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Research Article

PETROLOGY, GEOCHEMISTRY AND TECTONIC SETTING OF MAFIC DYKE SWARMS OF KADIRI SCHIST BELT, EASTERN DHARWAR CRATON, SOUTH INDIA

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ABSTRACT
The mafic dyke swarms of Kadiri Schist Belt revealed the voluminous emplacement of mafic melts through the continental crust. They represent the last phase of igneous activity in the area. They are essentially doleritic in composition; gabboroic dykes are also seen at places. The mineral assemblage classifies them into olivine dolerite, quartz dolerite and micrographic pegmatite dolerite. These dykes exhibit NE-SW, NW-SE & E-W trends. The rocks are characterized by ophitic to flow type of textures. The petrological and geochemical interpretation revealed that the dolerites of the study area resemble those of continental tholeiites. The parent magma is of tholeiite which on differentiation gave rise to different types of dolerites in the study area. The petrogenetic studies attribute 30 to 40 kms thick crust at the time of emplacement of these dykes.

Key Words: *Kadiri Schist Belt, Dolerites, Gabbroic Dykes, Tholeiites*

INTRODUCTION
Eastern block of Dharwar Craton has been profusely intruded by the mafic dyke swarms during Precambrian times. They are an important feature of most cratonic blocks (Halls, 1982). The available geochronological data on the dykes around cuddapah basin suggest four major episodes of dyke intrusive activity during 1700-1800 ma, 1300-1500 ma, 1000-1200 ma and 650 ma. (Padmakumari and Dayal, 1987). Rao *et al.*, (1992) assigned Rb-Sr age of 1875 ± 84 ma for the ENE-NSW trending dykes of Kadiri Schist Belt.

Geological Setting
The study area is a part of Kadiri Schist Belt which lies between North latitude 14° 05' and 78° 12'30" in the Survey of India Toposheet No. 57 J/4 and is geologically mapped on 1:50,000 scale (Figure 1). The Kadiri Schist Belt which lies in the Eastern Dharwar Craton includes bimodal, mafic-felsic, volcanic association like many Archaean greenstone belts (Barker and Peterman, 1974; Condie, 1981; Ayres *et al.*, 1985; Peate *et al.*, 1997). The kadiri schist belt is unique in having larger area occupied by meta-acid volcanics compared to basic volcanics and hence represents the higher stratigraphic level in the greenstone model of Anhaeusser *et al.*, (1969).
The rocks encountered in the study area are schist belt litho units, granitoids and mafic dyke swarms. The schist belt litho units comprise Rhyodacite, Rhyolite, Quartz Porphyry, Quartz Felspar Porphyry, Metabasalts and Metagabbros. The granitoids includes Tonalite Trondhjemite Granodiorite, Trondhjemite Granodiorite Monzogranite, Monzo Syenites and Alkali Granite suites.
The mafic dykes of the study area cut all along the schist belt litho units and adjoining granitoids. The bigger dykes traversing the schist belt litho units are boulder (Figure 2) while the dykes in the granitic terrain are massive.
They emplace along fractures which were originally present in the pre-existing rocks. They exhibit mainly three different trends namely NE-SW, NW-SE and E-W; however a few dykes show N-S trend also. The chilled margins are clearly seen in smaller dykes (Figure 3). At places, some dykes were seen off-set by lateral faults displaced either sinistrally or dextrally (Figure 4).

Petrography

The modal analysis of the dyke rocks classify them into three categories namely olivine dolerite, quartz dolerite and micrographic pegmatite dolerite (Table 1). Variations in the grain size are observed across the dykes; central portions are coarse, intermediate portions are medium and marginal portions are fine or glassy. The mineral assemblage constitutes plagioclase, clinopyroxene, orthopyroxene, olivine, micrographic pegmatite, quartz and opaques. The dyke rocks exhibit ophitic to flow type textures. The ophitic texture is present in the central portion, intergranular texture in the marginal portion and flow texture in chilled portions. Microscopic study shows that most of the samples are fresh, while a few of them show alteration features, such as formation of chlorite and epidote.

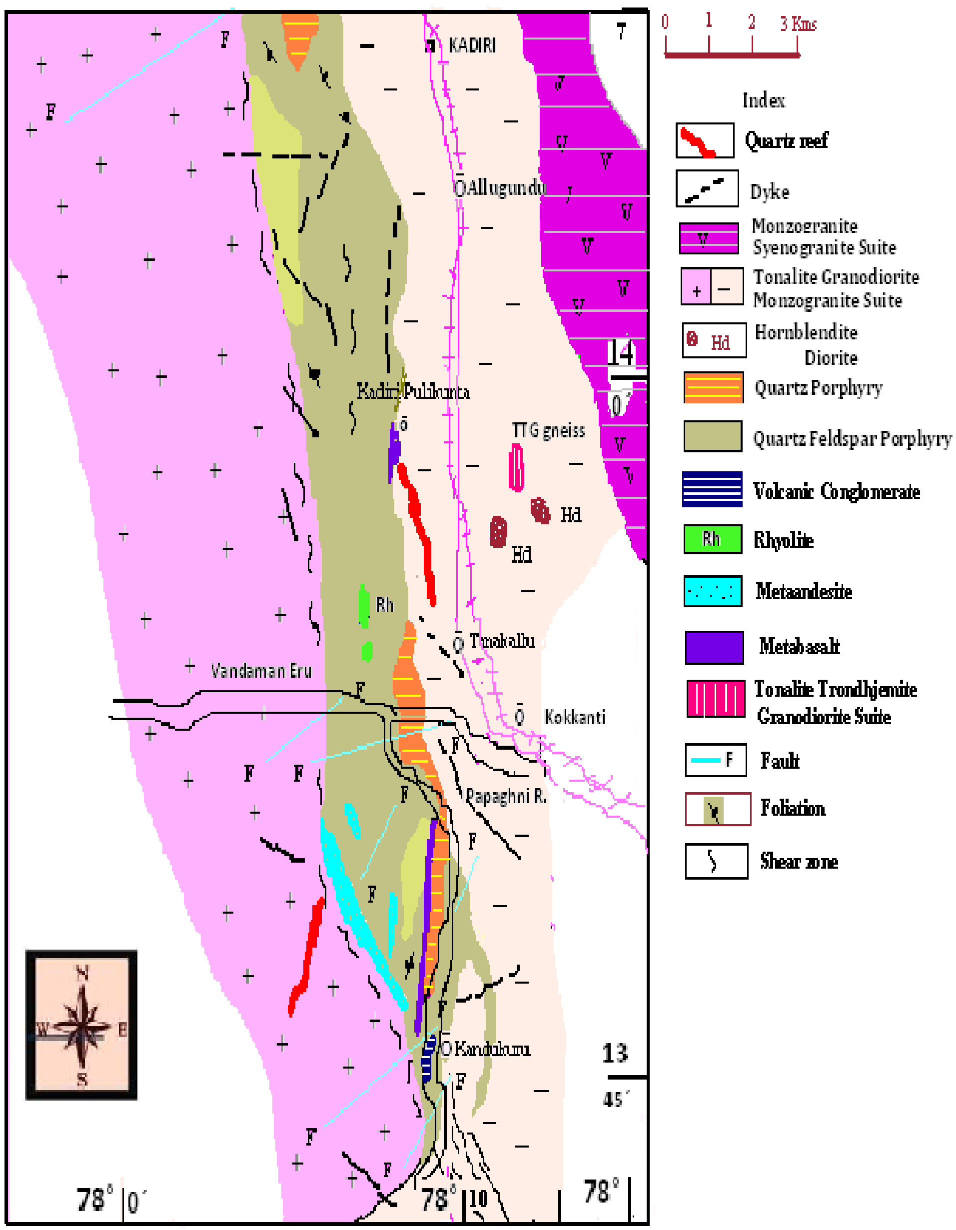

Figure 1: Geological Map of The Study Area (KSB)

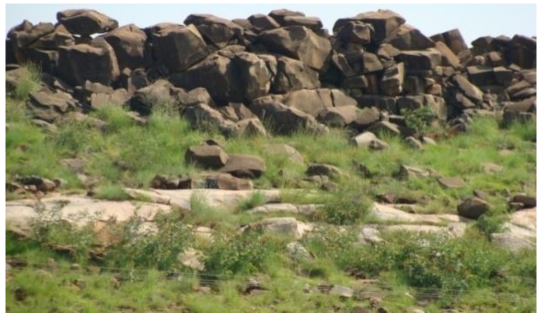

Figure 2: Bouldary Dyke in the Schist Belt

Figure 3: Chilled margins

Figure 4: Lateral faults in dykes

Olivine Dykes

They are medium grained, hard and compact rocks with dark brown colour. They exhibit intergranular texture with pyroxenes occupying the interstices between the plagioclase laths (Figure 5). Minerals present are olivine, clinopyroxene, plagioclase and opaques. Anhedral olivine is identified with its high relief, numerous cracks and is often charged with dusty opaque grains. It has 2V = (-) 74°, Nz-Nx = 0.038; and is found as inclusions in clinopyroxenes. Clinopyroxene is subhedral and mostly occurs as interstitial grains; however a few discrete grains are also noted. From its optical values, 2V = (+) 55°, Z ^ C = 44°; Nz-Nx = 0.025, it is identified as augite. Plagioclase (An 60-68) laths are mostly fresh, euhedral and twinned on albite, Carlsbad and albite-carlsbad laws. Concentrically zoned microphenocrystic plagioclase feldspars are also seen in olivine dykes. Opaque minerals are randomly distributed. The modal compositions are given in the Table 1.

Table 1: Modal Analysis of Dykes (Volume Percentages)

ROCK SAMPLE	1 PS204	2 PS153	3 PS 166	4 PS 174	5 PS 177	6 PS 179
Olivine	17	13	-	-	-	-
Clinopyroxene	46	41	34	41	39	41
Orthopyroxene	-	-	2	1	7	3
Plagioclase	35	44	52	47	42	45
Epidote	-	-	2	1	-	-
Chlorite	-	-	2	1	-	-
Quartz	-	-	4	2	3	2
Micrographic pegmatite	-	-	-	-	6	4
Opaques	2	2	4	7	3	5

1&2 Olivine Dykes, 3&4 Quartz Dykes, 5&6 Micrographic pegmatite dykes

Quartz Dykes

Quartz dykes exhibit ophitic to sub-ophitic texture. Plagioclase, clinopyroxene, orthopyroxene, and quartz are the major constituents; chlorite and epidote are seen as altered products. Opaques also occur as inclusions. By optics, clinopyroxene is identified as augite with 2V = (+) 56°, Z^C = 46° and Nz-Nx = 0.025 and sub-calcic augite 2V = (+) 36°, Z^C = 38° and Nz-Nx = 0.027. Plagioclase laths (An55-65) are euhedral, radiating and interpenetrating with each other exhibiting ophitic to sub-ophitic texture (Fig. 6). Orthopyroxene shows yellow to pink pleochoroism and has 2V = (-) 67-70° and Nz-Nx = 0.016 indicating it as hypersthene and it is found replacing clinopyroxene. The presence of orthopyroxene within the clinopyroxene is a diagnostic feature of slow cooling of tholeiitic magma (Ratnakar and Leelanandam, 1998). Anhedral quartz occupies the interstices between plagioclase and clinopyroxene. Epidote occurs as alteration product of plagioclase, while chlorite results from the alteration of clinopyroxene. In some sections of quartz dykes, glomeroporphyritic texture with phenocrysts of plagioclase feldspar is noted (Figure 7). The modal composition is presented in the Table 1.

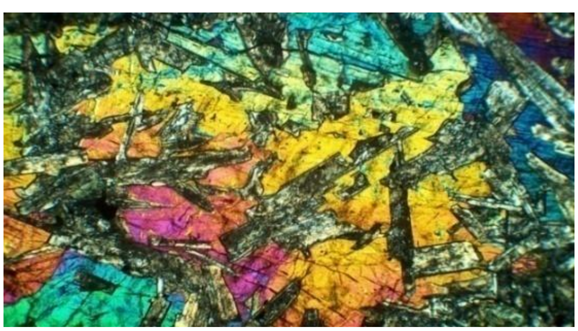

Figure 5: Intergranular texture of plagioclase and pyroxene in olivine dyke rocks

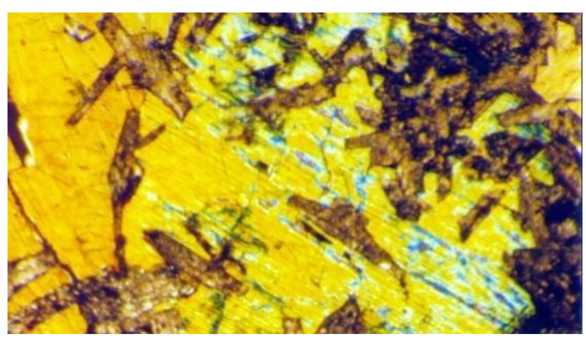

Figure 6: Ophitic texture in dolerite 10X’10X’XPL

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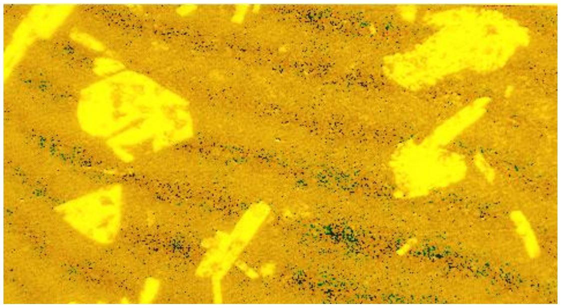

Figure 7: Glomeroporphyritic texture with phenocrysts of plagioclase feldspar (10X'10X'PPL)

Figure 8: Micrographic pegmatite (MGP) in Gabbro

Micrographic Pegmatite Dyke

The rocks are medium to coarse grained and exhibit ophitic to sub-ophitic texture. Clinopyroxene, orthopyroxene, plagioclase, quartz, micrographic pegmatite and opaques constitute the mode of the rocks. Clinopyroxene is augite with 2V = (+) 42 to 52°; Z^V = 42 to 55°; and Nz-Nx =0.020 to 0.025. It is often replaced by orthpyroxene. Plagioclase (An50-58) is euhedral to sub-hedral. Micrographic pegmatite is associated with anhedral grains of quartz (Figure 8). In medium grained rocks micrographic pegmatite is confined to interspaces of plagioclase while in the coarse grained varieties, micrographic pegmatite extends into plagioclase laths along cleavages and composition planes. The rock shows typical micrographic texture in intergranular spaces showing reaction relation with easily formed pyroxenes and mantle of plagioclase. The modal composition is given in the Table 1.

Petro Chemistry

Table 2

Constituents **Sample No.** **Major (Wt %)**	**1** **PS** **101**	**2** **PS** **107**	**3** **PS** **119**	**4** **PS** **142**	**5** **PS** **127**	**6** **PS** **133**	**Average**
SiO2	47.85	48.90	51.37	51.22	52.20	52.04	50.58
Tio2	0.74	0.71	1.18	1.06	0.96	0.88	0.92
Al2o3	14.39	14.42	12.97	12.59	13.32	13.05	13.36
Fe2o3	2.00	2.50	3.52	3.65	2.50	3.03	2.87
FeO	10.17	10.89	10.69	11.65	10.13	10.03	10.59
MnO	0.18	0.10	0.16	0.12	0.12	0.16	0.14
MgO	8.09	7.45	4.05	4.26	4.30	4.65	5.47
CaO	12.45	13.24	12.40	12.61	13.26	12.09	12.68
Na2O	2.49	2.28	2.58	2.25	2.25	2.16	2.34
K2O	0.58	0.69	0.84	0.96	0.96	0.98	0.84
P2O5	0.16	0.13	0.24	0.16	0.18	0.16	0.17
LOI	1.37	0.83	0.58	0.48	0.52	0.46	0.71
Total	100.47	102.14	99.98	101.01	100.60	99.69	100.85
Trace PPM							

CO	36	34	28	32	30	30	32
Ni	175	160	130	144	122	140-	145
Cr	210	180	145	120	120	105	147
Cu	82	75	60	62	64	85	71
Pb	15	15	15	15	15	15	15
Zn	56	54	50	65	50	58	56
V	300	205	400	510	500	420	389
Ba	20	30	50	65	80	90	56
Sr	125	120	100	105	95	110	106
Zr	30	30	100	100	105	95	77
Rb	28	25	25	20	20	25	24
K/Rb	100	144	220	252	252	206	196
Rb/Sr	0.22	0.21	0.20	0.19	0.21	0.22	0.20
θ Value	32	33.5	31.6	33.6	35.6	35.7	33.67
Mg No.	54	51	35	34	39	40	42.17
C.I.P.W. Norm							
Quartz	-	-	2.94	2.64	3.00	3.84	3.11
Orthoclase	3.89	3.89	5.00	5.56	5.56	5.56	4.91
Albite	16.77	17.29	22.01	18.86	18.86	18.34	18.69
Anorthite	27.24	27.24	19.46	21.41	23.63	23.07	23.68
Nepheline	1.99	1.14	-	-	-	-	1.57
Diopside	28.93	30.76	34.25	33.85	34.64	33.34	32.63
Hypersthene	-	-	7.82	10.57	8.62	9.61	9.16
Olivine	15.20	14.92	-	-	-	-	15.06
Magnetite	3.25	3.25	5.10	5.34	3.71	4.41	4.18
Ilmenite	1.67	1.52	2.28	1.98	1.82	1.67	1.82
Apatite	0.34	0.34	0.67	0.34	0.34	0.34	0.40
Niggli values							
si	100.77	102.03	124.06	120.11	124.53	124.79	116.05
al	18.37	17.74	17.54	17.30	18.79	18.34	18.01
fm	46.68	46.70	42.75	44.58	40.60	42.26	43.94
c	29.08	29.91	32.32	31.65	34.00	32.95	31.65
alk	5.87	5.58	7.39	6.47	6.60	6.45	6.39
mg	0.54	0.54	0.34	0.34	0.38	0.39	0.42
k	0.15	0.16	0.18	0.22	0.22	0.22	0.19

1-2 Olivine Dolerites *3-4 Quartz dolerites* 5-6 Micropegmatite dolerites

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Major and trace element analysis of six dykes together with their C.I.P.W norm and Niggli values are presented in the Table -2. Major element oxide concentrations in the Kadiri Dykes are as follows: SiO_2 shows a restricted range from 47.85 to 52.04 (Wt %). TiO_2 shows a variation form 0.74 to 1.18%. Al_2O_3 in the Kadiri Dykes varies from 12.59 to 14.42%. Total iron as FeO ranges from 11.97 to 14.94%. MnO is low and varies from 0.10 to 0.18%. MgO shows variations from 4.05 to 8.009%. Mg number varies from 34 to 54 and in a sense reflects the relative stages of formation of individual rocks. Apparently, the rock with highest Mg no. is the early formed one and the one with the least Mg No. is the last formed one during the evolution of magma (Vijaya Kumar and Ratnakar, 2001). Based on these values, it may be assumed that the olivine dolerites are the early formed ones and the quartz dolerites are the last formed ones in the study area. CaO varies from 12.09 to 13.26%. The compositional range in CaO in the Kadiri Dykes is within the limits of chemical screen (5 to 15%) for basaltic and gabbroic rocks (Manson, 1967). Na_2O shows a narrow range from 2.16 to 2.58% and K_2O varies from 0.58 to 0.98%. The SiO_2 and total alkali contents of the Kadiri Dykes are within the range of 45% to 52% and less than 5% respectively suggesting their basaltic affinity according to the TAS scheme recommended by IUGC (Bas and Strickeisen, 1981). P_2O_5 varies from 0.13 to 0.24% and highest amount records a few grains of apatite.
The major and trace element concentrations o the dolerites of the study area resemble those of continental tholeiites (Condie, 1976). According to Muller and Rogers (1973), the continental tholeiites are characterized by their Al_2O_3 (~12%) low K/Rb ratio (85%□<250) and high Rb/Sr ratio (average 0.17). In the study area, the average dolerites show Al_2O_3 = 13.35, K/Rb = 196 and Rb/Sr = 0.20. These values correspond to those of continental tholeiites. The high Ni contents in samples 1 and 2 (Table 2) are significant and indicate crystallization of olivine. The rocks are olivine-nepheline normative and quartz-hypersthene normative. Presence of hypersthenes in the norm in most of the samples suggests them to be tholeiites (Yoder and Tilley, 1962).

Classification

The chemical classification diagrams designed for basaltic rocks can also be used for dolerites. To discriminate whether the dolerites are tholeiitic or calc-alkaline, the dolerites of the study area are plotted in the SiO_2 Vs FeOt/MgO diagram (Miyashiro, 1974) (Figure 9) and A.F.M. diagram (Irvine and Baragar, 1971) (Figure 10). These diagrams confirm their tholeiitic nature and also depict a restricted range of alkalies for the dolerites. The K_2O-TiO_2-P_2O_5 trilinear diagram of Pearce *et al.*, (1975) (Figure 11) discriminates the oceanic and continental tholeiites. In this plot, the dolerite dykes of the study area plot in the continental field. The above chemical classification diagrams indicate that the dolerites of Kadiri area correspond to those of continental tholeiites.

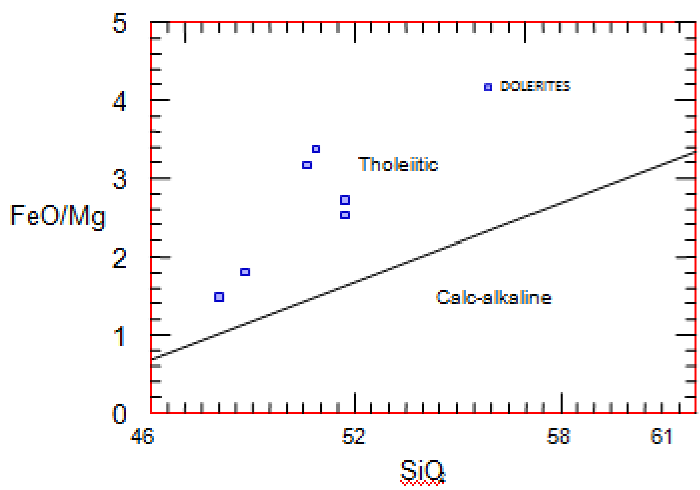

Figure 10: FeO-MgO Vs SiO_2 DIAGRAM FOR DOLERITES (after Miyashiro, 1974)

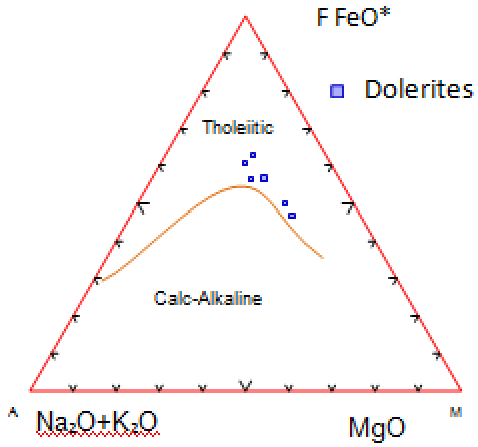

Figure 11: AFM Diagram (After Irvine and Baragar, 1971)

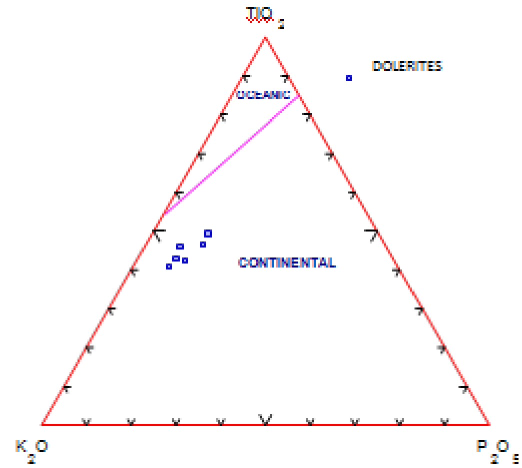

Figure 12: K_2O-TiO_2-P_2O_6 Diagram (after Pearce *et al.*, 1975)

Conclusion

Based on the field, petro graphic and geochemical evidences, an attempt is made to discuss the petro genesis of mafic dykes of Kadiri Schist Belt. Gradational contacts and continuous grain-size variations suggest that the rocks are co magmatic and magma chamber products. They exhibit variations in the texture from ophitic, intergranular to flow types. The ophitic texture is present in the central portion, intergranular texture in the marginal portion and the flow texture in peripheral portions. The textural variations indicate that the rocks are formed under varying plutonic to volcanic conditions. The increase in grain size from chilled margins to central portions is explained by the different velocities in the zones of the dykes and the textural variations by different rates of cooling in different zones (Winkler, 1949; Sadashivaiah and Ikramuddin, 1972). The variation in grain size and texture of kadiri dolerites may also be explained by the same mechanism. The dominance of albite, Carlsbad and albite-carlsbad twins in the dolerites indicate that these twins are formed in magmatic rocks (Turner, 1951; Gorai, 1951).

The presence of quartz in most of the dolerites indicates tholeiitic parent magma. This is confirmed from the chemical classifications also. All dyke samples fall on a continuous petrogenetic trend i.e. tholeiitic trend in all chemical classification diagrams, suggesting their derivation from a common magma through variable degrees of fractional crystallization (Sarma, 1997). The presence of olivine in some dolerites, its absence in some and the presence of quartz and micropegmatite in some dolerites indicate that they are early, intermediate and late differentiate respectively. The high content of Ni and Cr in dolerites indicates that they might have been derived from the mantle source.

Some of the dolerites are actually metadolerites and only relict ophitic texture is seen in them. If there is scope for the metamorphism subsequent to dyke formation, it would have affected all the preexisting rocks. But this is not the case with the study area. Therefore, it may be attributed to auto metamorphism resulted by the hydrothermal solutions present in certain of the dolerites.

According to Kuno (1996), different basaltic magmas are produced independently at different depths. According to Yoder and Tilley (1962), olivine-tholeiite, which is slightly poorer in silica than normal tholeiites, is produced by partial melting of garnet-peridotites of the mantle at greater depth. If this magma fractionates at shallow depth, it evolves into oversaturated tholeiite and if the same magma undergoes fractional crystallization at great depth, it gives rise to alkali-olivine basalts. In both the hypotheses, the depth of magma generation of fractionation is an important factor in controlling the composition of the magma. Recent experimental studies suggest that the depth of magma generation is one of the important factors in controlling the composition of magmas (Sugimura, 1968; Condie *et al.*, 1969; Naqvi and Hussain, 1973; Naqvi *et al.*, 1974; Armbrustmacher, 1977; Satyanarayana *et al.*, 1980 Balayerikal Reddy, 1984; Hanumanthu and Babaiah, 1999; Hanumanthu *et al.,* 2008).

The fractionation and contamination of basaltic magma lead to an increase of the molecular ratio Na_2O + K_2O/ Al_2O_3. This concept has been utilized by Sugimura (1966, 1968) in calculating the θ index which gave an idea about the depth of magma generation. In the study area average θ value of dykes varies from 31.60 to 35.70 and the average 33.66 (<36) is characteristic of continental tholeiites (Condie *et al.,* 1969; Naqvi and Hussain, 1973). The highest θ value (35.70) and the high Ba content (90ppm) in micropegmatite bearing dolerite may be due to the contamination of magmas by continental crust (Jayaramsahu and Balakrishnan, 1994). The θ value of the Kadiri area dolerites suggests that the thickness of the crust would have been of the order of 30- 40 kms at the time of emplacement of these dykes.

The petrological and geochemical interpretation infers that the parent magma is of tholeiite which on differentiation gave rise to various members of dolerites. The evolution of the granitic crust of the Indian Peninsular was almost complete before the emplacement of these dykes.

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