

## Geochemistry of Mafic Dykes of Chittoor District, Andhra Pradesh, Southern India

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**Abstract:** Mafic dykes are a kind of minor intrusions, usually occur within granitic pluton in Chittoor district, Andhra Pradesh, India. The origin of these dykes and its implications to the formation of granitic plutons in Chittoor were studied. The analytical results suggest that these mafic dykes are alkali dolerite and derived from continental arc. The mafic dyke samples contain 5.61wt % MgO; exhibit negative Ba, Nb, Sr, Zr and Ti anomalies and they are enriched in Cs, Rb, U, K, Nd and Sm. It suggests that the mafic dykes are subduction related and contaminated during their intrusion. It is concluded that mantle wedge melting during the subduction process and basaltic underplating had provided the necessary heat to cause partial melting of continental crust, and generation of voluminous felsic magma.

**Keywords:** Mafic dykes, Geochemistry, Petrogenesis, subalkaline and alkaline

### Introduction

Mafic dykes and Dyke swarms, having different orientations, are conspicuous in all the protocontinents of Indian Shield *viz.* Aravalli-Bundelkhand Protocontinent, Dharwar Protocontinent, Bastar – Bhandra Protocontinent and Singhbhum Protocontinent<sup>1,2</sup>. Further the mafic dykes are often parallel to major transpersonal shear zones, which clearly indicates the tectonic control on their genesis. Hence, injection of mafic dykes at intervals throughout the Proterozoic provides a window to monitor mantle evolution and /changing magmatic style<sup>3,4</sup>. A number of geochemical studies were carried out, with emphasis on the nature of the deep crust and the origin of igneous rocks. According to Drury<sup>5</sup> and Murthy *et al.*,<sup>6</sup> in the southern region near Tirupati the oldest NE-SW trending dykes are followed by NNE trending dykes and the NW trending dykes emplaced near Anantapur in the southwestern area were oldest which were followed by NE-SW trending dykes. The intrusive igneous rocks in Chittoor include sub-volcanic intrusions of granodiorite and granite, minor intrusions of monzonite, quartz monzonite, rhyodacite, rhyolite and Precambrian mafic dykes are also noticed. In spite of the above detailed studies, uncertainties regarding the formation of such large granitoid bodies in Chittoor district were still under question. It was believed that continuous and huge amount of heat was required for the extensive crustal

melting and generation of voluminous felsic magma in Proterozoic. However, the source of heat to cause the partial melting of continental crust was unknown. Within some granite plutons, there are mafic dykes which are believed to be derived from mantle magmas. The present study was carried out to determine the origin of the mafic dykes with control on the partial melting event occurred during Proterozoic.

## Experimental

Fifteen rock samples were collected from five mafic dykes (D1 to D5) in Chittoor district, Andhra Pradesh, India (Location: 12°37' - 14°8' north latitudes and 78°3' - 79°55' east longitudes). Samples collected did not display any evidence of oxidation or hydration in hand specimen. Chilled margins are defined on the basis of both grain size and chemical composition. Detailed petrographic studies were carried out followed by the chemical analysis.

Major oxides were obtained using the X-ray fluorescence (XRF) on fused glass pellets. Accuracies of the XRF analysis were estimated as 2% for major elements present in concentrations greater than 0.5 wt% and 5% for trace elements. Trace elements Rb, Th, U, Nb, La, Sr, Ce, Nd, Zr, Hf, Sm, Tb, Y and Pb, including Rare Earth Elements (REE) were determined by a VG Elemental Plasma Quad 2 inductively coupled plasma-mass spectrometer (ICP-MS). The analysis yields accuracies better than 5%. Elements were measured simultaneously and a complete analysis can be made in the space of about 2 minutes, making it an extremely rapid analytical method.

### *Petrography*

Mafic dykes occurring as individual, clusters and swarms intruding into Precambrian litho units, that exposed in Chittoor district. These mafic dykes are strong, dark greenish black in colour and slightly decomposed. The wall rock is granite, which is also strong, massive, pinkish-grey, with medium grained in texture. The contact between the dyke and wall rock is sharp and with fine grained at the chilled margin. The dyke is basically composed of basaltic composition with ophitic texture, including plagioclase feldspar, clino-pyroxene olivine, epidote and interstitial glass. The phenocrysts of quartz, olivine and biotite are observed in some and some of the phenocryst showed alteration by epidote and chlorite.

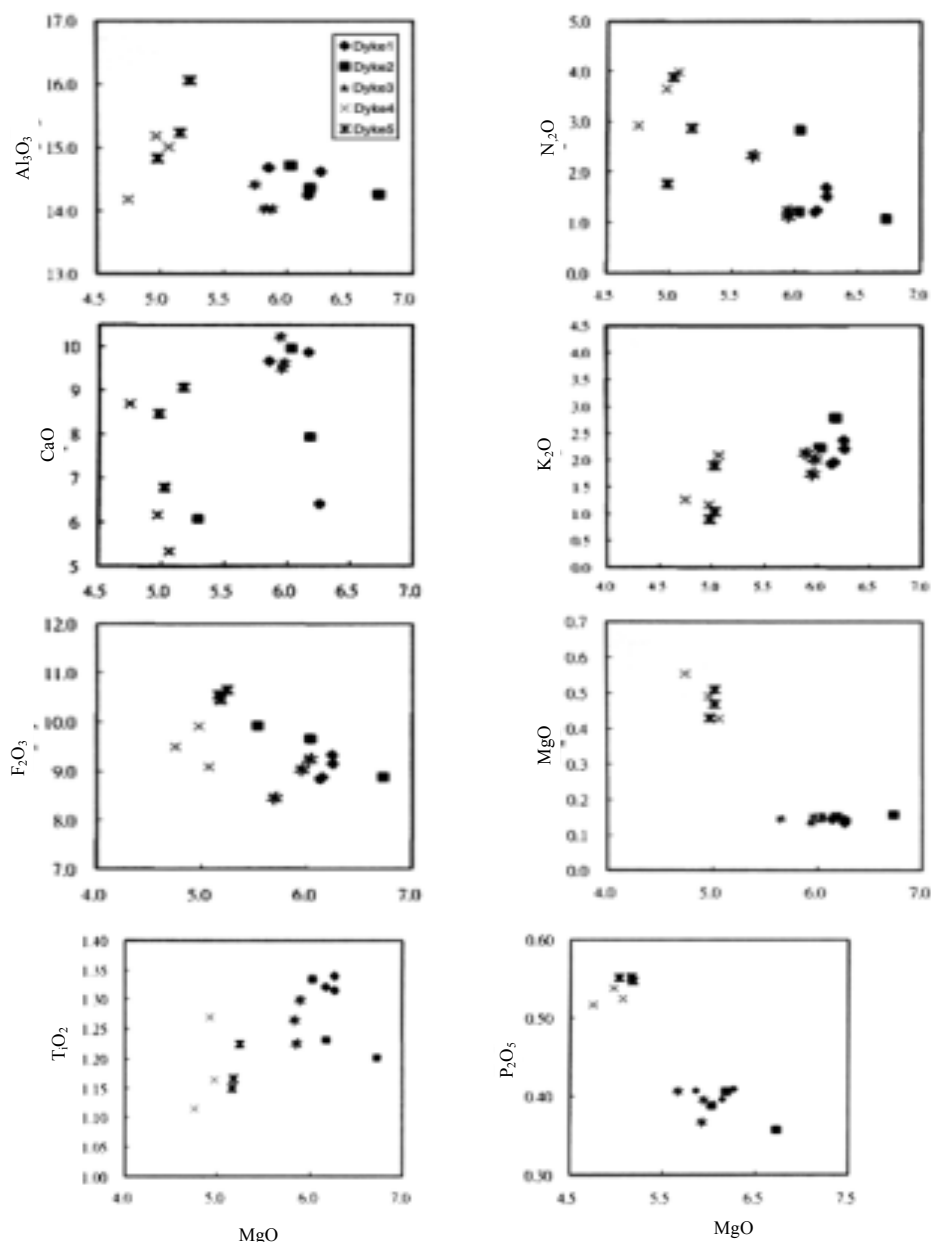
## Results and Discussion

### *Major oxides*

Major element data are shown in (Table 1). Since the dykes in the Chittoor were intruded to a very shallow crust surface and very fine grained, they could be classified as sub-volcanic rocks. With reference to the TAS diagram<sup>7</sup> for volcanic rocks (Figure 1), most of the samples in this study are classified as basalt and a few of them are trachy basalt, which usually be found on stable continental crust or some oceanic islands. The silica content of the samples is within 46.5% to 51.62%, which fall in the range of basic rocks. The AFM diagram plotted at its apices - Alkalis ( $\text{Na}_2\text{O} + \text{K}_2\text{O}$ ), Fe oxides ( $\text{FeO} + \text{Fe}_2\text{O}_3$ ) and MgO. The diagram shows boundary between the calc-alkaline field and the tholeiitic field. Most of the rock samples in the falls in the field of calc-alkaline (Figure 2).

Irvine & Baragar<sup>8</sup> developed the Bivariate plot of silicate against total alkalis which divides rocks into sub-alkaline and alkaline series (Figure 3). The samples of this study area were plot in the sub-alkaline field. The samples of this study are rich in silica (46.6% to 51.6%) and the concentration of alkalis ranges from 3.6% to 6.1%, which indicates the magma was initially rich in pyroxene and olivine than alkali one. As the magma evolved, it was gradually depleted of pyroxene and olivine, and plagioclase and K-feldspar (Alkali-rich minerals) are crystallized.

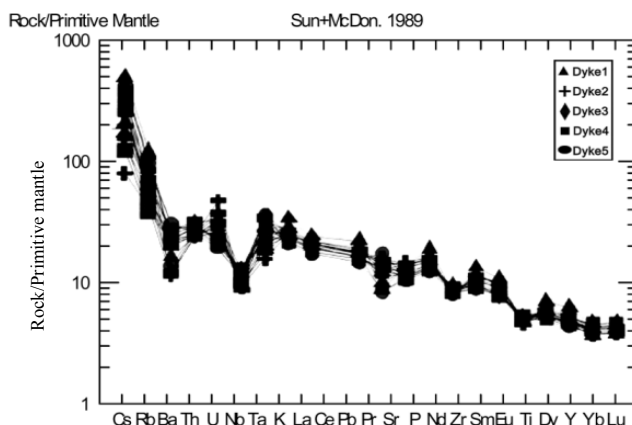




**Figure 4.** Harker variation diagram for mafic dykes of the study area

#### *Trace elements and rare earth elements*

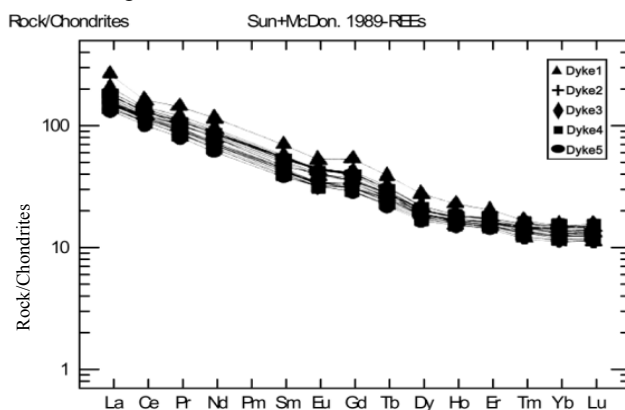
The trace and REE concentrations are given in Table 1. Trace elemental data are normalized<sup>9</sup> to the primitive mantle (Figure 5). These dykes exhibit negative anomalies of Ba, Nb, Sr, Zr and Ti, and they are enriched in Cs, Rb, U, K, Nd and Sm. The result reflects the magma is contaminated by crust during its intrusion. Moreover, all samples show negative Nb and Ta anomalies and positive Pb anomalies, which are similar to island arc volcanics and continental crustal rocks.



**Figure 5.** Primitive mantle normalized Trace elemental patterns (Normalization values are from Sun and Mc Donough<sup>9</sup>).

Chondrite-normalized REE pattern shows in Figure 6. The pattern is controlled by the REE chemistry of its source and the crystal-melt equilibria that have taken place during its evolution. The reasoning here is based upon the partition coefficients for the REE in the major rock-forming minerals. From the diagram, LREE enrichment and slight negative Eu anomalies. Feldspars (both plagioclase and potash feldspars), particularly in felsic magmas chiefly control europium anomalies. Therefore, the removal of feldspar from a felsic melt by crystal fractionation or the partial melting of a rock in which feldspar is retained in the source will give rise to a negative Eu anomaly in the melt. The extreme depletion of the HREE relative to the LREE may due to the large variation in the partition coefficients of the REE. The absence of a negative Ce anomaly indicates that these rocks are generally not affected by low-temperature alteration.

The Rb/Sr ratio of mantle segment is of 0.24. The contaminated crust, on the other hand, which has differentiated from the mantle showing higher Rb/Sr ratio upto 0.320, and consequently radiogenic<sup>8</sup> Sr than the mantle<sup>10</sup>. A still higher value of 0.35 was calculated by Shaw *et. al.*,<sup>11</sup>. The data for this study area indicates (Rb/Sr ratio is 0.12 to 0.4) that this dolerites are of assimilation product.



**Figure 6.** Primitive mantle normalized REE diagram (Normalization values are from Sun and Mc Donough<sup>9</sup>).

**Table 1.** Major oxides (Wt%) and Trace and REE (ppm) concentrations of mafic dykes

Element	Dyke - 1		Dyke - 2				Dyke - 3		Dyke - 4			Dyke - 5			
	DBS1	DBS2	DBS3	DBS4	DBS5	DBS6	DBS7	DBS8	DBS9	DBS10	DBS11	DBS12	DBS13	DBS14	DBS15
SiO <sub>2</sub>	51.620	49.245	50.419	47.753	46.510	47.348	47.031	48.204	48.426	47.888	50.547	49.739	46.615	49.222	50.179
TiO <sub>2</sub>	1.340	1.321	1.314	1.201	1.231	1.334	1.369	1.289	1.235	1.114	1.205	1.232	1.165	1.181	1.224
Al <sub>2</sub> O <sub>3</sub>	15.266	14.246	14.623	14.259	14.360	14.719	15.524	14.209	14.405	14.185	15.028	15.385	15.544	15.487	16.061
Fe <sub>2</sub> O <sub>3</sub>	9.267	9.377	9.030	8.873	9.234	9.653	8.524	9.247	8.834	9.497	9.090	11.496	10.457	11.753	10.655
MnO	0.134	0.149	0.143	0.157	0.151	0.149	0.150	0.157	0.133	0.554	0.429	0.468	0.501	0.575	0.501
MgO	6.257	6.166	6.264	6.724	6.181	6.029	5.665	5.980	5.949	4.747	5.066	5.025	5.173	5.289	5.236
CaO	6.405	9.8641.278	8.663	8.280	7.929	9.953	9.416	9.676	10.243	8.689	5.340	6.689	9.062	6.117	5.193
Na <sub>2</sub> O	1.264	1.278	1.407	1.058	1.425	1.197	2.230	1.137	1.177	2.919	3.986	2.541	2.866	2.164	1.742
K <sub>2</sub> O	2.375	1.965	2.212	2.906	2.791	2.226	1.340	2.122	1.739	1.270	2.096	1.899	1.364	2.894	3.185
P <sub>2</sub> O <sub>5</sub>	0.409	0.465	0.409	0.357	0.406	0.388	0.408	0.397	0.375	0.517	0.524	0.551	0.547	0.563	0.585
LOI	4.230	4.790	4.350	7.65	8.680	6.150	7.570	6.880	6.720	7.340	4.220	3.780	5.790	3.340	4.060
Total	98.568	98.865	98.746	99.21	98.899	99.145	99.317	99.198	99.236	98.720	97.520	98.806	99.084	98.584	99.248
Trace elements and REE															
Cs	12.086	13.427	15.726	23.283	16.390	25.546	4.355	20.403	12.906	8.970	32.433	5.092	2.403	5.745	5.733
Ba	461.81	397.72	447.56	545.11	539.37	172.88	340.08	443.80	361.91	139.97	319.53	282.64	329.79	405.11	404.29
Th	6.813	6.119	6.509	5.064	5.408	5.137	6.087	6.066	5.735	4.484	4.664	4.873	4.898	5.089	5.079
U	1.785	0.999	1.045	0.845	0.902	0.842	1.025	1.040	0.934	1.316	1.774	1.722	3.026	2.331	2.327
Nb	15.985	14.432	15.328	12.759	14.626	13.868	15.806	14.965	13.591	9.842	9.944	10.455	10.814	11.04	11.02
Rb	128.19	117.02	130.64	25.36	217.25	250.75	66.281	152.11	104.38	152.91	352.93	121.67	79.541	217.02	216.59
Ta	1.119	0.922	0.914	0.740	0.853	0.784	0.856	0.810	0.747	0.522	0.566	0.553	0.571	0.578	0.577
La	36.622	35.055	35.984	30.645	34.791	32.947	40.424	35.373	32.498	37.868	47.295	40.371	40.660	45.481	45.389
Ce	70.909	70.210	72.518	61.060	69.692	64.671	79.133	68.517	65.017	73.366	85.330	78.686	79.286	85.998	85.824
Pr	8.904	8.646	8.788	7.379	8.442	8.004	9.586	8.421	8.005	9.422	11.137	10.050	10.103	11.080	11.058
Nd	33.732	33.195	33.566	28.412	32.222	31.127	36.488	32.518	30.439	36.401	43.155	39.050	39.417	43.132	43.405
Sm	6.769	6.529	6.649	5.764	6.304	6.193	7.064	6.417	5.992	7.602	8.656	8.0852	8.286	8.873	8.855
Eu	1.978	1.926	1.979	1.856	1.985	1.826	2.296	1.903	1.808	2.231	2.461	2.567	2.2525	2.620	2.614
Gd	6.839	6.502	6.678	5.787	6.351	6.199	7.174	6.358	5.912	7.167	8.483	7.827	7.866	8.4921.192	8.475
Tb	0.971	0.932	0.954	0.806	0.917	0.866	1.021	0.912	0.847	0.980	1.176	1.068	1.079	1.194	1.191
Dy	4.999	4.781	4.905	4.212	4.659	4.569	5.158	4.679	4.373	4.675	5.445	4.896	5.111	5.670	5.659
Ho	0.987	0.938	0.998	0.844	0.942	0.910	1.007	0.933	0.874	0.862	1.030	0.926	0.959	1.051	1.049
Er	2.858	2.662	2.809	2.408	2.66	2.557	2.833	2.624	2.509	2.321	2.803	2.488	2.603	2.838	2.832
Tm	0.399	0.370	0.393	0.337	0.376	0.364	0.392	0.368	0.342	0.304	0.365	0.331	0.342	0.386	0.385
Yb	2.574	2.323	2.484	2.104	2.380	2.277	2.525	2.346	2.181	1.887	2.235	2.022	2.105	2.364	2.359
Lu	0.388	0.358	0.380	0.317	0.358	0.345	0.377	0.360	0.334	0.286	0.338	0.300	0.318	0.350	0.349

### *Partial melting and crustal fractionation*

The trace element and ratios should vary considerably throughout the formation of rock, the enrichment in incompatible and depletion in compatible elements increasing uniformly with smaller degree of melting or more advanced crystal fractionation. The most highly incompatible elements such as Rb, Nb, Ta and Th should increase more rapidly than Sr and REE<sup>12</sup>. At depths of less than 40 km, plagioclase can be stable phase and will exert significant control on trace element patterns, because its distribution coefficients for REE, Sr/Ba differ markedly from those of other common igneous minerals. The depletion of Sr/Ba and negative Eu anomaly together with enrichment of incompatible elements reflects the dominants of plagioclase in the late stages of differentiation<sup>13</sup>.

### *Contamination and mixing*

The contamination, in the more common usage of the world, means built assimilation of crustal rocks by a mantle magma and this should be amenable to the mixing model. Trace elements are generally prepared for this purpose, since they frequently show a greater range of variation than major elements. The trace elements are mostly affected and becoming enriched in the altered igneous rocks, which are most mobile during weathering and show become relatively enriched (*i.e.* Na, K, Rb, Cs, Sr, Ba and P). On the other hand Ti, Zr, Nb, Y and HREE are extremely resistant to alteration (and/or relatively depleted) in metamorphosed basalts<sup>14,15</sup>.

### *Petrogenesis*

The AFM diagram, Indicates that most of the rock samples in the study are calc-alkaline. Calc-alkaline rock is given to suite of rocks comprising the plutonic association of gabbro- diorite-granodiorite - granite. They are typically developed on the continental side of plate subduction zones. The mafic dyke rocks in this study have relatively low TiO<sub>2</sub> and Nb/La ~0.40 which are similar to the rocks that associated with the seduction process<sup>15</sup>. The dykes were also enriched in elements Cs, Rb, U, K, Nd, Sm, which are commonly enriched in subduction related rocks<sup>16</sup>. It suggests that mantle sources previously modified by subduction processes. The plotting of magnesium oxide against major oxides and trace elements, it is suggested that the magma sources of intrusion were different and result in the difference of geochemical composition. Another possible reason that contributes to the difference is that the dykes were from the same magma chamber but intruded in different time period. It is accepted that the mafic dykes were derived from mantle magma. Contamination of asthenospheric melts occurs during their ascent through the lithosphere. This contribute to a marked increase of Cs, Rb, U, K, Nd, Sm and LREE; little change in Ba, Nb, Sr, Zr, Ti and HREE concentrations. Thus, negative anomalies of Ba, Nb, Sr, Zr, Ti and Rb/Sr are resulted. It can be explained by the fact that the mafic magma was contaminated by the granitic country rock.

### **Conclusion**

Most of the dyke rock in the study area is calc-alkaline dolerites in nature. The mafic dyke rocks have relatively low TiO<sub>2</sub> and Nb/La ~0.40 which are similar to the rocks that associated with the subduction process. The mafic dykes were enriched in elements Cs, Rb, U, K, Nd, Sm, which resembles the subduction related rocks. Thus it is suggested that the magma sources of intrusion were different and result in the difference of geochemical composition or intruded in different time period. A marked increase of Cs, Rb, U, K, Nd, Sm and LREE; little change in Ba, Nb, Sr, Zr, Ti, Rb/Sr and HREE concentrations suggests the mafic magma was contaminated by the granitic country rock.

## References

1. Naqui S M, Geology and evolution of the Indian plate. Capital Publishing Company, New Delhi, India, 2005, 450.
2. Srivastava R K, Sivaji C H and Chalapathi Rao N V, (Eds.), Indian Dykes: Geochemistry, Geophysics and Geochronology. Narosa Publishing House Pvt. Ltd., New Delhi, 2008, 626.
3. Tarney J, Geochemistry and significance of mafic dyke swarms in the Proterozoic. In: Condie K C, (Ed.), Proterozoic Crustal Evolution. Elsevier, Amsterdam, 1992, 151-179.
4. Hall R P and Hugges D J, J Geological Society of London. 1993, **150**, 625- 635.
5. Drury S A, *J Geol Soc India*, 1984, **25(7)**, 437-444.
6. Murthy Y G K, Babu Rao D, Guptasarma, Rao J M, Rao M.N and Bhattacharji S, Tectonic, Petrochemical and geophysical studies of mafic dyke swarms around the Proterozoic Cuddapah Basin., South India, In: Mafic dyke swarms (Ed., Halls H C, and Fahrig W F), Geol Ass Canada, 1987, **34**, Spl. Paper, 303-316.
7. Lebas M J, Lemaitre R W, Streckeisen A and Zanettin B, *J Petrology*, 1986, **27(3)**, 745-750.
8. Irvine T N and Baragar W R A, *J Geol Soc Canada*, 1971, **8**, 131-148.
9. Sun S S, McDonough W F, Special Publication, Geological Society, 1989, **42**, 313-345.
10. Taylor S R, *Geochim Cosmochim Acta*, 1964, **28**, 1273-1285.
11. Shaw D M, Reilly G A, Muysson J R, Pattenden G E and Campbell F E, *Can J Earth Sci.*, 1967, **4**, 829-853.
12. Staudigel H and Hart S R, *Geochim Cosmochim Acta*, 1983, **47**, 337-350.
13. Zielinski R A, *Geochim Cosmochim Acta*, 1975, **39**, 713-734.
14. Pearce J A and Cann J R, *Earth Plan Sci Lett.*, 1973, **19**, 290-300.
15. Winchester J A and Floyd P A, *Earth Plan Sci Lett.*, 1976, **28**, 459-469.
16. Hart S R and Brooks C J, *Contr Mineral Petrol.*, 1977, **61**, 109-128.