



Mafic Dykes of Moyar Shear Zone, North Kerala, India: Emplacement History and Petrogenetic interpretation based on Structure, Geochemistry and Magnetic Fabric

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Received 17 February 2010; accepted 26 February 2011

Abstract

Creaceous mafic dykes in the Moyar Shear Zone (MSZ) area, north Kerala, India, provide signatures to probe into the nature of their source and thereby the evolution of the Mesozoic lithospheric mantle beneath the South Indian Granulite Terrain (SIGT). Bulk of the dykes in northern parts of Kerala is broadly in spatial association with the shear system. Mafic dykes striking NE-SW, NW-SE, NNW-SSE and ENE-WSW are widespread in the MSZ and surrounding areas. Width of these dykes varies from 30cm to 5m in general, while dykes wider than 10m also occur. These mafic dykes are olivine/quartz normative tholeiites showing strong correlation to N-Type MORB and within plate basalt affinity. Anisotropy of Magnetic Susceptibility (AMS) data imply normal magnetic fabrics nearly parallel to dyke trends, but with highly variable plunge of magnetic lineation. The compositions of the least altered and least metamorphosed dykes help to define the properties of their mantle source region, as well as the nature of the crust through which the magma traveled. The present contribution on the mafic dyke swarms in Moyar Shear Zone (MSZ) provides new interpretations on the temporal relations of magmatism and tectono-metamorphic evolution of the south Indian high grade terrain.

Keywords: Mafic Dykes, Moyar Shear Zone, Tholeiite, Anisotropy of Magnetic Susceptibility.

1. Introduction

Mafic dyke swarms which are widespread in the earth's crust occur in a variety of tectonic environments and provide a record of the orientation, kinematics as well as timing of crustal extension. Emplacement of mafic dykes is strongly associated with the lithospheric and mantle processes like plume events, rifting or coalescence of lithospheric blocks and they are therefore important sources for unraveling internal processes of the Earth and their expression in geodynamics.

Dykes of various composition and age have been studied in detail to bring out the crustal evolution history [1, 2 and 3]. The continental flood basalts and major dyke swarms have their origin also related to the up-rise of hot mantle plumes that may lead to rifting and ultimately to continental break-up [4, 5, 6, 7, 8 and 9]. Mafic nature of dykes is very common and the study of mafic dyke swarms is an important tool in understanding the evolution of the sub-continental lithosphere [10]. The Indian shield also hosts mafic dyke swarms having diverse orientations and emplaced in contrasting tectono-metamorphic settings [11, 12 and 13].

Geochemical and tectonic constraints on the emplacement processes of mafic dykes receive renewed interest world over, mainly because dykes represent former conduits of magma from deeper levels of the Earth to the surface. Moreover, dyke swarms give information about tectonic processes that deformed the lithosphere and also the spatio-temporal evidences for super continental reconstructions [14, 15]. Most of the geological researches in the South Indian shield are centered on the reworking of the Gondwana Palaeo-supercontinent [16, 17]. The late Phanerozoic mafic magmatism has received vital attention as a major constraint in deciphering the evolution and reconstruction of Gondwanaland [18, 19]. Apart from the Deccan magmatic event, South Indian shield has been punctured also by a large number of mafic dyke swarms with relatively similar origin [20].

The geologic records provided by these dykes are significant because they provide crucial evidences for magmatic and tectonic events that contribute to the incessant modification of the Southern Granulite Terrain (SGT). However, there is a dearth of data and models on the emplacement process of the dykes in different tectonic settings in the South Indian shield and their temporal relations. The present paper embodies the results of the structural, geochemical and AMS analysis of mafic dykes from a shear zone in the SGT.

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2. Geological Background

The South Indian Shield is a composite continental segment, formed by the accretion of various crustal blocks during the mid-Archaean to Neoproterozoic [21, 22 and 23]. This shield comprises relatively low-grade granite-greenstone assemblages (the Sargur Group) juxtaposed against high-grade granulites which include the Charnockites and Khondalite group of rocks. Various thermo-tectonic events that operated in the evolution of different units of the shield have also left their imprints in terms of deep crustal structure [24, 25 and 26]. SGT is dominated by granulite facies rocks with several regional *en echelon* Neoproterozoic shear zones dissecting the terrain into different Late Archaean and Proterozoic crustal blocks (Fig.1a). Moyar Shear Zone (MSZ), one of the prominent Proterozoic tectonic zones in the South Indian Granulite Terrain, provides the challenge of deciphering its kinematic evolution, which in turn can throw light on the crustal evolution. The ESE-WNW trending, 10km wide and 200km long Moyar shear zone, usually considered together with the NE-SW trending Bhavani shear zone, marks a major crustal discontinuity in the SGT. Swarms of mafic dykes are common along the SGT of Peninsular India and are found intruding all the rock formations ranging from Archaean to early-middle Palaeocene. But the mafic dykes in the MSZ area represent the less extensively studied group of dykes in the SGT.

The area selected for detailed analysis is located in and around the western part of the Moyar shear zone. The area is also characterised by the occurrence of several igneous plutons of felsic and mafic composition emplaced within the gneisses and schists. The schist–gneiss complex of the Kannur/Manathavady area extends for about 150 km in a WNW–ESE direction with an approximate width of 10–20 km. The movement picture along the MSZ is interpreted as dextral with possible multiphase reactivation [27, 28 and 29]. The rocks in the region, except the syenite pluton and gabbro/dolerite, are characterised by polyphase deformation fabrics. The most widely developed planar fabric is a penetrative foliation (S1), subparallel to the rarely preserved primary planar fabric (S0). The foliation, defined mainly by flakes of biotite, crystals of hornblende and flattened and elongated grains of quartz and feldspar, is closely spaced in sheared rocks. Structural analysis indicates formation of folds of different tectonic styles and orientations [30]. Precambrian crystalline rocks comprising hornblende-biotite gneiss, mylonitic augen gneiss, garnetiferous hornblende-biotite gneiss and amphibolite are punctured by magmatic activity (Fig.1b). Thin mylonite zones are common in the gneiss. Mylonitic augen gneiss, characterised by feldspar augens, is confined to the northern part.

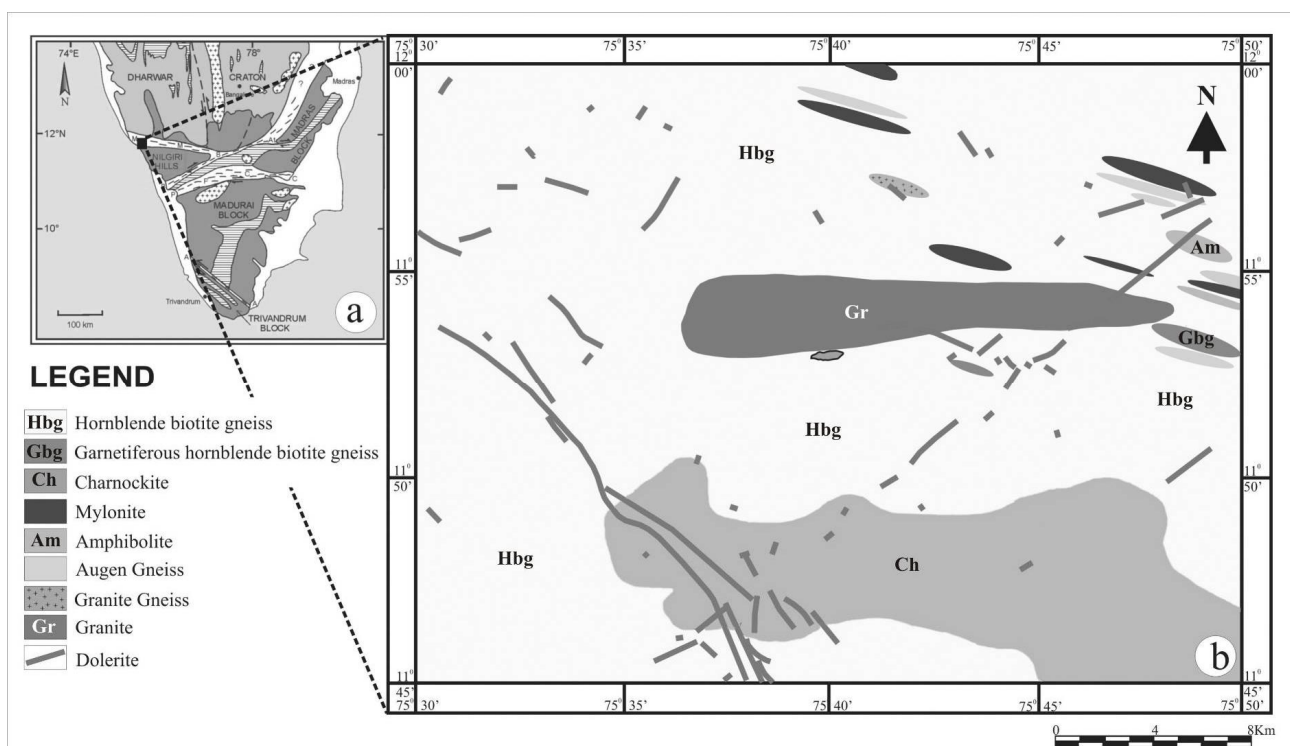


Fig.1. (a) Tectonic map of South India with disposition of shear zones (b) Geological map of the Study area.

The syenite pluton occurs as an elongate body of about 20 km length and an average width of about 4 km. Gabbroic rocks occur as both massive plutons and dykes and bear considerable amount of differentiation signature. Mafic dyke intrusions cross cut the gneisses and mylonites, the syenitic pluton and the younger leucogabbros (Fig.2.a & b). Mafic dykes show widespread occurrence with major strike directions of NE-SW, NW-SE, NNW-SSE and ENE-WSW and varying widths from 30cm to 5m (Fig.2.c), while dykes wider than 10m also occur. There are small dyke veins less than 30cm occurring in the major dykes as dyke-in-dyke structure (Fig.2.d). The dykes show very sharp contact with the host rocks and do not show any signature of assimilation with them. Petrographically these mafic dykes vary from fine-grained basalt (samples from the dyke margin) to medium-grained dolerite (samples from the central part of the dyke) having very similar chemical compositions, which may be classified as quartz or olivine normative tholeiites.

3. Methodology

The area for detailed study was selected using Survey of India toposheets and satellite images

(Landsat image) with the help of GIS and remote sensing methods followed by detailed fieldwork. Samples of all the rock types including the Precambrian crystalline rocks and their sheared equivalents along with the younger acid to basic intrusives were subjected to detailed field and laboratory analyses. Representative samples were analyzed for their major, trace and REE contents using XRF spectrometry and ICPMS methods. Anisotropy of Magnetic Susceptibility (AMS) analysis was also performed on the samples for determining the magnetic fabrics. In the present study, oriented core samples from gneiss, mylonite, syenite and gabbroic/basaltic dykes were used for AMS analysis. Sampling was undertaken following the oriented block method. Each block was cored and cut into specimens of 2.5 cm diameter and 2.2 cm height by retaining their field orientations. A high-sensitivity Spinner version of the latest AGICO (Czech) MFK-1A Kappa bridge anisotropy meter at the Structural Geology Laboratory of the department of Geology, University of Kerala, was used to measure the AMS.

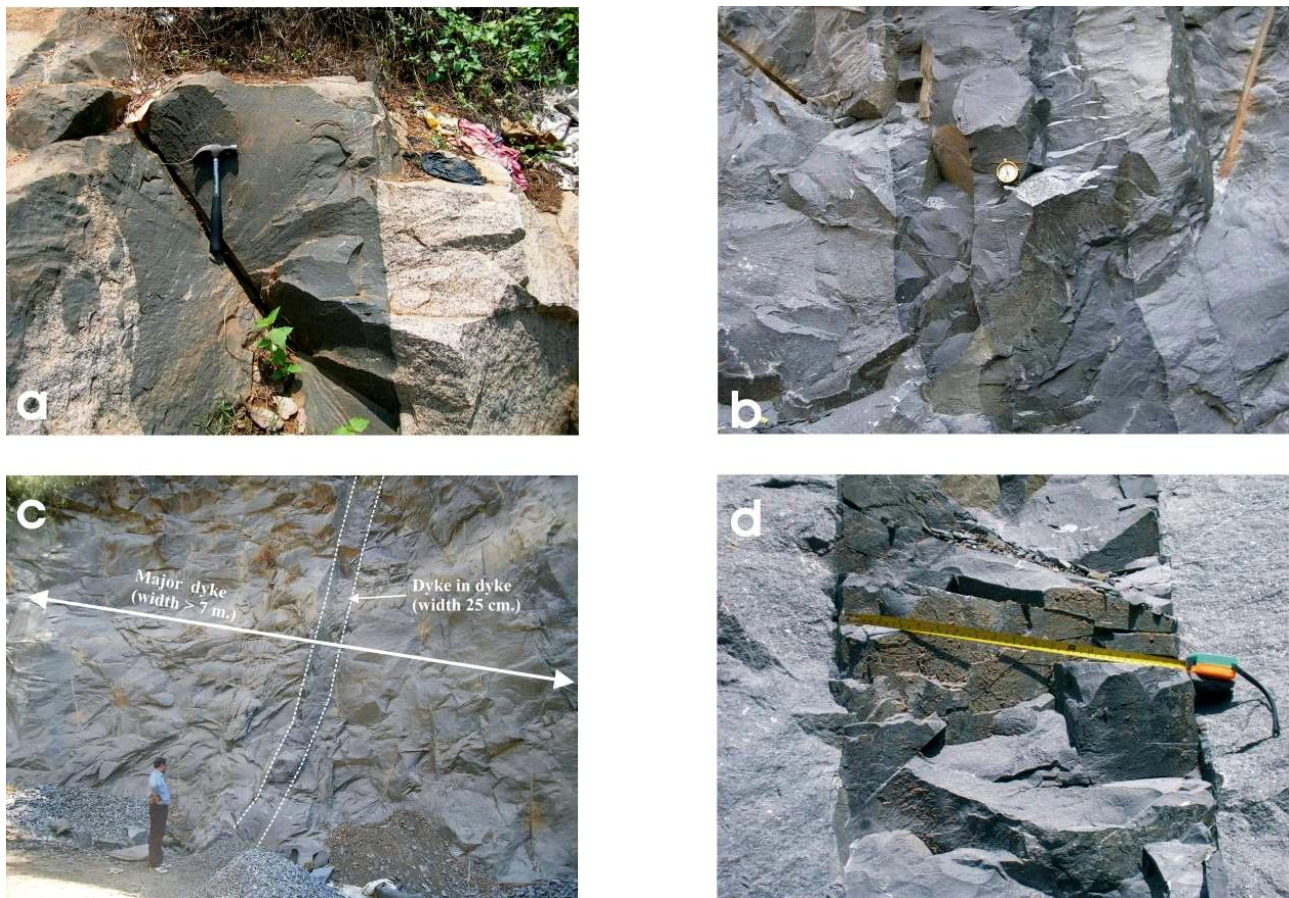


Fig. 2. MSZ dykes showing crosscutting relationship with (a) syenitic rocks (b) leucogabbro (c) dykes with width varying from few centimeters to few meters (d) dyke in dyke intrusion.

3-1 Petrography

The general petrographic features of dolerite dykes display chilled margins consisting of an aphanitic groundmass of plagioclase microlite laths, together with granular Fe–Ti oxides and fine clinopyroxene needles aligned parallel to the wall–rock contact. Both melanogabbro and dolerites are composed essentially of plagioclase and clinopyroxene, with hypersthene, olivine, and iron-titanium oxides as the accessories. Plagioclase occurs both as phenocryst and groundmass (typically andesine to labradorite) and shows strong compositional zoning and sericitization. The main mafic mineral is clinopyroxene, which is occasionally titaniferous and occurs as phenocryst clusters, indicating a cumulus phase. The Fe–Ti oxides are mostly magnetite and ilmenite occurring as elongated needles or subhedral grains distributed throughout the rock.

3-2 Geochemistry

The mafic dykes of MSZ are homogenous in terms of their geochemistry. The samples fall in the sub-alkaline tholeiitic basalt field in major element diagrams, with the composition varying from olivine-normative to quartz-normative. These dykes are distinguishable petrographically from the older dykes of Late Proterozoic age, especially in the degree of alteration, as the older dykes have undergone alteration probably with the multiphase reactivation of MSZ whereas, the group of dykes considered here are less altered. These mafic intrusions show evidences of differentiation from border to the centre in the form of fine grained chilled margin and a coarse grained central zone with occasional presence of pseudotachylite in the border zone. Early petrogenetic models of MSZ dykes recommend a different degree of partial melting of a heterogeneous source [31, 32].

The basalts that form the mafic dykes of the MSZ area are typically tholeiitic with general enrichment in silica, low K_2O , Na_2O and MgO with normative quartz / olivine. The concentration of major oxides in these basalt have SiO_2 ranging from 45.15 to 49.71 wt %, Al_2O_3 from 13.32 to 15.97 wt %, CaO from 8.44 to 11.79 wt % and total alkalis (K_2O+Na_2O) from 2.23 to 4.85 wt % exhibiting its tholeiitic nature in the AFM diagram (Fig.3). Trace element discrimination diagram of MSZ dykes gives a clear picture of the tectono-magmatic settings. The *Ti-Zr-Y diagram* (Fig.4) is the most effective one to discriminate between within plate basalts, i.e. ocean-island or continental flood basalts and other type basalts. In this diagram MSZ dykes show an affinity towards border zone of MORB and within plate basalts with more affinity towards the latter. The discrimination based on the immobile HFS elements like *Th-Hf-Ta* of MSZ dykes after Wood [33]

shows enrichment in elements relatively similar to N-MORB (Fig.5). Primordial mantle-normalized multi-element and chondrite-normalized rare-earth element patterns were also plotted (Fig.6) to examine the supplementary geochemical characteristics of the MSZ dyke samples. From these patterns, it is observed that in all the plotted elements there are alternate enriched and depleted concentrations, both in the primordial mantle and the chondrite values. The large-ion lithophile elements (LILEs) are comparatively more depleted than the high-field strength elements (HFSEs). Overall flat patterns are observed from the LILE to HFSE and prominent negative anomalies are observed for Ba, Nb, Pb, Sr and Yb and positive anomalies for Hf and Zr in the primordial mantle spidergram.

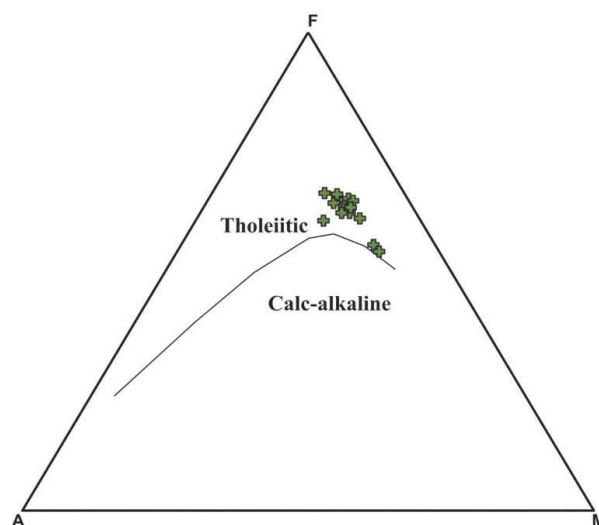


Fig.3. AFM diagram after Kuno [41] of MSZ dykes showing tholeiitic affinity.

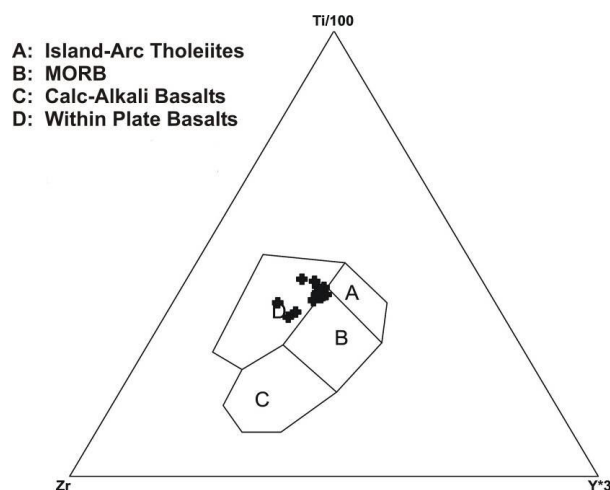


Fig.4. Ti-Zr-Y discrimination diagram for basalts after Pearce and Cann [42]. MSZ dykes fall in the margin of MORB and within plate basalt (WPB), mostly in WPB.

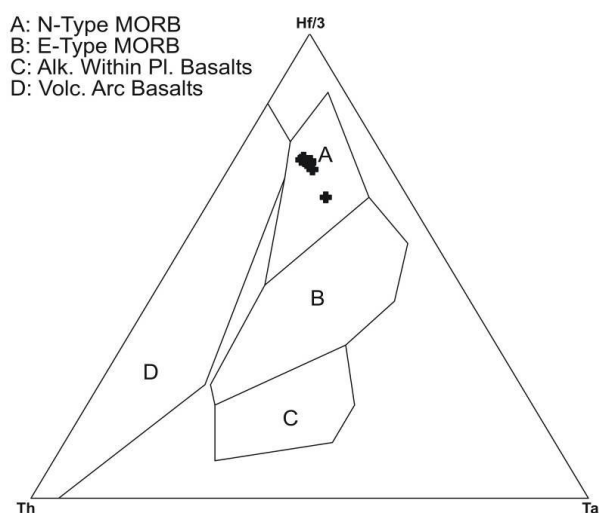


Fig. 5. Th-Hf-Ta discrimination diagram for basalts after Wood [33], in which the MSZ dykes fall in the field of N-Type MORB

Similarly, the slightly enriched light rare-earth elements (LREEs) show strong depletion in Pr and the heavy rare earth elements (HREEs) are depleted in Tb and Yb (Tm), hence the REE pattern shows gentle slope. A less prominent negative Eu anomaly is observed on the REE patterns, probably precluding the possibility of plagioclase fractionation. Comparable geochemical characteristics and similar spider patterns are reported in some part of the Deccan flows [34] and elsewhere [35, 36].

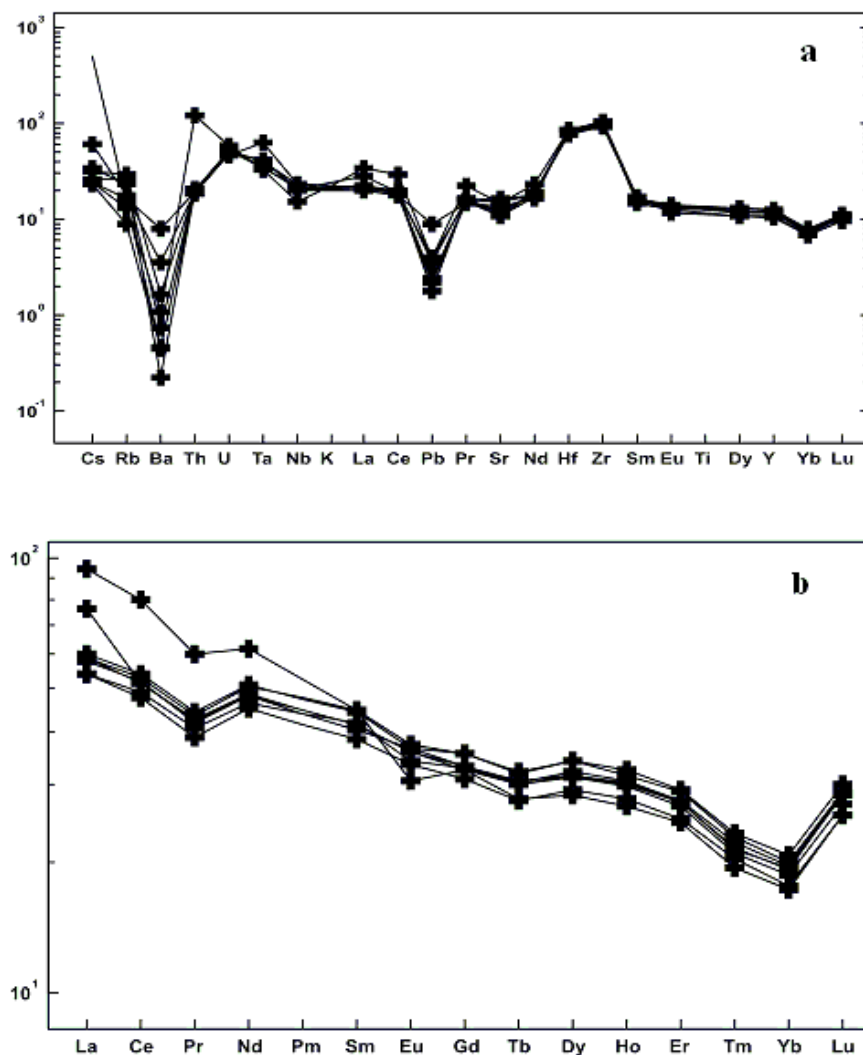


Fig. 6. (a) Primordial mantle-normalized spider diagrams for MSZ dykes after McDonough & Sun [43] showing low/depletion in Ba, Pb and Yb and peaks in Hf and Zr, indicating fractionation (b) Chondrite normalized REE pattern after Sun & McDonough[44] for Moyar dykes, indicating relative enrichment of LREE with local depletion of HREE and a negative Eu anomaly.

3-3 Magnetic Susceptibility

AMS data of dykes show normal magnetic fabrics nearly parallel to their trends, but with variably plunging magnetic lineation. The mean susceptibility (K_m) values for dykes show a range with higher and lower limits of $10620 \mu\text{SI}$ (10^{-5}SI) and $83.43 \mu\text{SI}$ (10^{-5}SI) respectively. In contrast the mylonite generally shows low K_m values, ranging from $1569.533 \mu\text{SI}$ (10^{-5}SI) to $9.453 \mu\text{SI}$ (10^{-5}SI). The high K_m in dykes are mainly due to the higher percentage of ferromagnetic (titanomagnetite and clinopyroxene) minerals while the relatively low susceptibility values of mylonite (shear zone) suggest that either the magnetite was destroyed or the composition was different for the opaque

minerals in this zone. The distribution of ellipses, at 95% confidence level, for each of mean principal susceptibility directions and orientation of magnetic minerals for both dyke and mylonite are presented in figure 7. Figure 7a represents the distribution of the $K_{max}>K_{int}>K_{min}$ ($K1>K2>K3$) axes for the dykes where samples consist of varying amounts of scatter in orientation of tensors and 7b shows the preferred orientation of magnetic fabric which is in WNW-ESE direction. The principal directions for shear zone rocks which show significant clustering and the preferred orientation of mylonites which is more or less E-W and the corresponding macroscopic field foliation are presented in figures 7c and 7d respectively.

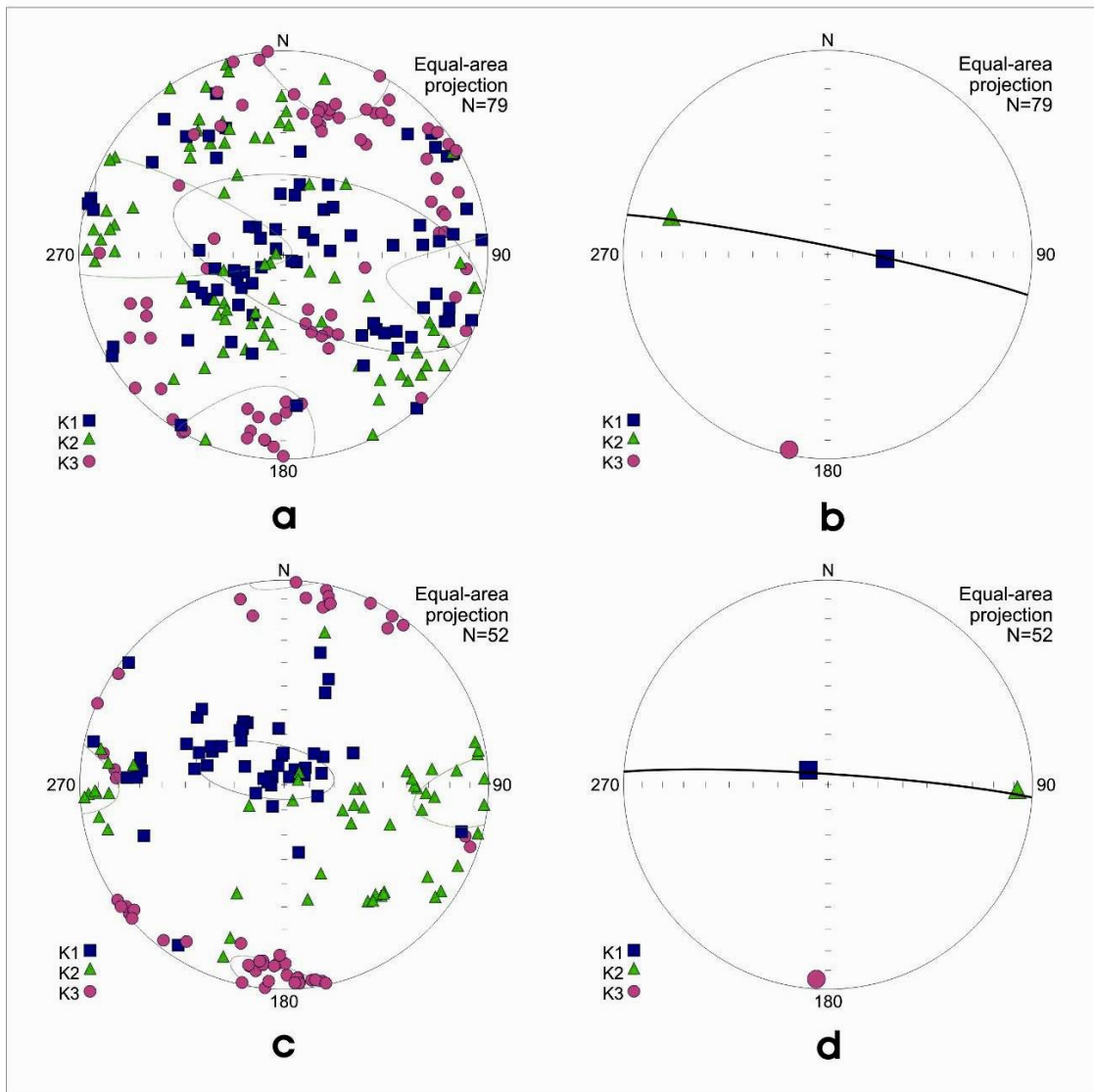


Fig.7. Distribution of 95% confidence ellipses for each of the mean principal susceptibility directions and orientation of magnetic minerals for both dyke and mylonite (a) distribution of $K_{max}>K_{int}>K_{min}$ ($K1>K2>K3$) axis for the dykes, all dyke samples consist of varying amounts of scatter in orientation of tensors (b) preferred orientation of magnetic fabric which is WNW-ESE. (c) principal directions for shear zone rocks (d) preferred orientation of mylonite fabric which is more or less E-W and in agreement with the macroscopic field foliation.

4. Discussion

Magnetic fabric data of the rocks are described using the Jelinek parameters P and T [37]. The magnetic foliation trajectories of the syenite pluton in the MSZ have a sigmoidal shape and curve into the shear zone to the north of the pluton suggesting a dextral sense of shear. Both the magnetic foliation and the measured field foliation have similar orientation, indicating that the magnetic fabrics in the pluton were influenced by the regional tectonic events that controlled fabric development in the region. Systematic analysis of magnetic fabrics of the rocks of the shear zone and the pluton has indicated that the pluton has also been deformed by the last phase of reactivation of the shear zone [30]. However, the mafic dykes postdate the shear zone and the pluton emplacement. The classical interpretation of dyke emplacement, in general, is that they form perpendicular to the minimum principal stress direction although the flow of magma inside fractures is one issue of basic importance in understanding how continental swarms developed [38]. While magma flow directions are traditionally investigated by petrographic fabrics,

oriented vesicles and fingers, grooves or lineations [39], among the AMS data, the K_{max} in flows is often considered as parallel to the direction of flow [40]. Therefore, consistency in alignment of K_{max} is a good proxy for determining magmatic flow directions. Among the samples M21a which is located at the centre of the Maximum Concentration Cluster (MCC) of the dyke swarm shows a confident vertical orientation (0/90) for K_{max} . In all other locations, away from the junction of dykes, K_{max} shows a near vertical to horizontal orientation. The samples from M3a, M5a, M10 and M69a show near vertical to inclined flow directions while those from locations M2a, P30, P32, T1 and T2 indicate inclined to sub-horizontal flow directions. Inclined flow directions dominate in this swarm because the magma emplacement is mostly through the deformed metamorphic rocks and fractures associated with shearing. Spatial analysis of flow directions reveals a systematic pattern suggesting a common conduit of emplacement for all dykes (Fig.8). At the conduit the flow trajectories are vertical while they gradually change to moderately to gently plunging and to sub- horizontal away from the conduit.

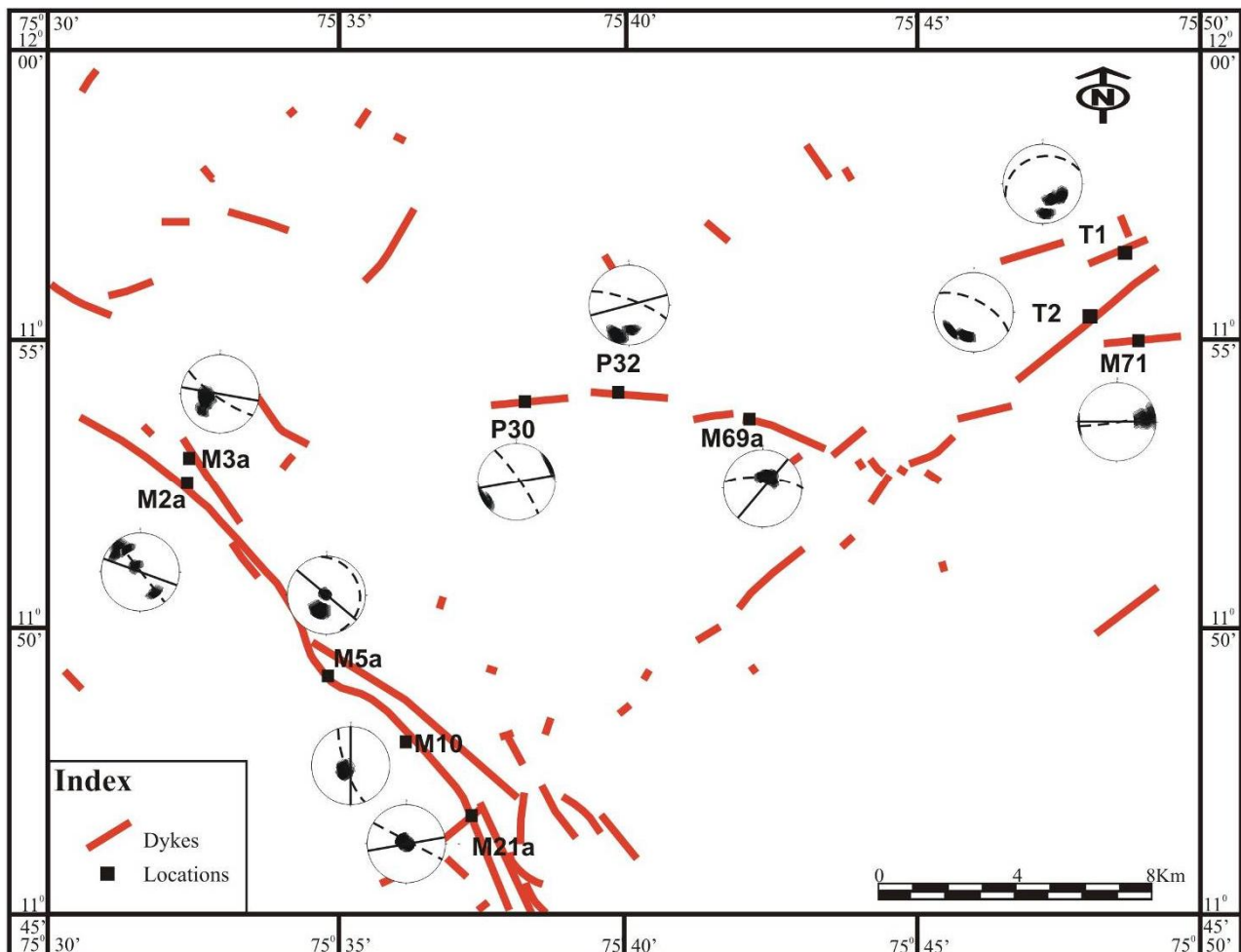


Fig.8. Spatial distribution of magnetic foliation and K_{max} in the MSZ dykes.

5. Conclusions

The major and trace element geochemistry of the MSZ dykes, mostly basalts, show evidences for fractional crystallization of magma with an enriched mantle source. The mafic dykes of the MSZ area formed contemporaneous with the Deccan Continental Flood Basalts, and show similar geochemical concentrations, which can be considered as an indication of continued plume interaction with the intrusion. On the basis of the geochemical characteristics, it can also be suggested that the low-K mafic dykes encountered in the MSZ area are Within-Plate continental tholeiitic N-type MORB with considerable amount of fractionation.

The magnetic foliation and lineation trajectories in the deformed metamorphic rocks and syenite pluton indicate a dextral sense of shear in agreement with the megascopic and microscopic structural fabrics. However, the magnetic fabrics in mafic dykes and gabbro are of post-tectonic character. Thus, while the fabric development in the syenite pluton indicates Pan-African tectonic reactivation of the MSZ, the mafic dykes indicate a late stage crustal dilation due to up-warping of crust caused possibly by a plume activity in the early formed crust of Southern Granulite Terrain. The younger isotopic age of the dolerites of the north Kerala can be interpreted in terms of Reunion mantle plume and consequent rifting which gave rise to the great Deccan basalts. The magmatic emplacements in MSZ are mainly controlled by the reactivated stress and hence the magnetic fabrics of these intrusives are of great tectonic significance in characterizing the South Indian crustal evolution.

Acknowledgement

VPK is thankful to the Department of Science and Technology, Govt. of India, New Delhi, for providing financial assistance through project number ESS/16/284/2006 for the work.

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