at Mbaoussi (Adamawa Plateau, Cameroon, Central Africa). They have also confirmed little or no crustal contamination from the host Granites. They have reported a low values (3 - 7) of $(Ce/Yb)_N$ suggesting a fairly high partial melting degree of the sub-continental lithospheric mantle, whose composition was close to fertile mantle component, yet Nb-Ta depleted after a former subduction.

To observe the effect of contamination from Granites, in the Bastar dyke swarms, Primordial mantle-normalized multi-element spidergrams and Chondrite-normalized rare-earth element patterns (Figures 8-11) have been examined. Primordial mantle-normalized multi-element spidergrams, for the average of BD1 and BD2 dykes and the average of Bastar Granitoids, the host rock of Bastar dykes [24] are compared in Figure 8 & Figure 10. Similarly, Chondrite-normalized rare-earth element patterns for the average of BD1 and BD2 dykes with the average of Bastar Granitoids are compared in Figure 9 and Figure 11, respectively.

Comparison of Spidergrams of BD1 dykes and Bastar Granitoids (Figure 8) show that both have almost similar trends in LILE and "Nb" but other HFSE show different trends. BD1 dykes show flat pattern but Granitoids show negative "Sr" and "Ti" anomalies with high "La", "Ce", "Nd" and "Zr" concentrations. LILE and "Nb" concentrations in Granitoids are much higher (6 to 10 folds) in comparison to that in BD1 dykes. These observations do not support any contamination of BD1 dykes by these Granitoids.

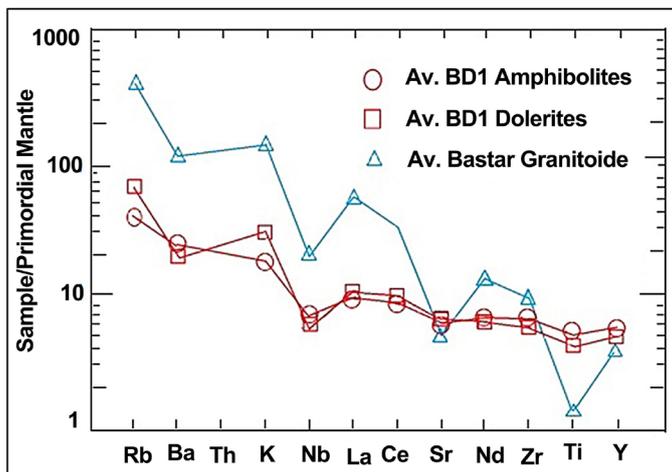


Figure 8. Multi-element spidergram of bastar granitoids & BD1 dykes (Source: Verma, R., 1998).

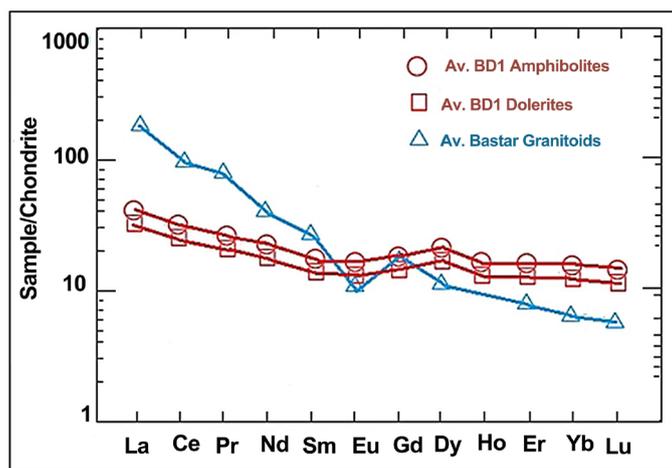


Figure 9. Ree pattern of bastar granitoids & BD1 (Source: Verma, R., 1998).

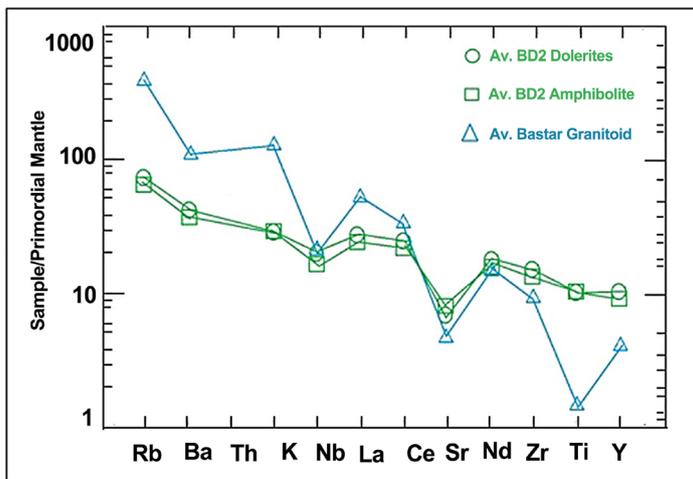


Figure 10. Multi-element spidergrams of bastar granitoids & BD2 dykes (Source: Verma, R., 1998).

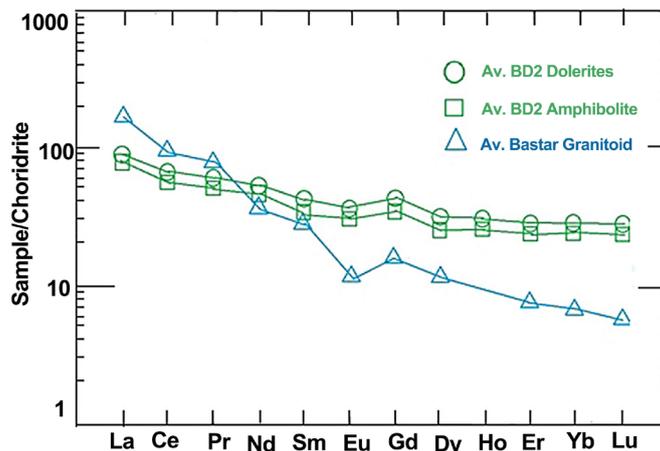


Figure 11. Ree pattern of bastar granitoids & BD2 dykes (Source: Verma, R., 1998).

This inference is corroborated by rare-earth element patterns (Figure 9). BD1 dykes show almost flat pattern with very little LREE enrichment, whereas the Granitoids show LREE enriched and HREE depleted pattern with negative “Eu” anomaly. It is clear that the Granitoids could not possibly supply the required amount of HREE to BD1 dyke swarms. Similar results are obtained for the pattern of multi-element Spidergram of BD2 dyke & Bastar Granitoids (Figure 10) and REE pattern of BD2 dykes and Bastar Granitoids (Figure 11). BD2 dykes have higher concentrations of “Nd”, “Zr”, “Ti” and “Y” as well as REE (“Sm” to “Lu”) than in the Bastar Granitoids, which again obviates any possibility of crustal contamination with these Granitoids.

The average “Nb”/“La” and “Nb”/“Ce” ratios of BD1 and BD2 swarms, have been taken from the work done by the author. And the average “Nb”/“La” and “Nb”/“Ce” ratios of Bastar Granitoids, have been taken from the thesis of Hsean [24]. Average primordial mantle and average crust values have been taken from [25] and [26] respectively. All these values are presented in Table 5.

The ratios of “Nb”/“La” and “Nb”/“Ce” in the Bastar dykes are lower than in the primitive mantle. Bastar dykes have higher average Nb/La ratios than in the average crust but at the same time, they have lower average “Nb”/“Ce” ratio than in the average crust. This contrast is not possible had there been any crustal contamination. Similarly, Bastar dykes have much higher average “Nb”/“La” ratios than in the Bastar Granitoids, although they have similar “Nb”/“Ce” ratios. Such a high “Nb”/“La” ratio of Bastar dykes is not possible from Granitoids contamination.

Table 5. Comparative Nb/La and Nb/Ce Ratio.

Ratio	BD1 (a)	BD2 (a)	Av. Bastar Granitoids (b)	Primordial Mantle (c)	Average Crust (d)
Nb/La	0.62	0.61	0.46	1.01	0.46
Nb/Ce	0.26	0.20	0.21	0.39	0.30

Sources: Verma, R. (1998)^a; Hsean (1994)^b; McDonough *et al.*, (1992)^c; Weaver and Tarney (1981)^d.

7. Conclusions

[9] [10] have very clearly defined the crustal contamination as “the contamination of mantle-derived melts by continental crust. Further [11] [12] [13] [14] [19] [21] [22] [23] have carried out intensive research on the possibilities of crustal contamination from different dyke swarms, globally.

The current work is also streamlined with the same motive. After a comprehensive petrological and geochemical study, the following conclusion has been drawn.

The comparative study of the Primordial mantle-normalized multi-element spidergrams, and Chondrite-normalized rare-earth element patterns (**Figures 8-11**) for the average of BD1 and BD2 dykes and the average of Bastar Granitoids, clearly reflect that the great degree of variation in LIL elements, observed in the Bastar dykes, is either due to metamorphism or due to secondary alteration, and not due to crustal contamination. This is further supported by much higher average “Nb”/“La” ratios in Bastar Mafic Dykes, than in the Bastar Granitoids.

Considering the above discussion on the possibility of any crustal contamination or wall rock reaction, it may be concluded that crustal assimilation has played a little or no role in the petrogenesis of the Bastar mafic dykes. Their unusual incompatible element characteristics are certainly mantle derived.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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