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Late Cretaceous mafic dykes in the Dharwar craton

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Abstract. Palaeomagnetic, geochemical and geochronological studies have been conducted on a set of dolerite dykes intruding the Peninsular gneisses near Huliyurdurga town, Karnataka, as a reconnaissance survey indicated a Cretaceous age for them. The dykes are mainly tholeiitic in composition with their 87Sr/86Sr ratios tightly clustered around 0·7045. Their palaeomagnetic data ($D_m = 329°$, $I_m = -55°$) and the corresponding palaeopole coordinates ($\lambda_p = 34°$S, $L_p = 108°$E) are strikingly close to those of the Deccan Traps to the north. Whole rock K-Ar ages of these dykes ranging between 69 and 84 Ma are also similar to the range of K-Ar ages of the Deccan basalts. The chemical, palaeomagnetic and temporal coherence between the dykes and the Deccan basalts indicate that they may indeed be tectonically related events.

Keywords. Cretaceous dykes; Deccan volcanism; geochronology; geochemistry; Palaeomagnetism.

1. Introduction

In an attempt to understand the crustal conditions and stress systems during early-mid Proterozoic times in continental areas, a concerted study of various dyke swarms in Karnataka has been taken up as NGRI and IGCP-257 projects. As part of this programme, systematic sampling was carried out over several selected dyke swarms in parts of Tumkur and Hassan districts. Palaeomagnetic results on two dykes near Huliyurdurga (referred to in this paper hereafter as Huliyurdurga Cretaceous Dykes, HCD) differed markedly from the rest and indicated Cretaceous magnetic signatures. As a quick check on their very young age, we carried out magnetogranulometric tests, which were successfully used by Radhakrishnamurthy and Deutsch (1974) to distinguish Cretaceous and younger basalts from much older ones. The measurements on HCD samples suggested Cretaceous or younger origins.

This finding prompted more intensive geological, palaeomagnetic, geochemical and geochronological studies on HCD to explore the manifestation of Cretaceous magmatism in the south Indian shield. Preliminary findings of these studies are reported here.

2. Geological setting

HCD are a part of a prominent dyke swarm to the east of the Huliyurdurga (Kunigal) schist belt. The swarm comprises mafic dykes of several generations, most of which are believed to be of Proterozoic origin. The HCD (dykes A and B; figure 1) are observed to

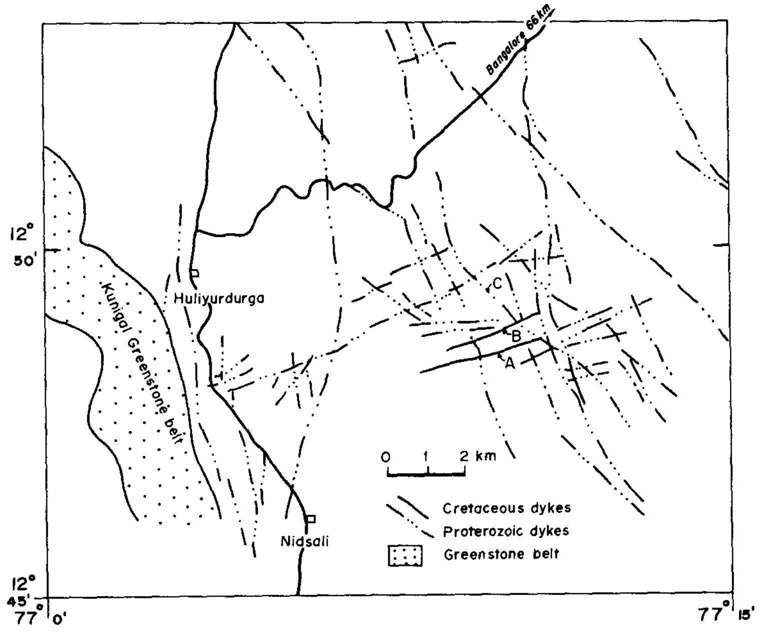

Figure 1. Distribution of dykes in the area.

intrude several of the older dykes and the Archaean gneiss. The contacts with the gneiss are often sharp with a chilled zone. The dykes strike N 70°E and dip vertically with an average width of about ten meters. Field observation of the dyke and its contacts does not show any features indicative of shearing such as brecciation, slicken-sliding along margins or offset of foliations in the country rock along the contacts with the dyke. Therefore, it is inferred that these dykes intrude tensional fractures. There exist a large number of similar dykes in the region whose age and petrological characteristics are not known.

3. Experimental methods

Over twenty fresh samples from dykes A and B and three from dyke C (figure 1) were studied for their magnetic, petrochemical and geochronological signatures. The block samples collected were oriented using a magnetic compass. Cores were later drilled from the block samples and sliced into specimens of nominal dimensions 2·5 cm in diameter × 2·3 cm in height. Three or four cores were usually taken from each block sample and 2 or 3 specimens prepared from each core. The remaining part of the samples was used for geochemical analysis and K-Ar dating.

The intensity and direction of natural remanent magnetization were measured on a model DSM-2 Schonstedt spinner magnetometer with a measurement range from 5 to less than $2{\cdot}5 \times 10^{-7}$ emu, and accuracy of moment better than ± 5% and an angular accuracy of 2°. Of the several core specimens drilled from each block sample, at least one was subjected to detailed alternating field (AF) demagnetization to 1000 Oe (100 mT) using a two-axis tumbling device similar to that described by Creer (1959). An equal number of specimens were thermally demagnetized using a Schonstedt TSD-1 instrument.

Whole-rock Ar analysis was made on about 1 mm chips. A part of this material was ground to less than 200 mesh for potassium analysis. Argon was extracted in an all metal low-blank ($\sim 1 \times 10^{-9}$ cc STP ^{40}Ar at 1500°C) ultrahigh vacuum system and isotopic analysis on a MS-10 mass spectrometer in the static mode. Potassium was determined by flame photometry on an IL443 instrument using lithium as the internal standard. An inter-laboratory standard Mica-mg (phlogopite) was analysed along with HCD samples which yields an age of 533 ± 12 Ma. This agrees to within the experimental error with the recommended value of 522 ± 12 Ma (Govindraju 1979).

The samples were chemically analysed on lanthanum-doped fused pellets using a Philips PW 1400 X-ray fluorescence spectrometer.

4. Results

The dykes are medium-grained in the interior with a decrease in grain size towards the margins. Petrographic studies show ophitic and subophitic textures. The principal mineral constituents are plagioclase and augite, with pigeonite, ilmenite and titanomagnetite as accessories.

The major element composition of six representative samples of the dykes is given in table 1. It can be seen that the rocks have a uniform chemical composition which is

Table 1. Geochemistry of Huliyurdurga dykes.

	HD86/2	HD86/5	HD86/36	HD86/37	HD86/42	HD86/43
SiO_2	50·05	49·73	50·17	49·77	50·35	50·28
TiO_2	3·07	3·03	2·80	2·93	2·98	3·01
Al_2O_3	12·90	12·71	12·34	12·58	12·89	13·37
Fe_2O_3	4·82	5·19	5·44	5·14	4·44	5·01
FeO	10·44	9·92	9·60	9·24	10·60	10·08
MnO	0·22	0·23	0·22	0·21	0·24	0·21
MgO	5·05	4·47	5·10	4·50	5·02	4·86
CaO	9·78	10·03	10·20	10·27	9·79	9·72
Na_2O	2·18	1·77	1·90	1·74	2·00	2·03
K_2O	0·43	0·43	0·39	0·42	0·36	0·42
P_2O_5	0·32	0·33	0·36	0·34	0·35	0·32
Total	99·26	97·84	98·52	97·14	99·02	99·31
			CIPW norms			
q	8·222	11·331	10·516	11·925	9·369	9·623
or	2·560	2·597	2·339	2·555	2·148	2·499
ab	18·584	15·308	16·319	15·157	17·091	17·297
an	24·323	26·027	24·351	26·019	25·379	26·310
wo	9·374	9·447	10·282	10·081	8·919	8·410
en	12·671	11·378	12·892	11·537	12·626	12·188
fs	10·607	9·559	9·054	8·517	11·434	9·859
mt	7·041	7·691	8·006	7·692	6·501	7·314
il	5·874	5·882	5·898	5·729	5·716	5·756
ap	0·764	0·799	0·866	0·829	0·837	0·763

Table 2. Summary of K/Ar dating data.

Sample No.	K%	^{40}Ar rad		Age Ma
		mol./g × 10^{-11}	%	
Dyke A				
HD 86/2	0·366	5·2668	55	81 ± 3
HD 86/5	0·384	4·7110	52	69 ± 3
HD 86/42 (a)	0·351	4·4580	57	72 ± 2
HD 86/42 (b)	0·351	4·4730	58	72 ± 3
Dyke B				
HD 86/36 (a)	0·349	5·1601	54	83 ± 2
HD 86/36 (b)	0·349	5·2074	71	84 ± 2
HD 86/22	0·357	4·8777	53	77 ± 3
Dyke C				
HD 86/9	0·353	157·03	95	1596 ± 34

^{40}K decay constants after Steiger and Jager (1977). Errors are 2 sigma.

Table 3. Palaeomagnetic data for Huliyurdurga dykes.

		NRM					Cleaned					
S	N	n	D°	I°	K	A95°	AF	n	D°	I°	K	A95°
Dyke A												
1	4	26	333	−49	393	1·4	20	4	330	−54	614	2·8
2	4	17	11	−48	9	11·2	20	4	329	−54	1500	1·8
3	4	18	339	−44	71	3·9	20	6	329	−56	347	3·1
4	4	19	337	−41	50	4·5	20	8	331	−49	70	5·9
Dyke B												
5	4	16	332	−49	336	1·9	20	5	325	−58	588	2·6

Mean pole position = 107·7°E, 33·9°S; dm = 4·1°, dp = 2·9°.

Notes: S, Site number; N, number of block samples; n, number of specimens; D, declination; I, inclination; K, precision parameter; A95, radius of circle of confidence at 95% probability; AF, alternating fields established as the end points for samples of that site; dm and dp, semi-axis of ellipse of confidence at 95% probability.

tholeiitic and resembles the composition of the typical Deccan basalts (Mahoney *et al* 1982). 87Sr/86Sr ratios and Sr concentrations of 4 samples have been measured mass-spectrometrically, yielding the following values after age correction which is very small: HD 86/37 0·70486 ± 2, 218 ppm; HD 86/2 0·70414 ± 2, 229 ppm; HD 86/5 0·70572 ± 2, 231 ppm; and HD 86/42 0·70453 ± 2, 232 ppm. The error in Sr ratios is 1σm and refers to the last digit, and Sr determinations are accurate to within 1%. The Sr ratios are relative to a mean value of 0·71023 ± 2 measured for NBS 987 Sr standard.

Whole-rock K-Ar dating of HCD samples yields ages in the range 69 to 84 Ma (table 2). Though the samples represented central to marginal parts of the dyke, no

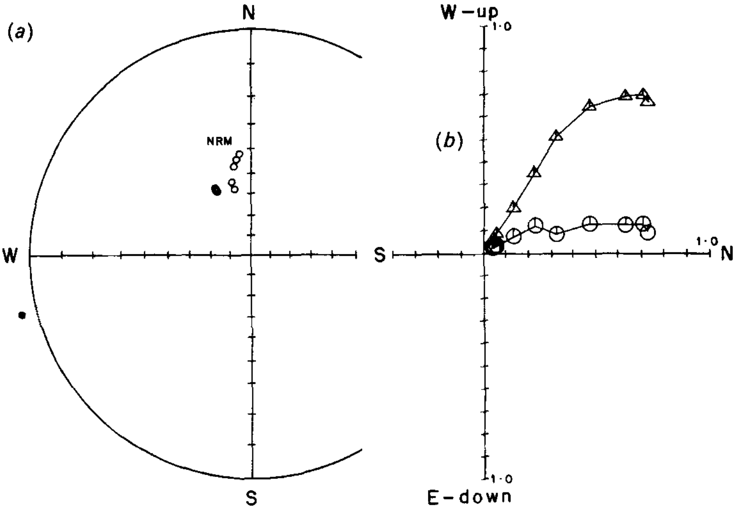

Figure 2. An example of the AF demagnetization characteristics of a specimen from HCD. (**a**) Stereographic projection showing directions of magnetization at successive peak fields (**b**) Zijderveld plots for vectors displayed in (**a**). Circles lie in the horizontal plane, triangles lie in the vertical plane.

systematic differences in age are seen. In order to check if these ages are reset ages caused by a later thermal episode, petrographic and K-Ar analyses of a sample from a prominent older dyke (C) cut by HCD was carried out. Dyke C shows unmetamorphosed and unaltered mineralogy with primary textures and has a much older age of about 1600 Ma. In the light of this result, we believe that the late Cretaceous K-Ar age of HCD represents their time of intrusion.

One site on dyke A and four sites on dyke B (figure 1) were sampled for palaeomagnetic studies with a minimum of four block samples from each site. Natural remanent magnetization (NRM) measurements showed fairly consistent directions (table 3). The angular dispersion further decreased after alternating field demagnetization. Typically by 150 Oe the directions began demagnetizing towards the origin (figure 2). The AF trends were carefully examined with the aid of stereo nets, orthogonal plots and vector subtraction (details of which will be published elsewhere). Based on these analyses, a single, discrete high coercivity component recorded in single domain titanomagnetites has been identified. This normally magnetized component ($D_m = 328{\cdot}9°$, $I_m = -54{\cdot}5°$, $K = 476$, $A95 = 2{\cdot}9°$) is interpreted to be of primary origin and is related to the time of intrusion of the dykes. The dykes yield a palaeomagnetic pole position of latitude 34°S, longitude 108°E ($d_m = 4{\cdot}1°$, $d_p = 2{\cdot}9°$).

5. Discussion

The dykes are tholeiitic in composition and falls within the range of compositions of continental basalts, as shown in figure 3. Since these dykes are relatively small volume intrusions into a Precambrian basement, the possibility of host rock contamination of

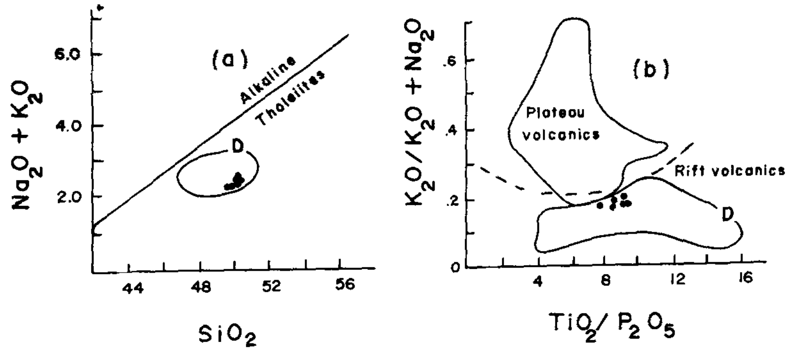

Figure 3. (a) Alkalies vs silica plot showing Huliyurdurga dyke compositions. Field of central Indian Deccan volcanics (D) after Krishnamurthy and Udas (1981). Alkalic and tholeiitic basalt discrimination after Irvine and Barager (1971). (b) Position of Huliyurdurga dyke with relation to plateau volcanics and rift volcanics. Deccan trap data (D) are from Chandrasekharan and Parthasarathy (1978).

the primary magma of the dykes cannot be ruled out. However, the tight cluster of the Sr isotopic ratios around 0·7045 and Sr compositions around 230 ppm suggest that such contamination, if present, is very small. It does not appear to be fortuitous that the Sr isotopic ratios and Sr concentrations of the dykes are almost identical to those of some of the least crustally contaminated Deccan lava flows in the Mahabaleshwar section (Mahoney *et al* 1982). This suggests very similar upper mantle sources for both the HCD's and the Deccan lavas. Nd isotopic compositions of the dykes will help confirm this interpretation.

Another feature of similarity between the HCD and the Deccan basalts is in their emplacement time. The K-Ar ages of HCD's show a spread between 69 and 84 Ma which is outside the analytical uncertainties. The average age is about 76 Ma. Though the conventional K-Ar ages of Deccan basalts show even larger spread from 35 to 85 Ma, there is increasing evidence that the main Deccan volcanism was a relatively sharp event centred around 65 Ma (Venkatesan *et al* 1986; Courtillot *et al* 1986). The HCD ages are only marginally older than this. It is not clear at this stage whether the higher and larger scatter of the HCD ages are mainly due to variable amounts of radiogenic argon inherited from the country rocks during dyke emplacement. While the present data indicate that the HCD and the Deccan basalts have very similar ages, the possibility that the HCD's slightly but distinctly predate the Deccan lavas cannot be ruled out. 40Ar/39Ar dating of some HCD samples is being attempted to resolve this issue.

The remarkable similarity in age and composition between HCD and Deccan basalts is reinforced by the magnetic signatures of both rocks. The primary magnetic composition of the HCDs is strikingly uniform, leading to a closely constrained palaeopole position at 108°E, 34°S. This agrees very well with the overall mean virtual geomagnetic pole for the Deccan traps (106°E, 34°S; Klootwijk 1979), and falls well within the palaeomagnetic data field of the Deccan volcanics as shown in the polar wander path (figure 4). This shows that both the HCDs and the Deccan lavas crystallized in nearly identical ambient magnetic fields.

Cretaceous dyke activity in Peninsular India has also been reported earlier in the

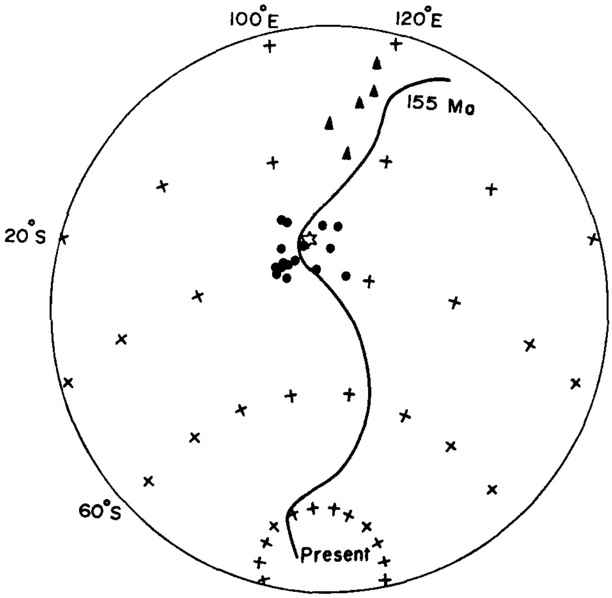

Figure 4. The Mesozoic-Tertiary APWP for India following Klootwijk and Priece (1979). The closed circles represent Deccan trap pole positions and the triangles represent Sylhet/Rajmahal traps (data from Klootwijk 1979). Results with A95 (radius of circle of confidence at 95° probability) less than 10° have been incorporated in the figure from Klootwijk's (1979) synthesis. Star refers to Huliyurdurga dykes pole position.

literature. These are generally from areas in close geographic association with the subaerial flows of the Deccan and Rajmahal provinces (Gondwana dykes 121 to 57 Ma BP, Murty 1985). Away from these provinces, dyke swarms of Cretaceous age have been described from the areas proximal to the subcontinental margin in Kerala state (Radhakrishna *et al* 1985). These apart, Hasnian and Qureshy (1971) reported Cretaceous dykes from Karnataka, one of them located very close to Chitradurga town and two others to the east of Mysore city. These authors correlated them with Deccan volcanism based only on palaeomagnetic and geochemical data.

The Kerala dykes (~ 100–150 Ma) are apparently synchronous with the break-up of the Gondwanaland (~ 125 Ma BP) and with the separation of Madagascar from India ~ 100 Ma BP (Barron 1987). Dykes of similar age (133–158 Ma) are also exposed in the south and southeast continental margins of Africa (Hunter and Reid 1985), India's immediate neighbour in the Gondwana supercontinent. Such dykes may therefore constitute an expression of crustal extension and rifting.

Unlike the Kerala dykes, the Huliyurdurga dykes are fillings into tensional fractures created in the Archean basement far away from zones of intense continental distention and related tectonics. Their strong coherence with the Deccan basalts in terms of composition, magnetic signatures and age is very significant and indicates both tectonic and magmatic links between them. It will be interesting to see if the higher heat flows (mean heat flow 64 mW/m^2) recorded in the Dharwar craton (Rao *et al* 1976; Singh and Negi 1982) are the relic of this late Cretaceous dyke emplacement within it.

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