PALEOMAGNETISM AND GEOCHEMISTRY OF SOME DYKES FROM MYSORE STATE, INDIA

SYNOPSIS

THESIS
PRESENTED TO
THE ALIGARH MUSLIM UNIVERSITY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
in
Geology

BY
SYED IQBAL HASNAIN, M.Sc.
NATIONAL GEOPHYSICAL RESEARCH INSTITUTE
HYDERABAD
1970
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This thesis embodies a detailed account of paleomagnetic and chemical studies carried out on some of the dykes in the Mysore State. In the last decade the integrated studies have been a fascinating field on account of its successful application in solving many of the complex problems of geosciences. The study includes paleomagnetism of ninety-one samples, 370 specimens and major elements of thirty seven samples from ten different dykes.

The preliminary investigations carried out on the natural remanent magnetization (NRM) of these dykes revealed large scatter from dykes 1, 2, 4, 5, 6, 7, 8, 9 and 10, whereas the directions from dyke 3 are clustered. On successive cleaning by a.c. demagnetization with the peak field values up to 300 oersteds on the specimens from all the dykes show that the scatter has been reduced in six dykes (1, 2, 5, 6, 7 and 10) and revealed consistent directions. However, the scattering in the four dykes (3, 4, 8 and 9) remained unchanged.

It has been shown by a.c. demagnetization curves that out of ten dykes studied, four dykes (3, 4, 8 and 9) did not improve after cleaning, thereby indicating that the original thermo-remanent magnetization (TRM) was destroyed to a large extent. Whereas, the directions of six dykes (1, 2, 5, 6, 7 and 10) form a cluster away from the present geomagnetic field.
At least two specimens from each of the six dykes showing consistent directions were heated up to Curie point to see the thermal stability and it was observed that within the limits of experimental error they remained in the group which was formed by the a.c. demagnetization. This suggest that natural remanent magnetization (NRM) in these dykes is of thermo-remanent magnetization origin. The Curie point values range from 280 to 480°C for all the dykes.

Remanence coercivities have been measured for a few specimens from each dyke by magnetizing them in a maximum field strength of 1500 oersteds and subsequently demagnetizing. The values of the remanence coercivity was found to be low and within the range of 150 to 300 oersteds. Titanomagnetite is the only iron-oxide which is known to have coercive force of this order.

Thermal behaviour studies have been made by heating few specimens from each dyke to higher temperatures for studying the decay of Jn and then cooled in the earths magnetic field to room temperature to produce Jt (total TRM). It has been observed that in most of the cases about 50% of Jn is demagnetized or 50% of Jt is acquired at a temperature between 300 to 400°C. A close resemblance of Jn and Jt curves also suggests that the NRM possessed by these dykes is of TRM nature.

Few polished specimens have been examined from each dyke which show chiefly titanomagnetite (Fe₂−₊ Ti₀₄ · Fe₃O₄ solid solution).
All specimens have lamellae of ilmenite and are oriented in (111) plane of magnetite. The dykes which show high magnetic stability also show high temperature oxidation effects and single Curie point. Whereas, the unstable dykes show two or more Curie points and low temperature oxidation.

The low Curie points, as shown by all the specimens, correspond to titanium rich titanomagnetites or low grade titanomaghemite thereby substantiating the conclusion that titanomagnetite is the main carrier of remanent magnetization.

The virtual geomagnetic pole positions have been derived from the mean directions of RM for six dykes. The poles derived from dykes 1, 5 and 6, are close to each other. This suggests that these dykes might have intruded contemporaneously. The poles of these dykes and dyke 7 are in broad agreement with mean pole positions of upper and lower Deccan traps. This suggests that these dykes are of much younger in age, probably contemporaneous to Deccan trap igneous activity. The poles from dykes 2 and 10 fix the position of India in the northern hemisphere thereby suggesting their probable Precambrian age.

The chemical composition shows that the dykes 2, 4 and 10 are alkalic in nature, characterised by high alkalis, titanium and low silica whereas dykes 1, 3, 5, 6, 7, 8 and 9 belong to tholeiitic type as they are rich in silica and poor in titanium. The tholeiite dykes show a remarkable similarity with the petrochemistry of Deccan traps.
The dykes of the Indian shield under study can be divided into two periods: (a) alkali basalt dykes of probable Precambrian age; (b) tholeiite basalt dykes of Deccan trap age (Upper Cretaceous–Eocene).

The above conclusions are drawn by making use of the combined geophysical and geochemical studies.
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The work presented in this thesis has been carried out by
Mr Syed Iqbal Hasnain. I certify that it is his bona fide work.
The work is original and has not been submitted for any other degree
to this or other University.

DIRECTOR,
National Geophysical Research Institute.

M. H. Qureshy
Assistant Director
NATIONAL GEOPHYSICAL RESEARCH INSTITUTE
(C.S.I.R.)
HYDERABAD

30.3.70
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National Geophysical Research Institute, HYDERABAD-7 (A.P.)

(S. IQBAL HASNAI)
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PREFACE

It is well-known that a rock body becomes more valuable, the more information we can obtain about it. In view of this fact, any study undertaken to explore the inner structure and the process of formation of earth, has been an invaluable addition to our present day knowledge in geology. The 'Upper Mantle Project', which is particularly designed to determine the variations in physical and chemical properties of the upper mantle (1,000 Km), as well as the crust, has received world-wide attention and co-operation. These studies will particularly lead to an understanding of the causes of tectonic, magmatic and metamorphic processes. Hence, investigations should be based on an integrated approach (geophysical, geological and geochemical), making combined use of available methods and data from various disciplines of earth sciences. The well-known Soviet geoscientist, V.V. Belousov named such a combined approach to study the structure and development of the earth's interior as "geonomic".

The mantle of the earth has distinctive physical characteristics as shown by seismic and other surveys, and it also has distinctive chemical properties. For example, elements, such as, Mg, Fe, Cr and Ni (to name a few), occur in higher concentration in the mantle than in the earth's crust; they were introduced into the crust by plutonic and volcanic processes at various times of the earth's history.
In India, a national committee has been constituted for the Upper Mantle Project, the membership of which is drawn from the Geophysical Research Board (GRB). The main objective of this committee is to initiate and formulate programmes for such integrated studies. Integrated studies being the highlight of the Upper Mantle Project, the following vital regions have been selected for such a study:

1. Dharwar region (Mysore State)
2. Singhbhum region (Bihar State)
3. Aravalli region (Rajasthan State)
4. Cuddapah and Eastern Ghats (Andhra Pradesh)

The above-mentioned areas, selected for inter-disciplinary studies, are the riddle of Indian geology, as they have contrasting structures coupled with a complex geological history.

The National Geophysical Research Institute (NGRI), Hyderabad, has taken up an integrated study of two of the regions, Dharwar in Mysore State and Cuddapah in Andhra Pradesh.

The Dharwar region offers a challenge to the inter-disciplinary studies. In view of this, studies were carried out on this area in general and on dykes in particular. Although extensive geological work has been undertaken on the dykes of this region, (which are intrusive into schists and gneisses), there is no consensus regarding their age, mode of emplacement and relationship to the tectonic development of the Indian shield.
In this thesis, an integrated study of the dykes of the Dharwar region is reported.
1.1 GENERAL HISTORY OF PALEOMAGNETISM

The natural remanent magnetization of magnetite was first studied in China sometime in 630 B.C. (Khramov, 1957). Much later, it was established that many minerals and rocks are magnetized. Robert Boyle (1661) discovered the presence of residual magnetism in bricks, while Melloni (1853), after a study of the lavas of southern Italy, found that when subjected to a temperature of few hundred degrees, they lose their residual magnetism, which they regained during cooling in the geomagnetic field.

Chevallier (1925), after studying the lava flows of Mt. Etna (Italy), in France, found that a rock possesses the magnetization parallel to the ambient field. This classic work which is considered to be a hallmark in geophysics, subsequently led to further studies in magnetization. Since then, with the sustained efforts of geoscientists, spectacular achievements have been made in the fields of instrumentation and in the techniques of experimentation.

The last decade saw a breakthrough in the development of sophisticated magnetometers and other instruments, which helped in the study of intricate magnetic properties. Blackett (1952), Collinson et al. (1957), Deutsch et al. (1967), De Sa and Molyneux (1963, 1967), Thellier (1967) and Cox and Doell (1967), devised astatic and spinner-
magnetometers to detect much weaker magnetization in rocks. With these inventions, the study of paleomagnetism and magnetic properties of rocks gained momentum.

1.2 PALEOMAGNETISM

The reconstruction of geological history in the geomagnetic field is due to the availability of fossilized "imprints" of the ancient field in the form of Natural Remanent Magnetism (NRM) in rocks. Most of the rock forming minerals are non-magnetic and do not contribute to fossil magnetism but iron-oxides and sulphides are present in very minute quantities and are the main carriers of magnetization. The obvious ways in which they might have acquired magnetization are discussed in 1.3.

1.3 TYPES OF MAGNETIZATION

(1) Thermo–Remanent Magnetization (TRM). When a lava containing a large number of fine magnetic grains is cooled down through its Curie temperature, in a magnetic field, the lava acquires intense and stable remanent magnetization. This type of magnetization is called the Thermo–Remanent Magnetization, or briefly TRM. When cooled in the geomagnetic field, the lavas acquire TRM in nature.

(2) Depositional–Remanent Magnetization (DRM). The natural remanent magnetizations of sedimentary deposits are considered to be caused in many cases by the statistical alignment of ferrimagnetic mineral
grains along the direction of the ambient magnetic field during their deposition. This is called Detrital (or depositional) Remanent Magnetization, or briefly DRM.

(3) **Chemical-Remanent Magnetization (CRM).** The formation of ferrimagnetic minerals by some chemical change, under the influence of a magnetic field, is accompanied by stable remanent magnetization. This kind of magnetization is called the Chemical (or crystalline) Remanent Magnetization or briefly CRM.

(4) **Isothermal Remanent Magnetization (IRM).** Rocks acquire IRM when they are subjected to strong magnetic fields at a constant temperature, associated with fields such as lightning bolts which may be as high as 25000 amperes (Cox, 1959). The IRM may easily be destroyed or its direction changed in a field stronger than that in which it is originally produced.

(5) **Viscous Remanent Magnetization (VRM).** A rock placed in a weak magnetic field for a short period of time will acquire little or no IRM at all. But over a long period, the rock will acquire a magnetization that is proportional to the logarithm of the time, and the magnetization increases with the increasing value of the weak field. This type of magnetization is known as the Viscous Magnetization or briefly VRM.

(6) **Piezo-Remanent Magnetization (PRM).** A simultaneous application of pressure and magnetic field produce a kind of magnetization by means of magnetostriction. This type is termed as
Piezo-Remanent Magnetization, or briefly PRM.

(7) Anhysteretic Remanent Magnetization (ARM). This type of magnetization (ARM) is produced by the simultaneous application of a constant magnetic field and an alternating field. When the constant magnetic field is removed, the remaining magnetization in the rock is called anhysteretic remanent magnetization, or briefly ARM.

The first three magnetizations are called primary components of magnetization as they are acquired by the rocks at the time of their formation. They represent the earth's magnetic field of the geological past. The remaining four types of magnetizations are acquired subsequently, due to various causes which are described in detail by Wilson and Smith (1988), and are called secondary components of magnetization. They may also be soft components of magnetization.

The rocks in general may possess one of the primary components and one or more types of secondary components superimposed over the primary component. The magnetization possessed by the rocks is the resultant of primary and secondary components of magnetizations and is termed the Natural Remanent Magnetization (NRM).

1.4 ACQUISITION OF MAGNETIZATION BY IGNEOUS ROCKS

Igneous rocks, which are formed by the cooling of a liquid magma, acquire most of their magnetization as they cool through the Curie temperature. Studies in the laboratory show that the direction of the magnetism acquired by this process of thermomagnetic remanence
accurately in the direction of ambient field. Thus, when physical and chemical changes do not occur, the rocks should give a reliable indication of the direction and intensity of the earth's field when they were formed.

1.5 REVERSE-MAGNETIZATION

In 1906, French physicist Bernard Brunhes found that some volcanic rocks were magnetized in exactly the reverse direction of the present field. He concluded that the field must have reversed. But very little attention was drawn to this fascinating discovery by workers in the field at that time.

The extensive researches made by Roche (1953), Hospera (1953, 1954), Graham and Hales (1957), Wilson (1962), Cox, Dalrymple and Doell (1967), and Pullaiah and Verma (1969), strongly suggest that the earth's dipole field has reversed frequently during geological times.

Frequent reversals of the geomagnetic field have been confirmed by investigations of paleomagnetic and radiometric age determinations on igneous rocks of late Pliocene and Pleistocene age. Cox et al. (1963, 1964), Gromme and Hay (1963), McDougall and Tarling (1963, 1964) and Wilson (1966), reviewed the paleomagnetic studies of numerous formations to establish the duration of field reversed and the nature of geomagnetic field during the period of reversal.

These researches showed beyond any doubt that earth's magnetic field has two stable states: it points either toward the North Pole as
it does today, or toward the South Pole; and it has repeatedly alternated between the two orientations.

The evidence that the reversed magnetic directions are invariably opposite to the present field direction at the sampling site, led in time to the hypothesis that the reversals are not local but global; in other words, the entire field of the earth reversed.

An important alternative explanation must be taken into consideration before accepting the field reversal hypothesis. The alternative is that reversely magnetized rocks may possess some special mineralogical property that causes them to become magnetized in a direction opposite to the applied field. The existence of "self-reversal" in rocks was suggested in 1950 by John Graham. Graham's suggestion stimulated the French physicist, Louis Neel (1955), to examine the problem, from the point of view of solid state physics, and Neel soon postulated four mechanisms by which a rock might acquire reverse magnetization. Later, some of his hypotheses were experimentally proved.

If both field reversal and self-reversal occur together, then the situation becomes very complex. Both field reversal and self-reversal within the specimens are reported from some lava flows.

1.6 GEOPHYSICAL AND GEOLOGICAL ASPECTS OF PALEOMAGNETISM

By paleomagnetic data we can obtain more accurate information about the variations of the geomagnetic field of the remote past, to
enable us to study the classical geophysical problems which interest
the modern geophysicists, such as, continental drift, polar wandering,
sea-floor spreading and expanding earth. Creer et al. (1958), Nairn
(1956), Hospers (1955), Heezen (1959), Deutsch (1963), Van Andel and
Hospers (1968), Cox and Doell (1961) and Egyed (1960), have success-
fully utilized the data for interpretation of these problems.

Apart from geophysical problem, paleomagnetic can be put to
use in stratigraphic correlation, tectonics and paleogeography as
studied by Sahasrabudhe (1963), Gough and Opdyke (1963), Irving (1957;
1958), Khramov (1958), Jones and McElhinny (1967) and McMahon and
Strangway (1968).

1.7 EARLIER RESULTS

Studies on Indian rocks were first initiated by Prof. P.M.S. Blac-
kett at the Imperial College of Science and Technology, London, around
1952, when J.A. Clegg, E.R. Deutsch and D.H. Griffiths undertook studies
on Deccan traps because of their wide areal extent. This work was
taken up in 1955, in greater detail at the Tata Institute of Fundamental
Research (TIFR), Bombay, where studies of the Deccan traps (of lower
Cretaceous to Eocene age) from various localities were done. Results
from the Deccan traps have been reported by Clegg et al. (1958),
Deutsch et al. (1958, 1959), Sahasrabudhe (1963), and Radhakrishnamurthy
(1963). Besides this unit, some upper Jurassic and Precambrian basalts
have also been studied by Clegg et al. (1958), Athavale et al. (1963), and
Radhakrishnamurthy et al. (1967).
Paleomagnetic studies in the National Geophysical Research Institute, Hyderabad, were started in 1962. Here, initial studies were undertaken on Deccan traps from a few localities (Gulberga, Chincholi and Vikarabad) in the south-central part of the main mass of the traps and the results were reported by Verma and Appa Rao (1963) and the Veldurthi hematite was studied by Verma et al. (1963). The group at the National Geophysical Research Institute (NGRI), Hyderabad, have also carried out studies on some other Deccan trap sites (Verma and Pulliah, 1969; Athavale, 1966). Paleomagnetic data from red sandstones belonging mainly to the Gandava system of Cretaceous (Verma and Pulliah, 1967), Triassic (Nailla and Verma, 1969), and Permian age (Verma et al., 1966, 1967, 1968) have also been reported.

Precambrian Formations

Paleomagnetic data from Precambrian formations of India unfortunately is very scanty, and unreliable as most of the formations studied are based on a few samples. The paleomagnetic parameters of the formations studied so far are given in Table I.

The youngest Precambrian formation studied is the upper Vindhyan sandstone (Misra, 1965). This formation has been classified as lower-most Cambrian on the basis of reports on the existence of fossils in them (Misra, 1965). The other extensively studied formations are the Malani Rhyolites in N.W. India (Athavale et al., 1963) and the Veldurthi hematites, Cuddapah basin by Verma et al. (1966). Apart from these two, data from other formations are based on smaller number of samples from both igneous and sedimentary rocks and these latter are of less
### Table 1

**Paleomagnetic Data from Precambrian Formations**

<table>
<thead>
<tr>
<th>No.</th>
<th>Geological formation and locality</th>
<th>Age in M.Y.</th>
<th>Co-ordinates Lat Long degrees deg.</th>
<th>No. of sites</th>
<th>No. of blocks</th>
<th>Mean remanent direction (in degrees)</th>
<th>Polarity</th>
<th>95 Paleolatitude</th>
<th>Paleomagnetic pole Lat Long</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Upper Vindhyan sandstone</td>
<td>540-580</td>
<td>24°37' 83°06'</td>
<td>1</td>
<td>143</td>
<td>0 +30°</td>
<td>N</td>
<td>13° N</td>
<td>82°N 103°W</td>
<td>Misra, 1965</td>
</tr>
<tr>
<td>B</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>1</td>
<td>38</td>
<td>186 -30°</td>
<td>R</td>
<td>do</td>
<td>do</td>
<td>do</td>
</tr>
<tr>
<td>2</td>
<td>Malani Rhyolites</td>
<td>580-735</td>
<td>26° 73°</td>
<td>9</td>
<td>170</td>
<td>353 +56°</td>
<td>N</td>
<td>10° 31°N</td>
<td>78°N 45°E</td>
<td>Athavale et al, 1963</td>
</tr>
<tr>
<td>3</td>
<td>Mundwara complex</td>
<td>650-650</td>
<td>25° 73°</td>
<td>1</td>
<td>25</td>
<td>329 -24°</td>
<td>N</td>
<td>21°</td>
<td>do</td>
<td>do</td>
</tr>
<tr>
<td>4</td>
<td>Banded Hematite quartzites</td>
<td>750-950</td>
<td>24° 81°</td>
<td>1</td>
<td>5</td>
<td>270 -12°</td>
<td>N</td>
<td>7° 9°30'S</td>
<td>2°N 3°W</td>
<td>Misra, 1965</td>
</tr>
<tr>
<td>5</td>
<td>Banded Hematite Jasper</td>
<td>do</td>
<td>24° 81°</td>
<td>1</td>
<td>5</td>
<td>289 -9°</td>
<td>N</td>
<td>7° 7°8'</td>
<td>15°N 25°W</td>
<td>do</td>
</tr>
<tr>
<td>6</td>
<td>Bijawar traps Gwalior</td>
<td>do</td>
<td>26° 78°</td>
<td>1</td>
<td>25</td>
<td>70 +3°</td>
<td>R</td>
<td>18°</td>
<td>do</td>
<td>do</td>
</tr>
<tr>
<td>7</td>
<td>Veldurthi Hematite</td>
<td>900-1200</td>
<td>15°36' 78°</td>
<td>4</td>
<td>170</td>
<td>133 -37°</td>
<td>R</td>
<td>14° 24°30'N</td>
<td>45°N 3°E</td>
<td>Verma et al, 1963</td>
</tr>
<tr>
<td>8</td>
<td>Chitloor dyke</td>
<td>1100-1200</td>
<td>14°38' 79°</td>
<td>1</td>
<td>3</td>
<td>146 +11°</td>
<td>R</td>
<td>19°</td>
<td>do</td>
<td>do</td>
</tr>
<tr>
<td>9A</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>1</td>
<td>3</td>
<td>296 -32°</td>
<td>N</td>
<td>3° 14°S</td>
<td>20°N 36°W</td>
<td>do</td>
</tr>
<tr>
<td>B</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>1</td>
<td>3</td>
<td>264 -29°</td>
<td>N</td>
<td>4° 9°30'S</td>
<td>9°N 25°W</td>
<td>do</td>
</tr>
<tr>
<td>9A</td>
<td>Cuddapah shales</td>
<td>do</td>
<td>15° 78°</td>
<td>1</td>
<td>5</td>
<td>295 -10°</td>
<td>N</td>
<td>5° 23'S</td>
<td>28°N 25°W</td>
<td>do</td>
</tr>
<tr>
<td>B</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>1</td>
<td>24</td>
<td>294 -6°</td>
<td>N</td>
<td>8° 0°</td>
<td>22°N 20°W</td>
<td>do</td>
</tr>
<tr>
<td>10</td>
<td>Hyderabad dyke</td>
<td>-</td>
<td>17°23' 78°28'</td>
<td>1</td>
<td>23</td>
<td>44 -3°</td>
<td>N</td>
<td>5° 3°N</td>
<td>43°N 173°W</td>
<td>Verma et al, 1963</td>
</tr>
</tbody>
</table>
practical value.

Many cases of mixed polarity have been reported from these results as for instance the Bijawar traps (Athavale et al., 1963) and the banded hematite quartzite (Misra, 1965). In these cases it is difficult to assign them to either normal or reverse groups for purpose of calculation. The decision in such cases was made on the basis of interpolation of progressive values of the angle of rotation.

Athavale et al. (1963) reviewed the post Precambrian paleomagnetic data to study the drift of the Indian land mass. The authors concluded that in Precambrian times, India more or less occupied an equatorial position, drifted southwards to about 50°S during the Paleozoic, remained almost stationary from the Permian to the Cretaceous, and then drifted rapidly northward. Another interesting point about the drift of India is that the rotation of the land mass was anti-clockwise during northward drift and in contrast was probably clockwise during the southward drift.

1.8 PRESENT WORK

The problem of Precambrian correlation particularly in India of the dyke swarms intruding them is far from a solution. The main reason of this is the lack of radiometric age data, due to the lack of facilities.

In the last decade classification of dyke swarms and to understand the early history of geomagnetic field was found useful. B.P. Radhakrishna
(1967) emphatically stated that: "it is possible that some of the dyke swarms may be related to the igneous activity younger than Precambrian and possibly even to Deccan basalts. Paleomagnetic studies and determination of remanent magnetism of the dyke rocks are fruitful fields of research to be undertaken for the light they throw on the age of the basic dykes".

Hitherto, no serious efforts have been made to study the Paleomagnetism and the magnetic properties of the dykes of the Indian shield. Qureshy et al. (1967) studied a few dykes from Pavagarh (Mysore State) but could not get consistent results due to inadequate sampling. Therefore, the present work has been undertaken to investigate the age and mode of emplacement of Mysore dyke swarms. The results obtained are presented here.

The main findings of this study are that the dykes studied can be of two periods: (a) alkali basalt dykes of probable Precambrian age; (b) tholeiite basalt dykes of Deccan traps age (upper Cretaceous to Eocene).
CHAPTER II

GEOLOGY

2.1 GENERAL

The Dharwar region of Mysore State seems to be the oldest rock complex in peninsular Indian shield, its age being in the order of 3000 million years (Crawford, 1969). This shield covers an area of about 192,000 square miles, bounded by Deccan traps in the north, the Arabian sea in the west and Cuddapah rocks to the east. Our present knowledge about the geology of this region is due to the data collected by such eminent geologists as Newbold (1848, 1850), Bruce Foote (1888), Smeeth (1916), Jayaram (1925), Sampat Iyengar (1920), Rama Rao (1940), Pichamuthu (1947, 1951a, 1951, 1959, 1967) and Radhakrishna (1963, 1967).

2.2 DHARWAR-SYSTEM

The term "Dharwar", named after a place in the Mysore State was first used by Bruce Foote (1888) to denote the existence of a series of sedimentary and schistose rocks in this area. He considered Dharwars as a younger formation resting on the older gneisses, which form the basement. Sometime back, the term, Dharwar, had taken wide dimensions and was freely used to correlate other Archean rocks of the Indian shield, such as the Iron-ore series of Singhbum, the Aravallis of Rajasthan and the Sakolis of Madhya Pradesh. Such correlations were
entirely done on the basis of lithological resemblances, as for example, the presence of hematite-quartz schists. But recently the consensus largely swings in favour of restricting the term to schistose formations in the characteristic area of Mysore State.

2.3 STRATIGRAPHY

The generalized stratigraphy of the Precambrian formation of Mysore worked out by Rama Rao (1936), Pichamuthu (1947) and Holmes (1955) is given in Table 2.

Radhakrishna (1963), considers the gneisses as the basement of Dharwars. He is also of the opinion that the most striking feature of the schistose rocks of this region is their remarkable uniformity of strike and dip, which is also true for the associated gneisses.

Pichamuthu (1967, p. 38), regarding the trend of the Dharwars, states that it varies from N.N.W-S.S.E to N.W.-S.E. Whereas, in the southern Mysore the trend becomes N.-S., and then turns S.W. and W.S.W., thus aligning with the trend in the Eastern Ghats of Salem and the Nilgiris in Tamil Nadu.

Since more and more data about the Dharwar geology is becoming available, Radhakrishna (1967) questioned the validity of the Dharwar classification into 'lower', 'middle' and 'upper', stating that "the Peninsular gneiss as a whole are not intrusive into Dharwars and the charnockites are elder than the Dharwars".
### TABLE 2

**GENERALIZED STRATIGRAPHY OF THE PRECAMBRIAN FORMATIONS OF MYSORE STATE**

<table>
<thead>
<tr>
<th>Mafic dykes?</th>
<th>Felsic and porphyry dykes</th>
<th>Closepet granites</th>
<th>Charnockite series</th>
<th>Peninsular gneiss complex (migmatites and granites)</th>
</tr>
</thead>
</table>

#### MAJOR ORGENESIS

<table>
<thead>
<tr>
<th>Upper Dharwars</th>
<th>Upper Sedimentary cycle</th>
<th>Cherty, ferruginous and calcareous shales, quartzites, conglomerates (containing pebbles of albitic rocks)</th>
</tr>
</thead>
</table>

#### EROSION AND PENEPLANATION

<table>
<thead>
<tr>
<th>Middle Dharwars</th>
<th>Middle Sedimentary cycle</th>
<th>Spilitic basalts and dykes (greenstone schists). Pegmatite and quartz veins. Orogenesis: migmatites and granites (including albitic types). Iron-stones, Limestones, Argillites, quartzites, Conglomerates, containing pebbles of pre-Dharwar gneiss.</th>
</tr>
</thead>
</table>

#### SLIGHT DISCORDANCE

<table>
<thead>
<tr>
<th>Lower Dharwars</th>
<th>Lower volcanic cycle</th>
<th>Champion Gneiss and Felsic Sills</th>
<th>Rhyolites, keratophyres and tuffs</th>
<th>Basic and spilitic lavas (chlorite and hornblende schists)</th>
</tr>
</thead>
</table>

**BASE NOT SEEN**
Aswathanarayana (1968) recognized the four orogenic cycles in the Dharwar region by radiometric dating. The oldest is the folding of the pre-Dharwarian (2950 million years), whereas, the youngest (2000 million years) is cross-folding and en-echelon folding of the earlier isoclinal folds, about an axis oblique to the earliest isoclinal axis.

2.4 BASIC DYKES

The presence of large dyke swarms which cut across both schists and gneisses is a characteristic feature of Dharwar region. However the other Precambrian region appears to be comparatively free from basic dykes (Radhakrishna, 1967). These are mainly doleritic in composition and project as elongated chains of hills above the surrounding country rocks. The weathering effect on these dykes is mainly seen in the form of spheroidal and columnar joints but in places the basic dyke swarms are exposed due to deep erosion. The great number of dykes, their regular orientation and the continuity of a single dyke over a long distance at some places show that the magma moved rapidly upward along tension fractures. These fractures must have extended deep into the crust to provide an access to the large supply of basic magma.

Nautiyal (1966) in his Presidential address to the session of geology at the 53rd Indian Science Congress, stated the following regarding the basic Mysore dykes: "approximately NS and EW and other system of dykes that are ramifying in the Mysore plateau belong to various geological periods". Pichamuthu (1959) stated that the
Deccan traps which is estimated to have covered nearly 500,000 square miles of peninsular India, is a flood basalts of tholeiitic affinities. This type is usually associated in many parts of the world with quartz-dolerite dykes and sills. The occurrence of such dykes in South India raises the possibility that some of them are probably of the same age as that of the Deccan traps.

2.5 SIGNIFICANCE OF THE BASIC DYKES IN THE INDIAN SHIELD

Flood basalts and basic dykes occurred at various times in geological history and have been reported from practically all shield areas of the world.

The dykes of the Indian shield are very extensive in space and time. A broad study of these intrusive rocks will give the clues, that will be useful in understanding the development of the shield.

Many flood basalts of the world have a multitude of basic dykes as their feeders. For instance, the Mysore dykes are both concordant and discordant with the structural trend and the assumption that these dykes swarms once had flood basalts with them is based on an analogy with other shield flood basalts in areas such as the Parana basalt of S. America, the Tertiary lava flows of Syke, Scotland, and the flood basalts of S. Africa and Australia.

The Deccan basalt presently covers a huge area of about 200,000 square miles and there is every likelihood that some of the dyke swarms in Mysore are associated with it. Gibson (1966) studied the crustal Flexures in Deccan basalts and stated, "Elsewhere in the Deccan the dykes appear to radiate from intrusive centres or to be
related to late folds of Deccan basalts, east of Bombay, the relationship is somewhat simpler. The majority of trends of shield dykes are N-S and are apparently related to a similarly oriented monoclinal fold, Panvel flexures. After a thorough study of the flexures from other flood basalts, he concluded that the flexures would seem to suggest that dykes are tensional features produced during the formation of a monocline, and they represent a late phase of igneous activity. Thus, dykes, lavas and flexures have all formed approximately contemporaneously. Fahrig and Wanless (1963) suggested that an intense folding and compression in the orogenic belt and less intense compression within the cratons result from sub-crustal currents. If relaxation occurs during and after a major orogenic cycle, as a result of diminution in the size of sub-crustal convection currents, basic dyke intrusion may occur both in the orogenic zone and in the adjacent stable craton. Aswathanarayana (1968) dated the latest orogeny in Dharwar region at about 2000 million years, which is accompanied by cross-folding and en-echelon folding and metamorphism. Therefore, it seems likely that the fractures and weak zones in the shield might have resulted from this orogeny. A series of dyke swarms in the Mysore shield might have reflected more intense rhythmic compression and relaxation in the neighbouring mobile belt of this age.

The Spanish peak dyke swarm in Colorado is of Eocene age. It is believed that the joints through which the dykes were intruded developed during the early stages of folding of the Laramide orogeny of late Cretaceous age. Badgley (1960) studied the structural trend of the area in great detail and concluded that the Laramide structural
trends were influenced by weakness directions established even earlier, during the Precambrian and Ancestral Rockies structural episodes.

The dykes of Mysore shield, therefore, may also indicate a tensional zone of continental proportions, for which the most reasonable explanation might be (a) flexures; or (b) sub-crystal flow in the form of convective cells; or (c) the weak zones developed by Precambrian structural episodes.

On the basis of the above, one is led to the conclusion that the regional tensional fractures combined with relative vertical movements produces cracking of the crust, by any of the mechanisms discussed. It is, therefore, likely that some of the tension cracks formed in Precambrian times or later, were filled by the magma of Deccan trap Igneous activity in Cretaceous period.
3.1 COLLECTION, SHAPING AND MEASUREMENT

Despite the handicap that poor exposures are found in Mysore State, 91 oriented samples were collected from 10 different dykes, during the winter of 1967-1968. The samples were collected mainly from road cuttings, quarries and river beds, in order to avoid the heavy oxidizing condition found in a tropical country like India. Locations of the dykes sampled are shown on the geological map of Mysore State in Fig. 1. Each sample, when in situ, was marked with an arrow, representing the geographical North, using Brunton Compass. Further, horizontal lines were drawn with the use of a precision spirit level.

From each oriented sample, four to six cores were drilled normal to the horizontal plane, cut into small cylindrical specimens (disk) and marked with a reference to the site and sample.

A summary of the collection of samples with site location, number of samples and specimens studied, and the trend of the dykes are listed in Table 3.

3.2 EXPERIMENTAL PROCEDURES

Precision and accuracy of paleomagnetic measurements are dependent upon sophisticated instrumentation and magnetic stability of the samples.
<table>
<thead>
<tr>
<th>Site No.</th>
<th>Reference letter</th>
<th>Dyke Location</th>
<th>No. of samples</th>
<th>No. of specimen</th>
<th>Trend of dyke</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ICD</td>
<td>14°10' 76°27' Near Chitaldrug</td>
<td>12</td>
<td>45</td>
<td>N 70°W</td>
</tr>
<tr>
<td>2</td>
<td>2CD</td>
<td>14°11' 76°22' Near Chitaldrug</td>
<td>13</td>
<td>48</td>
<td>N 70°W</td>
</tr>
<tr>
<td>3</td>
<td>3CD</td>
<td>14°15' 76°25' Near Chitaldrug</td>
<td>4</td>
<td>11</td>
<td>N 70°W</td>
</tr>
<tr>
<td>4</td>
<td>4CD</td>
<td>14°10' 76°24' Near Chitaldrug</td>
<td>8</td>
<td>22</td>
<td>N 15°W</td>
</tr>
<tr>
<td>5</td>
<td>GD</td>
<td>12°11' 76°4' Near Periyapatna</td>
<td>5</td>
<td>40</td>
<td>N 15°W</td>
</tr>
<tr>
<td>6</td>
<td>KD</td>
<td>12°25' 75°11' Near Kushalnagar</td>
<td>13</td>
<td>56</td>
<td>N 15°W</td>
</tr>
<tr>
<td>7</td>
<td>7HD</td>
<td>12°10' 76°14' Near Hunsur</td>
<td>22</td>
<td>82</td>
<td>N 15°W</td>
</tr>
<tr>
<td>8</td>
<td>8HD</td>
<td>12°18' 76°50' Near Hunsur</td>
<td>7</td>
<td>21</td>
<td>N 15°W</td>
</tr>
<tr>
<td>9</td>
<td>CK</td>
<td>12°20' 76°11' Near Chilkunda</td>
<td>3</td>
<td>23</td>
<td>N 15°W</td>
</tr>
<tr>
<td>10</td>
<td>HO</td>
<td>12°44' 77°31' Near Horahalli</td>
<td>4</td>
<td>22</td>
<td>N 70°W</td>
</tr>
</tbody>
</table>
In addition to the primary component, rocks may take up secondary components of magnetization, subsequent to their formation. This is due to effect of the geomagnetic field, lightning strokes, weathering effects etc. The secondary effects, in these samples, completely mask the primary component, resulting in a large scattering of the directions of magnetization. It is, therefore, necessary to study the stability of magnetization of a rock formation and remove the secondary components, if any. Later, computing the mean remanent magnetic directions, and intensities of NRM and assessing the stability of magnetization are done as briefly discussed below.

3.2.1 MEASUREMENT OF DIRECTIONS AND INTENSITIES OF RM

Directions and intensities of remanent magnetization of all the specimens were measured on an astatic magnetometer in a field-free space, set-up at the Paleomagnetism Division of the National Geophysical Research Institute. The sensitivity of the instrument is of the order of $3 \times 10^{-7}$ oersteds/cm deflection with a four meter optical path.

The intensity of each specimen was measured in three perpendicular directions with respect to geographic North. Measurements were taken in twelve orientations of the specimen with respect to the magnetometer in order to minimize anisotropy effects. Declination is measured, east of geographic North from $0^\circ$ to $360^\circ$ and inclination or (dip) from $0^\circ$ to $90^\circ$ downwards (positive) or upward (negative). The errors in measurement of the declination and inclination are not more than $\pm 5^\circ$. 
3.3 STABILITY TESTS

For testing the stability of NRM of rocks, Graham (1949) proposed a few field tests which can be used only in certain special cases. Apart from these, there are two laboratory techniques useful in "cleaning" the unwanted components of magnetization.

The first technique is known as the alternating current demagnetization techniques (a.c. demagnetization), for which an instrument was developed initially by Creer (1961). The second, the thermal-demagnetization technique was developed by Wilson (1962). This technique, besides providing information about the stability, enables us to determine the Curie points of ferromagnetic minerals present in the rock.

In the present studies both a.c. and thermal demagnetization techniques are used for assessing the stability of NRM of rocks and for magnetic cleaning.

3.3.1 INSTRUMENTAL AND EXPERIMENTAL PROCEDURES FOR A.C. AND THERMAL DEMAGNETIZATION

An a.c. demagnetization apparatus was constructed in the National Geophysical Research Institute, Hyderabad, which is similar to that of Creer (1961). An important part of this apparatus is a specimen holder, which is made up entirely of perspex and capable of rotating simultaneously in two perpendicular planes, at the centre of a demagnetizing coil system. It is powered with a motor with frequencies of rotation in the ratio of 30:32. The whole assembly is kept in a
field-free space, using Helmholtz coils. The field coil is connected in series with a suitable condenser to make the whole circuit resonant to 50 CPS, the commercial mains frequency. In this set-up the peak-field at the centre of the coil is 100 oersteds/ampere. The coil takes up a maximum current of 10 amperes when 220 volts a.c. supply is used.

3.3.2 EXPERIMENTAL PROCEDURES (A.C.)

The specimen to be demagnetized was kept in the specimen holder, and the motor was run. The current in the demagnetizing coils was put on gradually and smoothly to the desired maximum-value by means of a Variac. After demagnetizing the specimen for about 2-3 min. in the peak demagnetizing field, the field gradually decreased to zero. This is done by decreasing the current in the demagnetizing coil smoothly by means of an electrolytic potential divider. This consists of a glass tube 5" in diam. and 1.35 meter long mounted vertically. It has cylindrical electrodes at the ends connected to the output of the Variac. A third electrode of smaller diam. is suspended on a well-insulated wire and is raised smoothly up to the tube by means of a D.C. motor. The tube is filled with a solution of copper sulphate and sulphuric acid, the concentration of which is chosen in such a way that the impedance of the liquid column is roughly equal to that of the tuned solenoid circuit. The circuit is then connected between the moving electrodes and the upper fixed electrodes. This form of alternating demagnetizer has the advantage of decreasing the current gradually, resulting in a smooth decrease of the demagnetizing field. The main parts of this apparatus are shown in Fig. 2.
Fig. 2. A.C. Demagnetization set up

Fig. 3. Thermal demagnetization apparatus
After demagnetizing the specimen in the desired peak field, the directions of magnetization are measured under the astatic magnetometer. This method is repeated for different alternating peak fields. The original magnetization is considered to be stable if it retains its direction even in large demagnetizing fields (say a few hundred oersteds). The secondary component, if present, is often washed away in low fields, leaving the stable component.

In the present studies, pilot specimens of each sample from each site were subjected to progressive alternating field demagnetization in peak fields of 25, 50, 75, 100, 150, 200 and 300 oersteds, and a certain value of the field was ascertained above which the direction of magnetization became stable.

3.3.3 THERMAL DEMAGNETIZATION APPARATUS

This apparatus designed by Wilson (1968) was constructed at the National Geophysical Research Institute, to study the component of magnetic vector at high temperature.

An important part of this apparatus is a non-magnetic furnace under an astatic magnetometer. It has a carefully designed heating element which was made out of six parallel helices of nichrome wire, wound on quartz tubing with a \( \frac{3}{4} \)" diameter. Each helix was wired separately with an axial return-wire, and after fixing in position on a mica-sheet, the helix was connected to the adjacent ones in a series by spot-welding, so that the current passes in opposite directions in adjacent helices as shown in Fig. 3a. Then the mica
sheet was bent in the form of a cylinder and enclosed in an asbestos cement cylinder. The mica backing was filled with asbestos wool to prevent direct contact. To the exterior of the furnace a half-inch hole is provided. The rock specimen to be heated is seated on a V-shaped groove which also carries a platinum thermocouple held at the centre by plaster of paris. This arrangement not only shields the thermocouple from the direct radiation of the heating element, but indicates the exact temperature of the rock specimen. The specimen could be rotated round a horizontal axis with an aluminium screw driver which can be inserted through the hole, for engaging in a slot, made previously on the specimen along the X-direction. Fig. 3b is a schematic diagram of the furnace.

The magnetometer used over the furnace is absolutely unaffected either by the current in the heating element or by the temperature prevailing in the furnace and gives a spot deflection of about 100 cm at 3 meters distance.

3.3.4 EXPERIMENTAL PROCEDURE (THERMAL)

This type of apparatus was used in the present studies to test the stability of NRM and thermal behaviour of rocks. The procedure is as follows.

(i) To test the stability of NRM of a specimen all three components of magnetic vector were measured at different temperature with intervals of about 50° to 100°. The time required for this type of experiments is about two hours.
(ii) For studying the thermal behaviour of a rock, all the components were measured both while heating and cooling the specimen in the present earth field, to complete one specimen. This experiment takes about 4 hours.
Fig. 4 (continued)

- DOWN DIP
- UP DIP
- PRESENT DIPOLAR FIELD AT SITE

---

- DOWN DIP
- UP DIP
- PRESENT DIPOLAR FIELD AT SITE
CHAPTER IV
RESULTS OF NRM AND A.C. AND THERMAL DEMAGNETIZATION

4.1 RESULTS OBTAINED FROM DYKES

The preliminary measurements of NRM directions, intensities and stability tests using a.c., and thermal demagnetization techniques are made as discussed in Chapter 3.2. The mean direction (declination $D$ or azimuth and Inclination $I$ or dip) of RM (remanent magnetization) and other parameters, such as the length of the resultant vector ($R$), the precision parameter ($K$) and the radius of the 95% circle of confidence ($\chi^2_{95}$) are calculated for each dyke using Fisher's distribution on the sphere (Fisher, 1953) giving unit weight to each sample. The various formulae used are given in Appendix I. The results obtained from different dykes are discussed below.

(1) Measurement of NRM. Ninety-one samples were studied from 10 different dykes, belonging to Mysore dyke swarms. The different trends of dykes and their locations are given in Table 3 and Fig. 1.

The NRM directions of 91 samples and 370 specimens were studied from these dykes and the vectors are plotted on equal area projection as shown in Fig. 4.

Each one of the 91 samples is represented by three to six specimens. It is apparent from the figure that only a few of these specimens have a direction similar to that determined for other
Fig. 5. Histogram of $J_{NRM}$ for all specimens from dykes 1 to 10.
Fig. 5 (continued)

HISTOGRAM OF JNRM FOR ALL SPECIMENS FOR DYKE 5

HISTOGRAM OF JNRM FOR ALL SPECIMENS FROM DYKE 6
HISTOGRAM OF $J_{\text{NRM}}$ FOR ALL SPECIMENS FROM DYKE-2

HISTOGRAM OF $J_{\text{NRM}}$ FOR ALL SPECIMENS FROM DYKE-4
Fig. 5 (continued)

HISTOGRAM OF $J_{NRM}(10^3 \text{e.m.u./cc})$ FOR ALL SPECIMENS FROM DYKE-10

HISTOGRAM OF $J_{NRM}(10^3 \text{e.m.u./cc})$ FOR ALL SPECIMENS FROM DYKE-9

HISTOGRAM OF NRM FOR ALL SPECIMENS FROM DYKE 8
Precambrian rocks of India. It should be considered that the scattered
directions are due to one or a combination of the unstable magnetic
components, without testing their stability by a.c. demagnetization.
The NRM is not determined by the Precambrian field, the additional
component of NRM being superimposed upon the original TRM.

The mean NRM directions from those dykes which show less
scatter, along with other parameters for various dykes determined
by Fisher's statistical analysis are given in Table 4.

The NRM directions from dykes (1, 2, 4, 5, 6, 7, 8, 9 and 10)
show a large scatter, whereas the NRM directions from dyke 3 are
clustered. The histogram of intensities of NRM (Jnrm) for all dykes
are shown in Fig. 5. The intensities of NRM of these dykes spread
over a wide range, i.e., from $0.4 \times 10^{-4}$ to $206.3 \times 10^{-3}$ e.m.u./c.c.
Using the apparatus similar to that developed by Likhite and Radha-
krishnamurthy (1965), the susceptibilities are measured. The mean
susceptibility range of samples from different dykes range from
$0.8 \times 10^{-3}$ to $8.27 \times 10^{-3}$ e.m.u./c.c. and the mean Qn ratio from
different dykes range from 1.5 to 11.6.

The mean intensities, susceptibilities and Qn ratio from
individual dykes are given in Table 5.

(2) A.C. demagnetization studies and stable directions of RM.
Typical examples of a.c. treatment on the direction and intensity
of magnetization from dykes 1, 2, 5, 6, 7 and 10 are shown in Fig. 6.
A few pilot specimens from the above dykes were treated in peak
Fig. 6. Normalized a.c. demagnetization curves and equal area projections showing changes in direction after cleaning in various a.c. peak fields for typical specimens from dykes, 1, 2, 5, 6, 7 and 10.
NORMALIZED DEMAGNETIZATION CURVES FOR TYPICAL SPECIMENS FOR

DYKE-2

AREA PROJECTION SHOWING CHANGES IN DIRECTION OF MAGNETIZATION AFTER EXPOSING TO VARIOUS PEAK ALTERNATING FIELDS FOR FOUR SPECIMENS FROM DYKE 2.
Fig. 6 (continued)

NORMALIZED DEMAGNETIZATION CURVES FOR TYPICAL SPECIMENS FOR DYKE-5

EQUA ARIA PROJECTION SHOWING CHANGES IN DIRECTION OF MAGNETIZATION AFTER CLEANING IN VARIOUS PEAK ALTERNATING FIELD FOR FOUR SPECIMENS FROM DYKE-5
Fig. 6 (continued)

Normalized Demagnetization Curves for Typical Specimens for Dyke-6

Fig. Equal Area Projection showing changes in directions of magnetization after cleaning in various peak alternating fields for six specimens from Dyke-6.
Fig. 6 (continued)

NORMALIZED DEMAGNETIZATION CURVES FOR TYPICAL SPECIMENS FOR DYKE 7

EQUAL AREA PROJECTION SHOWING CHANGES IN DIRECTIONS OF MAGNETIZATION AFTER CLEANING IN VARIOUS PEAK ALTERNATING FIELD FOR SPECIMENS FROM DYKE 7

EQUAL AREA PROJECTION SHOWING CHANGES IN DIRECTION OF MAGNETIZATION AFTER CLEANING IN VARIOUS PEAK ALTERNATING FIELD FOR FOUR SPECIMENS
Fig. 6 (continued)

NORMALIZED DEMAGNETIZATION CURVES FOR TYPICAL SPECIMENS FROM DYKE-10

FIG. EQUAL AREA PROJECTION SHOWING CHANGES IN DIRECTION OF MAGNETIZATION AFTER CLEANING IN VARIOUS PEAK ALTERNATING FIELD FOR THREE SPECIMENS FOR DYKE 10

EQUAL AREA PROJECTION SHOWING CHANGES IN DIRECTION OF MAGNETIZATION AFTER CLEANING IN VARIOUS PEAK ALTERNATING FIELD FOR TWO SPECIMENS FOR DYKE NO.10
### TABLE 4

RESULTS OF ALTERNATING FIELD DEMAGNETIZATION

<table>
<thead>
<tr>
<th>Site</th>
<th>N</th>
<th>E</th>
<th>n</th>
<th>Before cleaning</th>
<th>After cleaning in 300 Oe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D  I  R  K</td>
<td>D  I  R  K  ( \alpha_{95} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(in degrees)</td>
<td>(in degrees)</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>-</td>
<td>45</td>
<td>359 -12 10.82 9.3</td>
<td>2 -30 11.57 25.5 6.6</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>1</td>
<td>48</td>
<td>12 +45 10.77 8.25</td>
<td>26 +50 11.70 36.7 12.8</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>-</td>
<td>11</td>
<td>6 +43 3.96 75.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Random directions</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>4</td>
<td>56</td>
<td>359 -55 7.20 4.06</td>
<td>18 -62 8.85 53.3 6.7</td>
</tr>
<tr>
<td>7</td>
<td>22</td>
<td>2</td>
<td>82</td>
<td>325 -14 8.18 1.52</td>
<td>329 -46 19.20 23.8 6.5</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>-</td>
<td>21</td>
<td>341 +47 4.95 2.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Random directions</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>-</td>
<td>22</td>
<td>238 -5 2.07 1.56</td>
<td>141 -75 3.94 50.0 9.9</td>
</tr>
</tbody>
</table>

(Various specimens exhibited stable RM directions at various peak fields ranging from 50-300 Oe).

N - Total number of samples  
E - Number of samples rejected  
n - Number of specimen considered  
I - Inclination of RM in degrees, down if positive and up if negative.  
D - Declination of RM in degrees  
K - Precision parameter  
R - Length of resultant vector of N unit vectors  
\( \alpha_{95} \) - Semi-angle of the cone of 95% confidence.
<table>
<thead>
<tr>
<th>Dyke No.</th>
<th>Mean NRM intensity</th>
<th>Mean susceptibility</th>
<th>Mean Qa ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$27.35 \times 10^{-4}$</td>
<td>$2.29 \times 10^{-3}$</td>
<td>2.43</td>
</tr>
<tr>
<td>2</td>
<td>$62.93 \times 10^{-4}$</td>
<td>$8.27 \times 10^{-3}$</td>
<td>2.56</td>
</tr>
<tr>
<td>3</td>
<td>$0.67 \times 10^{-4}$</td>
<td>$0.177 \times 10^{-3}$</td>
<td>1.94</td>
</tr>
<tr>
<td>4</td>
<td>$0.4 \times 10^{-4}$</td>
<td>$0.8 \times 10^{-3}$</td>
<td>2.05</td>
</tr>
<tr>
<td>5</td>
<td>$40.03 \times 10^{-4}$</td>
<td>$1.37 \times 10^{-3}$</td>
<td>2.87</td>
</tr>
<tr>
<td>6</td>
<td>$8.56 \times 10^{-4}$</td>
<td>$5.29 \times 10^{-3}$</td>
<td>2.05</td>
</tr>
<tr>
<td>7</td>
<td>$6.45 \times 10^{-4}$</td>
<td>$1.87 \times 10^{-3}$</td>
<td>5.92</td>
</tr>
<tr>
<td>8</td>
<td>$4.16 \times 10^{-4}$</td>
<td>$1.07 \times 10^{-3}$</td>
<td>1.51</td>
</tr>
<tr>
<td>9</td>
<td>$19.21 \times 10^{-4}$</td>
<td>$0.91 \times 10^{-3}$</td>
<td>5.21</td>
</tr>
<tr>
<td>10</td>
<td>$206.3 \times 10^{-4}$</td>
<td>$4.49 \times 10^{-3}$</td>
<td>11.6</td>
</tr>
</tbody>
</table>
Fig. 7. Equal area projections of RM directions after cleaning all the specimens from dykes, 1, 2, 5, 6, 7 and 10.
Fig. 7 (continued)
alternating fields, 25, 50, 75, 100, 200 and 300 oersteds. The field is found to be sufficiently high to remove the secondary and viscous components of magnetization, indicating that a stable component of magnetization is present. The stable components in dykes 1, 2, 5, 6, 7 and 10 were revealed after treatment in low a.c. fields of the order 150, 200, 200, 25, 50 and 150 oersteds, respectively. The RM directions of all the specimens from six dykes after a.c. demagnetization are illustrated in Fig. 7. In dykes 3, 4, 8 and 9 the scattering remained unchanged. Therefore, the remanent direction after a.c. cleaning were not plotted for these dykes.

It may be noted that after a.c. demagnetization in different fields, several specimens from different dykes which were originally polarised with down dips are now polarised with up dips as shown in Fig. 6. The polarity originally normal (away from the present earth field) have not changed as a result of a.c. cleaning to reverse polarisation. However, dyke 10 shows reverse polarisation with down and up dips but later changed to up dip with reverse polarisation after a.c. cleaning.

The increase in $K$ after a.c. cleaning of six dykes represents an appreciable decrease in scatter of magnetization and stable remanent vectors. The a.c. demagnetisation study of curves suggests that in most of the dykes, the secondary components reside in low coercive force domains. The secondary magnetization is therefore mostly of the viscous type acquired during the recent geological times.
Fig. 8b. Equal area projections showing changes in direction of magnetization after thermal demagnetization of specimens from dykes, 1, 5, 6 and 10.
Fig. 8a (continued)
Fig. 8a. Typical thermal demagnetization curves from dykes, 1, 2, 5, 6, 7 and 10.
The curves can be explained in general terms by the existence of two components of magnetization, a soft component which was removed completely by a.c. cleaning and the hard one which remained unaffected by still stronger fields, except in the decrease of intensity. The remaining magnetization appears to represent a true fossil magnetization.

After partial a.c. demagnetization six dykes were found to be stable. The mean RM directions of individual dykes along with other statistical parameters are given in Table 8.

(3) Thermal-demagnetization. Thermal demagnetization characteristics were investigated for two specimens, from each of the well-grouped dykes and were heated up to the Curie point to test the stability of remanent magnetization. The experimental procedure is described in Chapter 3.6. Few normalized thermal demagnetization curves and directions so obtained are illustrated in Fig. 8a & 8b. The intensity of the NRM of the specimens decreases with increase in temperature, depending upon the stability of magnetization. Thus the unstably magnetized specimens showed a rapid decrease of intensity as the temperature increased. The stably magnetized specimens show that the main intensity decreases at temperatures much close to the Curie point. On heating it was observed that within the limits of observational error, the directions of magnetization of all dyke specimen are quite stable up to 500°C and these directions agree with that obtained after a.c. cleaning as shown in Fig. 7. The Curie point ranges from 250°C to 480°C, suggesting that the main ferrimagnetic mineral is titanomagnetite, that is the main carrier of remanent magnetization.
TABLE 6

VARIOUS PALEOMAGNETIC PARAMETERS FOR MYSORE DYKES

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Dyke position</th>
<th>Stable RM directions</th>
<th>$\alpha_{95}$ (in degrees)</th>
<th>$\lambda$ (in degrees)</th>
<th>VGP</th>
<th>$\delta_m$</th>
<th>$\delta_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\lambda_0$</td>
<td>$\phi_0$</td>
<td>$D$ (in degrees)</td>
<td>$I$ (in degrees)</td>
<td>$\lambda_p$ (in degrees)</td>
<td>$\phi_p$ (in degrees)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>14°10'</td>
<td>76°27'</td>
<td>2</td>
<td>-30</td>
<td>8.6</td>
<td>21</td>
<td>55N</td>
</tr>
<tr>
<td>2</td>
<td>14°11'</td>
<td>76°22'</td>
<td>46</td>
<td>+50</td>
<td>12.8</td>
<td>30</td>
<td>45N</td>
</tr>
<tr>
<td>3</td>
<td>12°11'</td>
<td>76°4'</td>
<td>8</td>
<td>-59</td>
<td>9.9</td>
<td>39</td>
<td>39N</td>
</tr>
<tr>
<td>4</td>
<td>12°25'</td>
<td>75°14'</td>
<td>18</td>
<td>-62</td>
<td>6.7</td>
<td>43</td>
<td>32N</td>
</tr>
<tr>
<td>5</td>
<td>12°18'</td>
<td>76°50'</td>
<td>328</td>
<td>-48</td>
<td>6.5</td>
<td>28</td>
<td>39N</td>
</tr>
<tr>
<td>6</td>
<td>12°44'</td>
<td>77°31'</td>
<td>141</td>
<td>-75</td>
<td>9.9</td>
<td>61</td>
<td>34N</td>
</tr>
</tbody>
</table>

$\lambda_0$ and $\phi_0$ - Present latitude and longitude of dyke

$D$ and $I$ - Declination and Inclination, respectively of stable RM direction

$\alpha_{95}$ - Semi-angle of the cone of 95% confidence

$\lambda$ - Ancient latitude of dyke

V.G.P. - Virtual Geomagnetic Pole

$\lambda_p$ and $\phi_p$ - Latitude and Longitude of V.G.P.

$\delta_m$ and $\delta_p$ - Semi-axes of the oval of confidence about of the poles at 95 probability level.
As a further check a few a.c. cleaned specimens from individual dykes were heated up to 300°C to see the thermal stability and it was observed that within the limits of experimental error they remained in the group which was formed by a.c. demagnetization. This suggests that the NRM in Mysore dykes is of TRM nature.

4.2 SUMMARY OF MEAN DIRECTIONS OF STABLE RM FOR ALL THE DYKES

The studies discussed under 4.1 above indicate that the samples from the six dykes possess a stable, primary component of magnetization which was revealed after magnetic cleaning of an unstable, unwanted secondary component by a.c. demagnetization techniques; the stability of RM was also tested by thermal demagnetization.

These techniques for assessing the stability of NRM were found to be useful in revealing the stable component of RM from six dykes. However, specimens from four dykes could not be cleaned by a.c. and thermal demagnetization techniques. They were probably masked by secondary magnetization which might have distorted the original primary remanence.

The mean stable direction from six dykes are computed for calculating the virtual geomagnetic pole and the four dykes were not taken into account for computation due to their instability of magnetization.

The virtual geomagnetic pole (VGP) positions and other paleomagnetic parameters are discussed in Chapter VI.
5.1 GENERAL

In view of the igneous origin of the rock, the type of magnetization acquired by it must have been thermoremanent magnetization (TRM). It is studied extensively throughout the world, as it is the most important of the different types of NRM discussed in Chapter 1.3. The TRM of igneous rock is due to the small amount of ferromagnetic minerals present which become magnetized when the rocks cooled from a high temperature in the prevailing geomagnetic field. The igneous rocks owe their remanent magnetization to the presence of iron-oxides, or in a relatively few cases to sulphides. The oxides of iron often contain a considerable amount of titanium and traces of other ions.

In fact titanomagnetites are the main minerals responsible for the magnetization in most of the basaltic rocks, and these are frequently metastable (Sanver, 1968). They have a natural tendency for titanium to migrate out of the lattice under certain conditions, usually at high temperature, but it is also possible at lower temperatures; for example, decomposition of a metastable cation deficient spinel (O'Reilly & Banerjee, 1967).

By examining the a.c. and the thermal demagnetization curves described in Chapter 4.1, it was observed that the magnetizations of the specimens either decreased or increased in low fields due to the
presence of a soft component of magnetization. After the removal of the soft component by a.c. demagnetization techniques, the intensity of the primary components decreased slowly when further demagnetized in higher alternating fields. From this it is evident that the soft component can be easily removed by a.c. demagnetization and the primary component remains unaffected. Studies of polished sections, measurement of Curie points, thermal remanence and saturation magnetization will lead to a better understanding of the nature of iron-oxide minerals which account for the primary magnetization. These studies were carried out on the specimens from all the dykes to understand the origin of magnetization in them, as discussed in this chapter.

5.2 REMANENT COERCIVE FORCE (Hc)

It is well known that coercive force increases with decreasing particle size, although recent work by Oosterhout and Klomp (1962) indicate that much of the so-called size effect may in fact be due to strains introduced by grinding the dependence of coercive force and the size has no significant effect, as thought of earlier. Since most igneous rocks cool rather slowly, they should be well annealed and therefore show a minimum of strain (Strangway et al., 1968). In addition, coercive force has commonly been utilized as a physical parameter to characterize the stability of magnetization. Rocks generally contain several ferrimagnetic minerals and each mineral grain may differ from another in size, shape, minerology and magnetic behaviour. Therefore, the coercive force must vary from grain to grain and from subregion to subregion within a single rock (Larson et al., 1969).
Fig. 9. Remanence hysteresis curves for a few representative specimens from various dykes.
Fig. 9 (continued)
Fig. 9 (continued)

DYKE NO. 9
CK3 al

DYKE NO. 10
HO2 b II
Saturation remanence hysteresis curves were obtained for a few specimens selected from different dykes and the data given in Table 7. A procedure similar to that of Carmichael (1961) was followed in this respect.

The apparatus used for saturating the specimens consists of an electromagnet (UNICO Type NP-53 Electromagnet) which provides reasonably uniform fields and an air gap continuously adjustable from 0 to 10 cm. With this a maximum field of 1500 oersteds can be created, when the air gap is 1 cm. by passing a maximum current of 5 amperes from a D.C. supply fed with 230 volts A.C.

The specimens used for these studies were in the form of circular disks of 1" diam. and about 0.3 to 0.5 cm. thickness.

The specimen was first saturated and its remanence (Js) was measured with an astatic magnetometer. The remanence was again measured after the application of an oppositely directed field. The field was increased in steps till the specimen saturated in the opposite direction and each time its remanence (Js) was measured. A complete loop was obtained by repeating this procedure in the opposite sense. Fig. 9 shows the remanence hysteresis loop for a few representative specimens. The magnetic field required to reduce the remanent intensity of a saturated specimen to zero is called the remanent coercive force (Hc).

These experiments indicate that the specimens possess low coercive force ranging between 150 Oe to 300 Oe. The loops are of normal type and the remanence and coercive force have the same magnitudes.
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Specimen No.</th>
<th>J_{nrm} e.m.u./c.c.</th>
<th>J_s e.m.u./c.c.</th>
<th>Saturating field B_e</th>
<th>Remanent coercive force (H_c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CDI <em>III</em></td>
<td>40.8 \times 10^{-4}</td>
<td>119.2 \times 10^{-2}</td>
<td>3000</td>
<td>220</td>
</tr>
<tr>
<td>2</td>
<td>CK <em>III</em></td>
<td>3.27 \times 10^{-4}</td>
<td>28.8 \times 10^{-2}</td>
<td>2000</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>HD <em>III</em></td>
<td>106.7 \times 10^{-4}</td>
<td>10.72 \times 10^{-2}</td>
<td>1000</td>
<td>120</td>
</tr>
<tr>
<td>4</td>
<td>KD <em>X</em></td>
<td>16.49 \times 10^{-4}</td>
<td>38.4 \times 10^{-2}</td>
<td>800</td>
<td>150</td>
</tr>
<tr>
<td>5</td>
<td>HO <em>II</em></td>
<td>131.2 \times 10^{-4}</td>
<td>23.8 \times 10^{-2}</td>
<td>1000</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>HD <em>XII</em></td>
<td>5.01 \times 10^{-4}</td>
<td>8.8 \times 10^{-2}</td>
<td>1000</td>
<td>150</td>
</tr>
</tbody>
</table>

J_{nrm} - Intensity of NRM

J_s - Remanent intensity after saturating specimen

H_c - Remanence coercive force.
in both positive and negative directions. No other oxide of iron except the titanomagnetites is known to have coercive force of this order.

5.3 THERMAL BEHAVIOUR OF MYSORE DYKES

The nature of remanent magnetization of igneous rocks, and the various ferromagnetic minerals that could be present in the rock to account for the observed remanent magnetization are discussed in Chapter I. Ferromagnetic minerals contained in the rock samples and the nature of RM can be ascertained by studying the mode of decrease of NRM (Jn) in relation to the rise of temperature and mode of acquisition of TRM (Jt), acquired when the sample is allowed to cool to room temperature in the presence of earth's magnetic field. The Curie points of the minerals can be determined at the same time.

For this purpose at least two specimens each of 1" diam. and about 1" length from each dyke were heated to higher temperature for studying the decay of Jn and then cooled in the earth's magnetic field to room temperature to produce Jt (total TRM). These studies were made by heating the specimen in a non-inductive electric furnace, similar to that of Wilson (1962), up to the Curie temperature and cooling down to room temperature after being kept for about 30 min. above the Curie temperature. The results of these tests are shown in Fig. 9 and the values of \( \frac{Jn}{Jt} \) and the Curie temperature (Tc) for various specimens are given in Table 8.
### TABLE 8
RATIOS, CURIE TEMPERATURE FOR SPECIMENS FROM VARIOUS DYKES

<table>
<thead>
<tr>
<th>Sp. No.</th>
<th>Jn/Jt</th>
<th>Curie temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD₁₁ b₁</td>
<td>1.89</td>
<td>480</td>
</tr>
<tr>
<td>CD₁ b₁</td>
<td>9.10</td>
<td>370</td>
</tr>
<tr>
<td>CD₁ a₁I</td>
<td>0.50</td>
<td>400</td>
</tr>
<tr>
<td>CD₇ a₁</td>
<td>2.44</td>
<td>480</td>
</tr>
<tr>
<td>HD₈ y₁</td>
<td>1.60</td>
<td>375</td>
</tr>
<tr>
<td>HD₈ x₁</td>
<td>0.38</td>
<td>350</td>
</tr>
<tr>
<td>KD₉ c₁II</td>
<td>0.50</td>
<td>280</td>
</tr>
<tr>
<td>KD₈ b₁I</td>
<td>1.79</td>
<td>480</td>
</tr>
<tr>
<td>GD₆ c₁II</td>
<td>1.43</td>
<td>480</td>
</tr>
<tr>
<td>CD₂ b₁</td>
<td>2.50</td>
<td>480</td>
</tr>
</tbody>
</table>

**Jn** - Intensity of NRM

**Jt** - Intensity of TRM acquired on cooling from Curie temperature to room temperature in the earth's magnetic field

**Tc** - Curie temperature of magnetic minerals present in the rock.
The main conclusions that can be drawn from these studies are:

(1) The Curie temperature for various specimens spread over a fairly wide range from 280°C to 480°C, showing that the main ferromagnetic minerals contained in them are titanomagnetites and low grade titanomaghemite with varying amounts of titanium and magnetite in their solid solutions.

(2) The manner of demagnetization of Jn or acquisition of TRM is such that in most of the cases about 50% of Jn was demagnetized or 50% of Jt was acquired at temperatures of 300 or 400°C. It can be said that the magnetization in question was probably acquired at high temperature, so that the remanent magnetism of such rock specimens may be taken to be stable. A close resemblance of Jn and Jt curves also suggest that the NRM possessed by the rocks was a TRM. No indication of the self-reversal of TRM was observed in any of the specimens.

Although a vast amount of paleomagnetic knowledge has hitherto been supplied from various parts of the world, work concerning the intensities of former geomagnetic fields during geological times is appallingly low. There is no decisive evidence that the intensity of the former geomagnetic field has always been as that of the present geomagnetic field.
Fig. 10. Photomicrographs showing typical lamellae development
The values of $\frac{J_n}{J_t}$ for various specimens of Myeon dykes showed a variation from 0.38 to 9.10 and all the specimens were found to be equally stable.

The ratio $\frac{J_n}{J_t}$ may be a crucial factor for inferring the magnitude of the intensity of the former geomagnetic field and it may not be appropriate to omit specimens even if the value is abnormally small or large; the ratios should be considered as a tool of testing the stability of NRM.

5.4 POLISHED SECTION STUDIES

To determine what minerals are responsible for the remanent magnetic component in the rocks, the usual method is to examine the polished sections under the microscope and to identify the various oxides present in them.

The purpose of the present study is to observe the oxidation-effects and its correlation with magnetic stability. Twenty polished sections under the magnification x 330 from all the dykes were studied. Typical microphotographs are given in Fig. 10. All the studied dykes have ferrimagnetic oxides, chiefly titanomagnetite ($Fe_{2+\delta}^{3+0.4}Fe_{3.0}^{4+}O_4$ solid solution). In some of the specimens titanomagnetite is present in small amounts and in most of the specimens the original titanomagnetite as shown in Fig. 10 have oriented exsolution lamellae of ilmenite. *Typically, ilmenite may occur as fine lamellae, as thick "sandwich" laths, or as irregular forms in titanomagnetite (Watkins & Haggerty, 1967). Most of the specimens studied have lamellae of ilmenite,
and are oriented in the (III) plane of magnetite. The high temperature oxidation of titanomagnetite commonly results in the development of ilmenite lamellae which effectively sub-divides the initial magnetic crystals into a great many smaller, magnetically more stable grains. This is primarily a post-consolidation oxidational change (Larson et al., 1969).

Powell (1963), Watkins & Haggerty (1965, 1967), Larson et al. (1968), Zijderveld (1967), Wilson et al. (1968), Strangway et al. (1968), Ade-Hall et al. (1968) and recently Larson et al. (1969) have recognized a clear relationship in basaltic lavas between titanomagnetite high temperature-oxidation and stability of natural remanence.

Studies carried out on the Mysore dyke samples revealed that the dykes which show high magnetic stability also show high temperature-oxidation effects and single Curie points. The unstable dykes on the other hand show two or more Curie points and a small amount of high temperature-oxidation. The low Curie points as shown in most of the specimens correspond to titanium rich titanomagnetite or low grade titanomaghemite, the results being compatible with the thermomagnetic curves studies discussed in Chapter 5.2, thus substantiating the conclusion that titanomagnetite is the principal carrier of remanent magnetization.
5.5 SUMMARY

Studies described in this chapter revealed the following:

(1) The stable samples owe their magnetization to the well-developed high temperature-oxidation titanomagnetite. It is, therefore, most likely that the NRM of the Mysore dykes is of TEM origin.

(2) None of the samples from any dyke exhibited the self-reversing tendency in the laboratory.

(3) The magnetic component lies in the low coercive force domain and this shows a good correlation with a.c. demagnetization results discussed in Chapter 4.
6.1 RESULTS

It has been shown by the various stability techniques used on the Mysore dykes described in Chapter 3.2, that the TNM of dykes is highly stable. Specimens having unwanted, secondary soft components were cleaned. Out of 10 dykes studied, 4 dykes (3, 4, 8 and 9) did not improve after cleaning thereby indicating that the original TNM was destroyed to a large extent. Out of ten dykes studied, six dykes (1, 2, 5, 6, 7 and 10) possessed stable directions of magnetization and the remaining four dykes (3, 4, 8 and 9) did not improve after cleaning.

Fig. 7 shows the stereographic plot of the cleaned remanent magnetic directions of all the specimens studied from the six dykes. The stable mean magnetic directions for these dykes are given in Table 4. Using Fisher's (1953) method the radius of the 95% circle of confidence was calculated, which represents the precision ($\alpha_{95}$). The precision parameter ($K$) was calculated for all the dykes before and after cleaning. The precision increased appreciably in six dykes, indicating stability of magnetization, and in the four dykes, which did not have stable directions of magnetizations, $K$ decreased. The directions of the six dykes form a cluster, away from the present geomagnetic field. This good agreement indicates that scatter within a dyke is rather small and hence a statistically significant mean could be obtained. The mean directions of RM for various dykes given in Table 6 show that out of six
Discussions of RM, the directions for four dykes agree with each other within the statistical limits.

6.2 DISCUSSION

The virtual geomagnetic pole positions derived from mean directions of RM for each dyke, which possessed stable directions along with those of Deccan traps are shown in Fig. 11. It can be seen from the figure that the poles derived from dykes 1, 5 and 6 are close to each other. This suggests that these dykes might have intruded contemporaneously. The poles of these dykes and pole of dyke 7 are in close agreement with the mean pole position calculated for Upper and Lower Deccan trap igneous activity.

The dyke 2, petrochemically alkalic in nature, has a pole position which suggests the position of India in the northern hemisphere. It is, however, interesting to note that dyke 2 occurs near the tholeiite dyke 1 which shows the pole position similar to those of Deccan traps. The dyke 10 is also alkalic in nature and shows pole position similar to that of dyke 2. This led to the conclusion that the two dykes (2, 10) are probably of Precambrian age.

The results reported on the present dykes belong to Mysore dyke swarms and indicate that they were intruded into the Indian shield, may be in Precambrian times and in association with the Deccan trap igneous activity.
CHAPTER VII

PETROCHEMISTRY OF THE DYKES

7.1 PETROLOGY

Twenty-five thin sections from ten different dykes have been studied. A majority of them showed ophitic and a few porphyritic texture.

In all the above dykes pyroxenes are present and show lamellar structure, which is due to exsolution. In some dykes pyroxenes are enclosed by plagioclases and also show zoning. The dykes, 2, 4 and 10 show pinkish colour pyroxenes, due to the presence of high amount of titanium, which is indicated by the presence of titanamgite.

Plagioclases are sodic type in some dykes and they show inclusion arranged at borders. Hypersthene is present in all the dykes studied and in some it shows schillerization effect.

Iron ores are original in nature in some dykes whereas granular in some dykes probably secondary in origin. They are also present in the form of inclusions in hypersthene.

7.2 EXPERIMENTAL PROCEDURE

7.2.1 General scheme of analysis

Chemical analysis involved the following:

Estimation of

(a) SiO₂, Al₂O₃, MnO, P₂O₅, Fe₂O₃, FeO, TiO₂, spectrophotometrically (Shelkromom Spectrophotometer, type 202).
(b) $\text{Na}_2\text{O}$ and $\text{K}_2\text{O}$, flame-photometrically (flame photometer Carl-Zeiss, type 312315).

(c) $\text{CaO}$, $\text{MgO}$ and $\text{FeO}$ by titration by the rapid methods of analysis of Shapiro and Brannock (1962).

7.2.2 Rapid methods of major element analysis

(i) Dissolution of samples. The samples were dried up at $110^\circ\text{C}$ for 3 to 4 hr before bringing them into solution. Two sample solutions (A and B) were prepared for determining the major elements.

Preparation of sample solution 'A' for estimation of silica and alumina starts with fusion of 0.1 g of finely powdered sample in a nickel crucible with 8 to 10 sodium hydroxide pellets. First the samples and the pellets were gently heated for 3 to 4 min. and then intensely with two bunsen burners for five minutes. The fused melt was cooled for 4 to 5 hr and transferred into the glass beakers; 20 c.c. of dilute HCl (1:1) added and then the solution was gently heated till it is clear and was made up to 1 litre after cooling.

For estimation of elements $\text{FeO}$, $\text{MnO}$, $\text{P}_2\text{O}_5$, $\text{Na}_2\text{O}$, $\text{K}_2\text{O}$, $\text{TiO}_2$, $\text{CaO}$ and $\text{MgO}$, a second solution 'B' was prepared. Here 0.4 g. of finely powdered sample was taken in a platinum crucible. A few drops of sulphuric acid were added and the sample made into a paste. Later hydrofluoric acid was added very carefully to fill up to the crucible volume.
The crucible with its lid on was heated gently on a water bath for one hour and the heating continued after removing the lid, till the solution evaporated almost completely, leaving behind a pasty matter. The latter was cooled, and then carefully and completely transferred to a 250 c.c. pyrex beaker. The beaker was gently heated after adding distilled water to digest any remaining matter. Subsequently after cooling, the volume was made up to 250 c.c. and stored in a polyethylene bottle.

(2) Spectrophotometric estimation. Silica and alumina were determined from solution 'A' and $\text{P}_2\text{O}_5$, $\text{Fe}_2\text{O}_3 + \text{FeO}$, $\text{TiO}_2$ and $\text{MnO}$ were determined from solution 'B'. The details of chemical processing, before each oxide is determined spectrophotometrically, on the basis of percentage transmission, are summarised below.

Silica (red sensitivity): 5 c.c. sample

Solution 'A' was taken in a 100 c.c. beaker, 1 c.c. of ammonium molybdate reagent added and the solution was allowed to stand for 10 min. Next 4 c.c. of tartaric acid (10% concentration) was added to the mixture of 1 c.c. reducing solution (3.5 g. of sodium sulphite in 100 c.c. water and 0.15 g. of 1-amino-2-napthal-4 sulphon acid added to a solution of 45 g. of sodium meta bisulphite in 400 c.c. of water). The solution developed a blue colour. It was then allowed to stand for 30 min, and the volume was made up to 100 c.c. and analysed.

Alumina (blue sensitivity). 10 c.c. of solution 'A' was taken in a 100 c.c. beaker; 1 c.c. of calcium chloride solution (7 g. of
CaCl₂ in 500 c.c. of water) and 1 c.c. of 10% hydroxylamine-hydrochloride was added and the solution kept for 10 min. 1 c.c. of 0.1% potassium ferricyanide was added (this should be prepared fresh for each set of determination). After 5 min, 10 c.c. of buffer solution (70 g. of sodium acetate and 30 g. of glacial acetic acid in 500 c.c. of water) was added and after 10 min. 5 c.c. of 0.1% Alizarin red-S, solution was added. After one hour the volume was made up to 100 c.c. and analysed.

**Phosphorus.** 10 c.c. of sample solution 'B' was taken in a 100 c.c. beaker and 10 c.c. of reagent (0.625 g. of ammonium molybdate in 200 c.c. of 1:1 nitric acid mixed with 25 g. of ammonium molybdate in 200 c.c. of water) and 25 c.c. of water added.

**Manganese.** 20 c.c. of solution 'B' is taken and to this 0.5 c.c. of phosphoric acid, 25 c.c. of 1:9 sulphuric acid and 0.2 g. of potassium periodate were added. It was heated on a hot plate till it developed a pink colour and the volume made up to 100 c.c.

**Titanium.** To 20 c.c. of solution 'B', 20 c.c. of reagent (50 c.c. of 1:1 sulphonic acid + 50 c.c. of phosphoric acid and 400 c.c. of hydrogen peroxide made up to 500 c.c.) was added.

**Ferrous iron.** 5 c.c. of solution 'B' was taken in a 100 c.c. beaker and 5 c.c. of 10% hydroxylamine hydrochloride added, to which after 10 min, 10 c.c. of 0.1% orthophenanthroline solution was added. Finally 10 c.c. of sodium citrate was added and after 30 min, the volume was made up to 100 c.c.
(3) Determination of CaO, MgO and FeO by titration. CaO and MgO were determined together by double titration method. 25 c.c. of solution 'B' was taken and both CaO and MgO were estimated as CaO first, titrating against Versene (EDTA) using Erichrome Black-T indicator.

To the above solution 150 c.c. of water, 20 c.c. of Methyl-red ammonium chloride solution was added. It was neutralised with liquid ammonia and if any iron precipitated, it was filtered and, the volume made up to 250 c.c. 25 c.c. of this solution, 100 c.c. of water and 10 c.c. of buffer \((NH_4Cl + NH_4OH\) solution) were added and titrated against versene.

To determine MgO, 200 c.c. of the above solution, 10 c.c. of buffer, 5 c.c. of \(CaCl_2\) solution \((0.5\) g. of \(CaCO_3\) in few drops of HCl and 500 c.c. of water) and 10 c.c. of sodium tungstate \((20\%\) were added and the solution was boiled for 10 min, and then quickly cooled. Calcium tungstate precipitated thus was removed by decanting the solution and the latter was made up to 250 c.c. 25 c.c. of this was titrated against versene with buffer and indicator Erichrome Black-T as done previously.

\[
\text{CaO} + \text{MgO} \text{ and MgO were calculated from the equations:}
\]

\[
\frac{\text{CaO} + \text{MgO} \text{ (as CaO)}}{0.4x} = \frac{25}{x}
\]

where \(x\) is versene volume for standard solution and \(Y\) is sample solution.

\[
\text{MgO} = \frac{Y \times 25}{0.8x}
\]
where \( X \) and \( Y \) are same as in the above case. (CaO standard is taken for CaO + MgO determinations and MgO standard for MgO determination).

\[ \text{FeO: 0.4 g. of sample was taken in a platinum crucible and to} \]

\[ \text{this 10 c.c. of 1:1 sulphuric acid were added. The mixture was gently} \]

\[ \text{boiled on a hot plate for 5 to 6 min. Then 5 c.c. of hydrofluoric} \]

\[ \text{acid was added and again the crucible heated for 5 min. Then the} \]

\[ \text{crucible along with the contents were immersed in a 100 c.c. reagent} \]

\[ \text{solution (mixture of 200 ml of phosphoric acid, 175 ml of sulphuric} \]

\[ \text{acid, 50 g. of boric acid and 1800 ml of water made to 2 litres) with} \]

\[ \text{200 c.c. of water and orthophenanthroline indicator. It was titrated} \]

\[ \text{against potassium dichromate of known normality (0.062 N).} \]

The strength of standards used in various determinations is
given in Table 9.

The method of Shapiro and Brannock (1962) may be classified
as (i) accurate for silica, titania, total iron, ferric iron,
magnesium, calcium, alkalies and phosphorus; (ii) moderately accurate
for alumina, ferrous iron, and manganese.

7.3 CHEMISTRY OF THE DYKES

Table 10 lists the averages of chemical analyses of ten
Mysore dykes, and the analyses from literature of Deccan traps,
tholeiitic dolerites and alkali dolerites.

Prior to this study, the chemistry of few dykes were reported
from the Indian shield (Table 13). These data were not utilised for
TABLE 9  
STRENGTH OF STANDARDS USED IN VARIOUS DETERMINATIONS  

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Standard strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>14</td>
</tr>
<tr>
<td>MgO</td>
<td>0.01 (0.000/gm/ml)</td>
</tr>
<tr>
<td>CaO</td>
<td>0.01 (0.000/gm/ml)</td>
</tr>
<tr>
<td>MnO</td>
<td>0.5</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>10</td>
</tr>
<tr>
<td>TiO₂</td>
<td>2</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>-------</td>
<td>-----</td>
</tr>
<tr>
<td>SiO₂</td>
<td>50.25</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>17.54</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.10</td>
</tr>
<tr>
<td>FeO</td>
<td>11.33</td>
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<td>CaO</td>
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<tr>
<td>MgO</td>
<td>2.97</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.45</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.12</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.95</td>
</tr>
<tr>
<td>MnO</td>
<td>0.20</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.34</td>
</tr>
<tr>
<td>H₂O</td>
<td>-</td>
</tr>
</tbody>
</table>

Columns 1 to 10 give averages of Mysore dykes
Column 11 gives average of Deccan trap after Washington (1922)
Column 12 gives averages of all tholeiitic dolerites after Vincent Manson (1967)
Column 13 gives averages of all alkaline dolerites after Vincent Manson (1967)
MYSORE DYKES ANALYSES ON TERNARY DIAGRAMS

(A) Mgo-Fe (t)-(Na$_2$O + K$_2$O)
(B) CaO-Na$_2$O-K$_2$O

(FIG. 12)
the correlation of dyke swarms and in most of the cases the number of dykes studied were few to make any concrete conclusions and were exclusively utilised to identify the nature of basaltic suite.

One of the important objects of the chemical studies presented here is to know about the chemical compositions of basaltic suites, which has given rise to these dykes and to use the data so obtained for correlation of dykes.

7.3.1 C.I.P.W. norms

C.I.P.W. norms (Table 11) show that the samples analyzed vary from saturated to over-saturated with the normative quartz varying from 4.92 to 25.02. The presence of high value of normative hypersthene is in dykes 1, 3, 5, 6, 7, 8 and 9 which vary between 14.12 to 17.39 suggest the tholeiitic nature of basaltic suite.

7.3.2 Graphical representations

The Mg-Fe(+) alkali and Ca-Na-K (atomic weight present) diagrams represent the dykes under study. The MgO-Fe(+) alkali diagram (Fig. 12a) shows the usual iron enrichment of tholeiitic suites dykes followed by alkali enrichment. Points for average Deccan basalts (Washington, 1922) lie in the enclosed area which also show iron enrichment. In the CaO-Na₂O-K₂O diagram (Fig. 12b) most of the dykes fall on the sodic side of the diagram. The same diagrams have also been used by Nockolds and Allen (1953, 1954, 1956) Green and Poldervaart (1958) for average igneous rocks and Sukheswala and Poldervaart (1958) for averages of Deccan basalts.
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
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</thead>
<tbody>
<tr>
<td>C. I. P. W. norms of Mysore dykes and Deccan trap</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>9.81</td>
<td>4.82</td>
<td>21.54</td>
<td>18.54</td>
<td>4.56</td>
<td>8.94</td>
<td>11.7</td>
<td>6.6</td>
<td>2.04</td>
<td>4.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or</td>
<td>8.67</td>
<td>2.78</td>
<td>3.34</td>
<td>5.56</td>
<td>5.0</td>
<td>3.88</td>
<td>2.78</td>
<td>2.78</td>
<td>3.89</td>
<td>3.89</td>
<td></td>
</tr>
<tr>
<td>an</td>
<td>20.96</td>
<td>23.06</td>
<td>19.91</td>
<td>27.77</td>
<td>20.44</td>
<td>23.06</td>
<td>25.86</td>
<td>20.96</td>
<td>18.34</td>
<td>25.15</td>
<td>22.01</td>
</tr>
<tr>
<td>dy</td>
<td>9.9</td>
<td>18.5</td>
<td>16.18</td>
<td>16.6</td>
<td>13.8</td>
<td>17.9</td>
<td>17.3</td>
<td>18.4</td>
<td>18.8</td>
<td>17.78</td>
<td>17.14</td>
</tr>
<tr>
<td>m</td>
<td>2.41</td>
<td>6.03</td>
<td>5.10</td>
<td>5.10</td>
<td>3.71</td>
<td>3.71</td>
<td>4.41</td>
<td>4.41</td>
<td>4.56</td>
<td>4.56</td>
<td>4.56</td>
</tr>
<tr>
<td>n</td>
<td>2.28</td>
<td>3.95</td>
<td>3.5</td>
<td>5.47</td>
<td>3.04</td>
<td>3.04</td>
<td>2.43</td>
<td>2.43</td>
<td>2.43</td>
<td>2.43</td>
<td>1.01</td>
</tr>
<tr>
<td>ap</td>
<td>0.87</td>
<td>0.20</td>
<td>1.0</td>
<td>1.01</td>
<td>1.01</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
<td>1.01</td>
</tr>
</tbody>
</table>

Columns 1 to 10 give norms of Mysore dykes. Column 11 gives norms of Deccan trap.
Differentiation Index = \( \sum \) (Normative) qz, ab, or or

Differentialion Diagram

(After Thornton and Tuttle, 1956)

(FIG. 13)
Thornton and Tuttle (1956) suggested a differentiation diagram in which percentages of weights of oxide of the various elements are plotted against the differentiation index (sum of normative quartz, albite and orthoclase). The curves drawn in Fig. 13 indicate differentiation trends in the dykes and can only be considered as rough approximation. It is noticed here that the curve of Al$_2$O$_3$ show wide scatter, and because of this, the trend is not reliable. Boundaries of early, middle and late stage dolerites are approximately at differentiation indices at 20, 30 and 50. This figure leads to a better understanding of the petrology of dykes which are representative of basaltic magma. Practically all the dykes belong to middle and late stage of fractionation. Variations in major elements are normal, with linear increase in SiO$_2$, TiO$_2$, FeO and K$_2$O and linear decrease in Fe$_2$O$_3$, Na$_2$O, whereas MgO remains constant. Variation curve of SiO$_2$ is convex upward indicating moderate enrichment of silica. The variation of Al$_2$O$_3$ is peculiar, but wide scatter of points renders it likely that the variation is more apparent than real. CaO also shows a decrease.

The curves shown in the Fig. 13 lead to the conclusion that dykes 1, 3, 5, 6, 7, 8 and 9 are enriched in silica and low in alumina, indicating the tholeiitic nature of basalt.

MacDonald and Katsura (1964) showed that alkali basalts and tholeiite can be distinguished by plotting total alkalis against silica. The field of the tholeiitic rocks can be separated from that of alkalic rocks by a diagonal line drawn through the region of low
populations that lies between the respective population concentrations of the two suite. When this data are plotted (Fig. 14) all but seven dykes (1, 3, 5, 6, 7, 8 and 9) fall in the tholeiitic field and the remaining three dykes (2, 4 and 10) in the alkali field. In addition, high titanium and low silica are present in the dykes under the alkali field, a feature for distinguishing between alkali and tholeiitic basalts.

The diagrams discussed above denote the positive tholeiitic nature of seven dykes and the alkali dykes.

7.4 COMPARISON OF THE MY$	ext{SOKE}$ DYES WITH THE CANADIAN SHIELD DIBASE DYES

The Canadian dykes swarms are given in Table 12. A preliminary chemical study carried out on the Canadian dykes indicate that the Sudbury and Mackenzie are alkali basalt and Marathon, Abiti and Matachewan are tholeiitic dykes. A comparison of the chemical composition of the Mysore dykes with the above Canadian shield dykes shows a remarkable similarity between dykes 2, 4 and 10 studied with those of Sudbury and Mackenzie dykes; and dykes 1, 3, 5, 6, 7, 8 and 9 to the Marathon, Abiti and Matachewan dykes. This shows that the Indian shield, like the Canadian shield, have dykes belonging to two different basalts, alkali and tholeiitic.

7.5 DISCUSSION

The studies on the Mysore dykes show that dykes 2, 4 and 10 are alkaline in nature and characterized by high alkalies and titanium; they are also low in silica. The dykes 1, 3, 5, 6, 7, 8 and 9 belong to
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
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<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>51.38</td>
<td>50.40</td>
<td>54.40</td>
<td>49.46</td>
<td>48.35</td>
<td>52.78</td>
<td>48.60</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5.44</td>
<td>4.57</td>
<td>2.09</td>
<td>1.58</td>
<td>3.46</td>
<td>4.52</td>
<td>2.70</td>
</tr>
<tr>
<td>FeO</td>
<td>8.93</td>
<td>11.68</td>
<td>10.48</td>
<td>14.65</td>
<td>14.44</td>
<td>8.29</td>
<td>15.36</td>
</tr>
<tr>
<td>CaO</td>
<td>8.87</td>
<td>10.22</td>
<td>9.15</td>
<td>8.48</td>
<td>9.41</td>
<td>10.18</td>
<td>10.08</td>
</tr>
<tr>
<td>MgO</td>
<td>3.52</td>
<td>5.33</td>
<td>5.06</td>
<td>2.53</td>
<td>4.07</td>
<td>5.10</td>
<td>5.14</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.46</td>
<td>2.65</td>
<td>3.31</td>
<td>3.34</td>
<td>3.38</td>
<td>2.51</td>
<td>2.32</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.57</td>
<td>0.37</td>
<td>0.71</td>
<td>1.02</td>
<td>0.57</td>
<td>0.91</td>
<td>0.78</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.22</td>
<td>0.83</td>
<td>0.93</td>
<td>2.07</td>
<td>1.02</td>
<td>0.48</td>
<td>1.60</td>
</tr>
<tr>
<td>MnO</td>
<td>0.21</td>
<td>0.10</td>
<td>0.16</td>
<td>0.13</td>
<td>0.10</td>
<td>0.21</td>
<td>0.5</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>5.44</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.57</td>
<td>-</td>
</tr>
<tr>
<td>H₂O</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Column 1 - Dolerite dyke near Horahalli, Mysore State (Ikramuddin and Sadashiviah, 1967)

Columns 2, 3, 4, 5, 6 - Dyke rocks from Molalkalmura area, Mysore State (Naik and Sadashiviah, 1965)

Column 7 - Average of 20 analyses of Hyderabad dyke (National Geophysical Research Institute, unpublished work)

Column 7 - Dyke from Velgampalli, Chittoor district (Somaskar and Naganna, 1964).
tholeiite magma type and are richer in silica and poorer in titanium. A comparison of these dykes with the magmas from the Deccan trap averages of alkalic dolerites and tholeiite dolerites (Table 10) shows that the tholeiitic dykes studied have a remarkable similarity in petrochemistry with the tholeiite magma type and the Deccan traps tholeiites.

The chemical composition of the other dykes studied from the Indian shield (Table 13) shows that all the dykes are tholeiite, except the one from Molankalmura area in Mysore (Naik and Sadashiviah, 1965), which is alkalic in nature and similar to the alkalic dykes under study. On the other hand, Someskar and Naganna (1964) stated that the tholeiite dyke from Vegampalli in Chittoor district shows a similarity with the Deccan traps.

Fahrig et al. (1965) reported that the Sudbury and Mackenzie Canadian diabase dyke swarms are typical alkalic. Recent studies by Condie et al. (1969) also found a few Precambrian alkalic dykes from Wyoming area. Similar to the above findings the present investigations have also revealed the presence of alkalic dykes of probable Precambrian age (Paleomagnetic data) and this finding is contrary to the well-known fact that the continental dykes and sill swarms are strictly the intrusive equivalents of tholeiitic flood basalts (Turner and Verhoogen, 1962, p. 209).
### TABLE 12
THE CHEMICAL COMPOSITION OF CANADIAN SHIELD DIABASE DyKES

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SiO₂</strong></td>
<td>47.7</td>
<td>45.9</td>
<td>50.5</td>
<td>50.5</td>
<td>49.6</td>
</tr>
<tr>
<td><strong>Al₂O₃</strong></td>
<td>11.9</td>
<td>15.1</td>
<td>13.9</td>
<td>12.7</td>
<td>13.9</td>
</tr>
<tr>
<td><strong>Fe₂O₃</strong></td>
<td>3.4</td>
<td>2.9</td>
<td>4.0</td>
<td>3.5</td>
<td>2.4</td>
</tr>
<tr>
<td><strong>FeO</strong></td>
<td>12.7</td>
<td>12.1</td>
<td>10.8</td>
<td>10.3</td>
<td>9.9</td>
</tr>
<tr>
<td><strong>CaO</strong></td>
<td>9.8</td>
<td>8.5</td>
<td>9.6</td>
<td>9.5</td>
<td>10.3</td>
</tr>
<tr>
<td><strong>MgO</strong></td>
<td>4.7</td>
<td>4.2</td>
<td>4.8</td>
<td>4.7</td>
<td>6.8</td>
</tr>
<tr>
<td><strong>Na₂O</strong></td>
<td>2.8</td>
<td>3.5</td>
<td>3.0</td>
<td>2.8</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>K₂O</strong></td>
<td>0.7</td>
<td>1.2</td>
<td>1.0</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>TiO₂</strong></td>
<td>2.5</td>
<td>3.1</td>
<td>1.4</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>MnO</strong></td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>P₂O₅</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>H₂O</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Column 1 - Average of MacKenzie dykes swarm
Column 2 - Average of Sudbury dykes swarm
Column 3 - Average of Matachewan dykes swarm
Column 4 - Average of Marathon dykes swarm
Column 5 - Average of Abitibi dykes swarms

(Data after Fahrig et al., 1965).
The Mysore dykes which are intrusive into the schists and gneisses are investigated by the following techniques.

(a) Paleomagnetism (a.c. and thermal demagnetization techniques were employed to test the stability of remanent magnetization).

(b) Chemical (major elements determined by various instrumental techniques and wet chemical methods).

The data were processed from the following methods.

(a) Equal area projection of NRM directions.

(b) Histograms of intensities of NRM ($J_{NRM}$).

(c) Equal area projections of stable RM vectors.

(d) A.C. demagnetization curves.

(e) Thermal demagnetization curves.

(f) Remanence hysteresis curves.

(g) Studies on polished sections.

(h) Calculation of virtual geomagnetic poles.
(i) Calculation of C.I.P.W. norms.

(j) Ternary diagrams Mg-Fe-alk and Ca-Na-K.

(k) Total alkali-silica diagram.

(l) Differentiation index against weight per cent of oxides diagram.

The methods cited above have been employed to investigate the following problems:

(1) Classification of dykes by remanent magnetization and chemical composition.

(2) Age and nature of remanent magnetization.

(3) The nature of basalts which has given rise to the dykes.

The paleomagnetic and chemical data lead to the following conclusions:

(1) The scattered NRM directions are due to the presence of unstable magnetic components.

(2) A study of a.c. demagnetization curves suggest that the secondary magnetization is mostly viscous type acquired during the recent geological times.

(3) A study of thermal demagnetization curves suggests that the directions of magnetization are stable up to 500°C and are in close agreement
with those obtained after A.c. cleaning.

(4) A.C. and thermal demagnetization techniques have revealed the stable component of RM from six dykes. The four dykes which could not be cleaned are probably masked by stable secondary magnetization, which destroyed the primary remanence.

(5) Thermal stability tests show that the NRM in stable dykes is of TRM origin.

(6) The Curie point ranges from 280 to 480°C suggesting that the main ferrimagnetic mineral is titanomagnetites or low grade titanomaghemite.

(7) A study of the remanence hysteresis curves indicates that specimens possess low coercive force ranging between 150 to 300 Oe, suggesting the presence of titanomagnetites.

(8) A study on polished sections shows the presence of titanomagnetite, substantiating Curie points and remanence hysteresis curves studies that main carrier of magnetization is titanomagnetite.

(9) The dykes which show high magnetic stability also show high temperature oxidation effects and single Curie point. The unstable dykes on the other hand show two or more Curie points and a small amount of high temperature oxidation.

(10) Virtual geomagnetic pole positions derived from the mean of stable dykes 1, 5, 6 and 7 are close to the poles of mean
Deccan traps. The poles of dykes 2 and 10 indicate the position of India in the northern hemisphere thereby suggesting their Precambrian age.

(11) Petrographic studies show the presence of titanaugite in dykes 2, 4 and 10.

(12) The presence of high value of normative hypersthene in dykes 1, 3, 6, 7, 8 and 9 suggests the tholeiitic nature of basalts.

(13) The differentiation index diagram suggests that all dykes belong to middle and late stage basalts.

(14) The total alkali-silica diagram suggests that out of ten, three fall in the alkali field and seven in the tholeiitic field.

(15) The tholeiitic dykes show remarkable similarity in petrochemistry with the Deccan traps.

(16) The alkali dykes are characterized by high alkalis and titanium with low silica.

The paleomagnetic and chemical results show that the dykes have two periods of intrusion having different petrochemical characteristics. The poles of dykes 1, 5, 6 and 7 indicate the position of India to be in the southern hemisphere and are similar to those of the Deccan traps. Petrochemically these dykes and dykes 1, 3, 8 and 9 are typical
At least two specimens from each of the six dykes showing consistent directions were heated up to Curie point to see the thermal stability and it was observed that within the limits of experimental error they remained in the group which was formed by the a.c. demagnetization. This suggest that natural remanent magnetization (NRM) in these dykes is of thermo-remanent magnetization origin. The Curie point values range from 280 to 480°C for all the dykes.

Remanence coercivities have been measured for a few specimens from each dyke by magnetizing them in a maximum field strength of 1500 oersteds and subsequently demagnetizing. The values of the remanence coercivity was found to be low and within the range of 150 to 300 oersteds. Titanomagnetite is the only iron-oxide which is known to have coercive force of this order.

Thermal behaviour studies have been made by heating few specimens from each dyke to higher temperatures for studying the decay of Jn and then cooled in the earth's magnetic field to room temperature to produce Jt (total TRM). It has been observed that in most of the cases about 50% of Jn is demagnetized or 50% of Jt is acquired at a temperature between 300 to 400°C. A close resemblance of Jn and Jt curves also suggests that the NRM possessed by these dykes is of TRM nature.

Few polished specimens have been examined from each dyke which show chiefly titanomagnetite (Fe₂-TiO₄-Fe₃O₄ solid solution).
All specimens have lamellae of ilmenite and are oriented in (111) plane of magnetite. The dykes which show high magnetic stability also show high temperature oxidation effects and single Curie point. Whereas, the unstable dykes show two or more Curie points and low temperature oxidation.

The low Curie points, as shown by all the specimens, correspond to titanium rich titanomagnetites or low grade titano-maghemite thereby substantiating the conclusion that titanomagnetite is the main carrier of remanent magnetization.

The virtual geomagnetic pole positions have been derived from the mean directions of RM for six dykes. The poles derived from dykes 1, 5 and 6, are close to each other. This suggests that these dykes might have intruded contemporaneously. The poles of these dykes and dyke 7 are in broad agreement with mean pole positions of upper and lower Deccan traps. This suggests that these dykes are of much younger in age, probably contemporaneous to Deccan trap igneous activity. The poles from dykes 2 and 10 fix the position of India in the northern hemisphere thereby suggesting their probable Precambrian age.

The chemical composition shows that the dykes 2, 4 and 10 are alkalic in nature, characterized by high alkalis, titanium and low silica whereas dykes 1, 3, 5, 6, 7, 8 and 9 belong to tholeiitic type as they are rich in silica and poor in titanium. The tholeiite dykes show a remarkable similarity with the petrochemistry of Deccan traps.
The dykes of the Indian shield under study can be divided into two periods: (a) alkali basalt dykes of probable Precambrian age; (b) tholeiite basalt dykes of Deccan trap age (Upper Cretaceous–Eocene).

The above conclusions are drawn by making use of the combined geophysical and geochemical studies.
tholeiite. This indicates that some of the weak zones developed by the orogenies in the Indian shield during Precambrian (Pichamuthu, 1967, p. 38) were filled later by the Deccan trap igneous activity during upper Cretaceous to Eocene times.

The poles of dykes 2 and 10 suggest the position of India to be in the northern hemisphere and petrochemically these dykes and dyke 4 are alkalic. It is also evident by the study of Precambrian formation (Athavale et al., 1963) that India was in the northern hemisphere. Hence it can be inferred that these dykes are probably of Precambrian age.

It is interesting to note that dyke 2 occurs near the tholeiite dyke 1 which shows pole position such as to indicate that India was in the southern hemisphere. The presence of alkali basalt dykes probably of Precambrian age raises many questions about the origin of alkali magma. It is also interesting that the alkali basalt dykes 2 and 4 occur in close proximity with those of tholeiite Jogimardi traps (Pichamuthu, 1930; Naqvi, unpublished work) which are Precambrian in age (2385 ± 33 million years; Crawford, 1969).

The findings of this study can be summed up as follows: the dykes, probably of Precambrian paleomagnetic pole positions, are alkalic in nature. The dykes showing paleomagnetic pole positions, similar to those of upper Cretaceous to Eocene are distinctly tholeiitic in composition and might have been derived from the Deccan trap source.
APPENDIX I

For the analysis of the paleomagnetic data, the statistical method developed by Fisher (1953) was used. The various formulae used are as follows:

If \( N \) is the number of directions observed at one site and \( i^{th} \) unit vector has declination \( D_i \), east of north, and inclination \( I_i \) below the horizontal, then the mean direction of the population may be calculated from the relations:

\[
X = \frac{1}{N} \sum_{i=1}^{N} \cos I_i \cos D_i \quad \text{(North component)}
\]

\[
Y = \frac{1}{N} \sum_{i=1}^{N} \cos I_i \sin D_i \quad \text{(East component)}
\]

\[
Z = \frac{1}{N} \sum_{i=1}^{N} \sin I_i \quad \text{(Downward component)}
\]

\[
R = \left( X^2 + Y^2 + Z^2 \right)^{1/2}
\]

\[
\sin I = \frac{Z}{R}
\]

\[
\tan D = \frac{Y}{X}
\]

where \( X, Y, \) and \( Z \) are the components of resultant vector, \( R \) is its length, and \( D \) and \( I \) its declination and inclination respectively.

The precision parameter \( (k) \) describes the tightness of the group of vectors in the population about their mean direction. This is
calculated by the formula

\[ k = \frac{N-1}{N-R} \]

High values of \( k \) indicate tight groups and are confined to a small portion of the sphere near true mean direction and \( k = 0 \) corresponds to a population uniformly distributed over the entire surface of the unit sphere and the directions are random.

\( \lambda_{95} \) is the radius of the circle in degrees whose centre is the true mean and which contain 95\% of the individual directions. This is given by the formula

\[ \lambda_{95} = \frac{144}{(kN)} \frac{1}{2} \text{ degrees.} \]
APPENDIX II

For calculating the paleomagnetic parameters the formulae developed by Blackett et al. (1960) were used. They are as follows:

The formulae for calculating the latitude $\lambda_p$ and longitude $L_p$ of the Virtual Geomagnetic Pole (VGP) are

$$\text{Sin } p = \text{Sin } \lambda \text{Sin } \lambda_o + \text{Cos } \lambda \text{Cos } \lambda_o \text{Cos } \psi$$

$$\text{Sin } (L_p - L_o) = \frac{\text{Sin } \psi \text{Cos } \lambda}{\text{Cos } \lambda_p}$$

where

$\lambda$ is the ancient magnetic latitude of the site at the time when the rocks acquired their magnetization, and is given by

$$\text{Tan } \lambda = \frac{1}{2} \text{Tan } I;$$

$\lambda_o$ and $L_o$ are the present latitude and longitude respectively of the site of sample collection;

$\psi$ is called the rotation which is obtained from the declination $D$ of observed magnetic direction at the site as

$$\psi = D \text{ or } D-180^\circ \text{ if } 0^\circ < D < 180^\circ$$

$$\psi = D-360^\circ \text{ or } 180^\circ \text{ if } 180^\circ < D < 360^\circ.$$


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SYNOPSIS

This thesis embodies a detailed account of paleomagnetic and chemical studies carried out on some of the dykes in the Mysore State. In the last decade the integrated studies have been a fascinating field on account of its successful application in solving many of the complex problems of geosciences. The study includes paleomagnetism of ninety-one samples (370) specimens and major elements of thirty seven samples from ten different dykes.

The preliminary investigations carried out on the natural remanent magnetization (NRM) of these dykes revealed large scatter from dykes 1, 2, 4, 5, 6, 7, 8, 9 and 10, whereas the directions from dyke 3 are clustered. On successive cleaning by a.c. demagnetization with the peak field values up to 300 øersteds on the specimens from all the dykes show that the scatter has been reduced in six dykes (1, 2, 5, 6, 7 and 10) and revealed consistent directions. However, the scattering in the four dykes (3, 4, 8 and 9) remained unchanged.

It has been shown by a.c. demagnetization curves that out of ten dykes studied, four dykes (3, 4, 8 and 9) did not improve after cleaning, thereby indicating that the original thermo-remanent magnetization (TRM) was destroyed to a large extent. Whereas, the directions of six dykes (1, 2, 5, 6, 7 and 10) form a cluster away from the present geomagnetic field.