CHAPTER VII

DYKE ROCKS

After the formation of granites, igneous activity which was entirely hypabyssal in character broke out, and gave rise to the intrusions of basic dykes belonging to the tholeiitic magma type of Kennedy (1933, p. 240-242). These dykes, in fact, appear to have escaped investigation almost completely and in this chapter it is intended to give a comprehensive account of the whole suite than has hitherto been published. No claim to completeness, however, is made, for a great deal of work still remains to be carried out on these intrusive rocks.

The emplacement of the dolerite dykes, in general is not much different over large areas. However, the dykes are irregularly distributed within individual rock units as well as from one unit to another. Dolerites are far more numerous in the southern part, that is round about Sivarampet and Cheudampalle villages, where granites and gneisses, for the most part, occupy the terrain, while the dykes are rare in the northern portion of the area which is mostly occupied by amphibolites, and metasediments. Chapman & Wingard (1958) suggest that dyke frequency is virtually independant of the age of the host rock, but varies with brittleness, attitude of planar structures and amount of host rock stretching. According to Neumann (1947) p. 203), the fissure frequency is supposed to be highest where the original temperature was highest, that is within the igneous rocks and their immediate surroundings, while the frequency will decrease farther away from the plutonic rocks. The field relations of the M.P.R. area appear to be a good affirmation to the correctness of these assumptions.
Topographically the dolerites rise to form prominent hills, for example Ramapuram ridge (Plate XIV, Fig. 1). Because of their superior hardness to the other rocks through which they cut across they are almost invariably well-exposed. They occur as upstanding walls, or in level with the country or rarely as troughs depending upon their resistance to weathering. This inconsistent morphological habit, according to Gorbatschezo (1960), seems essentially to be a function of the amount of fractures traversing the dolerite dykes at right angles or parallel to their contacts and in medium sized dykes, still more often in two oblique directions, thus splitting the rock into sets of rhombic fragments.

The thickness of the dykes of the M.P.R. area varies from a few inches (Plate XIV, Fig. 2) to 70 feet, but the dyke at Ramapuram temple near the stream has exceptionally a width of 150 feet. In as much as the width of the dykes varies, it appears to be related, to some extent, to the degree of dilation suffered by the wall rock. Owing to the forceful intrusion of the magma into the pre-existing joint or shear planes, and due to lack of space in the fractures, the magma may probably spill out and occupy the minor joint planes forming dikelets, having connection with the major one (Plate XIV, Fig. 3).

Trains of reddish brown, brown or brownish black, rounded, exfoliated boulders ranging in size from a few inches to several feet in diameter or massive fresh blocks, as large as eight feet by twelve feet, mark the outcrops of the dykes for most part of their runs. At places it is concealed by the soil cover. The contacts with the country rock, in such cases, are not visible. At some places the contacts of the dykes with the country rock are
chilled, sharp and well-defined (Plate XIV, Fig.2), while in other cases the contacts are blocky and matched displaying assimilation effects (Plate XIV, Fig.4). The dykes of most commonly have their walls regular, but rarely irregularity in dyke walls is noticed and it is probably due to the irregularity in the original fracture in the country rock. In some cases the two contacts are seen to be more or less parallel with only minor curves and bulges. There is no regular relationship between the contacts and the foliation of the country rock. Some dykes sharply cross-cut uniformly foliated granites and gneisses; in a few cases foliation has been dragged out parallel to the dyke contacts, probably due to the dyke filling a fracture developed when foliation was deformed or may be resulting from later deformation. At a few places the dykes have been subject to intense late magmatic and post-crystallisation alterations in which process the contraction cracks have been filled with pegmatitic and granitic veins and veinlets.

Sometimes jointing is developed both parallel to, and at right angles from the contacts with the country rock. When developed at right angles to the cooling face, the dyke assumes a columnar habit, sometimes to a marked degree. Well developed hexagonal and other polygonal fracturing are found particularly in some of the smaller, massive, fine grained dolerites (Plate XIV, Fig.5).

In some cases at the very contact between the wall rock and the intrusive, apophysis-like fillings of microscopical cracks can occasionally be distinguished. Also, microscopical zones of shattering are parallel with and often coincide with the surface of contact. At such places, tongues of quartzo-feldspathic materials are seen (Plate XIV, Fig.6).
At places the dykes are intersected by minor vertical shear planes or fault planes (Plate XV, Fig. 1).

Evidence of a distinct contact metamorphic effects have, however, been observed in the wall rock at few places.

Since the dyke rocks are much later than any of the older rocks and are not involved in the tectonic history or alteration of the other rocks, both quartz dolerite and olivine dolerite occur and in most cases they are remarkably unaltered looking fresh even under the microscope.

The strike pattern of the dolerite dykes shows a marked preference for three directions: NW-SE, E-W, and a few N-S. Dykes trending NE-SW are typically absent. This preferential orientation is found not only in the M.P.R. area but also in many parts of peninsular India. The details on the dyke pattern of the M.P.R. area and comparison with the trend of those occurring in other areas, and also the relationship between the dyke pattern and drainage pattern in the M.P.R. area are discussed in Chapter II.

The similarity of composition and widespread distribution of each set of dykes suggests that basic material has probably not been derived from local pockets but from some deep and more universal layer. Therefore this basic melt may have been available throughout the area, in sufficient quantities, during the period of dyke formation.

Fresh dolerite is black or very dark greenish grey, but weathered outcrops are reddish brown or brownish black. The small dykes and dykelets are black and fine grained or even glassy. In the dykes having larger widths, textural variation is
discernible even megascopically, being glassy to fine grained at or near the contact with the wall rock, medium grained farther away from the contact and coarse-grained near about the centre and farthest away from the contact lath-shaped plagioclase, greenish black pyroxene and black granules of magnetite can be observed megascopically or with the aid of a hand lens.

At certain places the dyke rocks are so magnetic that the compass needle may be reversed. A reversal ranging from 30°-60° away from the north is noticed. When the dykes are hit with a hammer it sounds with a characteristic bell-ring.

The dolerite dykes are younger than the metasediments, amphibolites, gneisses and granites and older than most of the acid dykes of the area.

PETROGRAPHY

Petrographically the M.P.R. dolerites comprise the following types:

1. Chilled phases of dolerite.
2. Fine grained dolerite.
3. Medium grained dolerite.
4. Dolerite with micropegmatite.

1. Chilled phases of dolerite:

These constitute the thin selvages of dolerites against the country rocks, namely granites and gneisses. There are also chilled dykes of very narrow widths which are aphanitic to glassy. They are dense and dark grey in colour. Based on the texture under the microscope, they are classified into two types:
(a) Vitrophyric type;
(b) Pilotaxitic type.

(a) Vitrophyric type:

Under the microscope it is entirely made up of glassy matrix, without any phenocryst minerals. Microlites of plagioclase are occasionally seen. They are conspicuous even under the ordinary light because of their fresh appearance in contrast to the dark, glassy groundmass. Interpenetrated twins of plagioclase are not uncommon. Minute specks of magnetite and yellow to yellowish brown stain of haematite are noticed. In some sections it is composed of phenocrysts of pyroxene and plagioclase evenly distributed in black tachylytic groundmass. This glassy matrix is much more than the crystallised ones. Pyroxene occurs as rounded, rectangular or tiny prisms. Plagioclase occurs most commonly as tiny laths and rarely as rectangular or square shaped grains. There are also microlites of plagioclase developed in the groundmass and they, at places, show crude preferred orientation by the alignment of their longer axes (Plate XV, Fig.2). In some sections plagioclase and augite have undergone extreme alteration and the alteration products merge in the matrix. Secondary chlorite and hornblende occur with feeble pleochroism. Granular and dusty magnetite is uniformly sprinkled.

(b) Pilotaxitic type:

Under the microscope it is made up of granular pyroxene, plexus of plagioclase and granular and dusty magnetite. Plagioclase and pyroxene occur as glomeroporphyritic clusters and as individual grains (Plate XV, Fig.3). Average plagioclase grain
has 0.6 mm. in length and 0.22 mm. breadth. A few interpenetration twins are not uncommon. The composition is An₅₄ to An₅₈. Some laths contain inclusions of pyroxene and magnetite.

Pyroxenes range in size from very tiny grains to 0.64 mm. in length and 0.32 mm. in breadth. Elongation parallel to C-axis is common, but all variations are encountered from slender prisms to stout crystals. Some grains show wavy extinction, and a few show hourglass structure. Pigeonite occurs as uniaxial prisms either as xenomorphic grains or as mantles and cores to sub-calcic augite.

2. Fine grained Dolerite:

The fine grained dolerites are phaneritic, dense, dark grey, non-porphyritic dolerites and occur as marginal phases a little distance away from the contacts with the country rock. Sections of these specimens are more crystallised with slightly larger grains, the proportion of crystallised minerals to glassy matter being more.

(a) Olivine Dolerite:

In this, plagioclase occurs as branching sheafs, pyroxene being interstitial (Plate XV, Fig.4). Olivine occurs as colourless, subhedral crystals and anhedral grains with an average diameter of 0.29 mm. All grains are traversed by cracks filled with opaque ore. The optic axial angle of olivine is 85° and hence forsteritic. Bronzite occurs as colourless anhedral grains. Pyroxene is mostly represented by augite with 2V₂ varying from 40° to 52°, indicating the presence of sub-calcic augite among the olino-pyroxenes. Plagioclase occurs as twinned laths with An. content An₅₄ to An₆₀. Zoning is indistinct.
(b) Olivine-free Dolerite:

The chief constituents are augite and the intermediate plagioclase ($\text{An}_{40-58}$). The other pyroxene, pigeonite is also noticed in some sections. It occurs as irregular plates, often in association with augite, either as a core of augite or around the margin as shell to augite.

Plagioclase is abundant as twinned laths with An content 50%-58%. Sometimes the grains show oscillatory zoning and the anorthite content of core and margin differs by 8-12 percent.

Bronsitie is colourless and occurs as prismatic plates and anhedral grains. $2V_\times = 82^\circ$. Sometimes it wraps round augite showing wavy extinction. Most of the pyroxene is made up of augite and sub-calcic augite with $2V_\times = 40^\circ-46^\circ$. In places skeletal crystals of magnetite occur marginal to pyroxene and plagioclase (Plate XV, Fig.5). In some sections micropegmatite is sparingly present. Green chlorite and biotite, pleochroic from straw yellow to brown and a little hornblende, at the pyroxene plates, occur as alteration products.

3. Medium grained dolerite:

The Medium grained dolerite occurs away from the contact and towards the central portion of the dyke.

(a) Olivinge Dolerite:

Under the microscope it shows ophitic to sub-ophitic texture. Oliving occurs as euhedral (Plate XVI, Fig.1) to sub-hedral grains. It has an uneven distribution in different sections and commonly occurs as aggregates and sometimes as separate grains. It shows different degrees of alteration. In some cases they are conspi-
ouously emphasised by iron oxide, which fills the irregular cracks in olivine or surrounds its margins. Plagioclase is predominant with variation in size from tiny needles to long prismatic laths. The anorthite content is from 65% to 68%. In a few cases the twin lamellae are slightly bent. A few interpenetration twins are also encountered (Plate XV, Fig. 6). Sometimes small grains of plagioclase are enclosed within augite plates. Similarly small augite grains are enclosed in plagioclase. Augite occurs either as long, prismatic or as short, stumpy grains. Pressure-shadows traverse in some grains. Chlorite, serpentine and other fibrous minerals occur as alteration products, which in some cases form the pseudomorphs after olivine, and/or pyroxene. Opaque ore is invariably associated with olivine and pyroxene. The opaque ore is represented mostly by magnetite, ilmenite with or without leucoxene and pyrite. Haematite occurs as coating to the other grains. Sometimes the alteration products both in olivine and pyroxene look-alike.

In a variation of the above type, olivine occurs as small, subrounded grains. Except for a few cracks filled with magnetite the grains are devoid of alteration products and hence look fresh. Augite shows wavy extinction and is in sub-ophitic relation with the plagioclase laths. The triangular or polygonal spaces formed by plagioclase are occupied by olivine and pyroxene. Interpenetration twins of plagioclase in this section are very common and almost all laths occur as penetration twins (type-4 of Gorai, 1951, p. 889). Primary magnetite and pyrite, with cubic outlines, occur besides the opaque ores associated with olivine and pyroxene.

(b) Olivine-free Dolerite:

Under the microscope it is composed of elongate or irregular
grains of augite, large laths of plagioclase. These larger grains are embedded in a groundmass which is entirely composed of small plagioclase laths and pyroxene granules together with their alteration products. The anorthite content is An$_{50}$–An$_{55}$.

Most plagioclase grains are fresh and some grains are found to be partly corroded. Plagioclase occurs either as randomly oriented aggregates or as crudely radial aggregates. Interpenetration twins are rare. Most grains show normal zoning. Orthopyroxene is associated with augite. An intergrowth between ortho- and clino-pyroxenes are observed. Some pyroxene grains are partly or entirely occupied by fibrous aggregates of alteration products exhibiting patchy interference colours. The amount of opaque ores in different sections widely varies. Similarly the relative proportions of alteration products also vary in amount.

In a variation of the above variety, pyroxene is much more than plagioclase grains which have broad and few polysynthetic lamellae. The An. content varies from 50% to 60%. Pyroxene constitutes largest amount by volume and occurs mostly in clusters. A few grains are twinned. Larger grains tend to segregate into small, rounded, or oval-shaped or elongated granules. Interpenetration twin of augite is observed. Yellow serpentinitous, green chloritic and micaceous and clayey materials occur as alteration products, some of which form pseudomorphs after pyroxene. Subordinate amounts of biotite, a little hornblende occur at the margins of both clino- and ortho-pyroxenes.

4. Dolerite with Micropegmatite:

Plagioclase occurs as elongate or square-shaped plates. Some
grains show zoning, which is normal or oscillatory. Plagioclase is altered and the alteration products have an erratic distribution within or around plagioclase grains. In some cases, alteration products are confined to the composition and cleavage planes. Plagioclase often exhibits clouding. Rounded or elliptical grains of pyroxene occur as inclusions in plagioclase. Micropegmatite occurs associated with plagioclase and develops as outgrowths from the marginal parts of plagioclase grains and this pegmatitic intergrowth is initially fine textured and progressively becomes coarse textured away from the plagioclase grain. Fresh quartz occurs as subrounded grains and occurs surrounding the pegmatitic intergrowth or as rounded or elliptical grains within the intergrowth. A few grains of potash feldspar are rare. Tiny needles of apatite occur as inclusions within quartz and pegmatitic intergrowth.

Pyroxene in some cases is transformed into uralite becoming pleochroic from pale yellow to faint green. Some grains have different colorations of yellow and green due to alteration into patches of chlorite, biotite and hornblende. Opaque ore is common, and in some grains most part is occupied by vermicular or skeletal magnetite.

In a variation of the above type, quartz content is more. Plagioclase occurs as elongated plates, mostly corroded. Most of the grains occur in clusters and randomly oriented. Most of the grains show zoning and clouding.

Pyroxene occurs as irregular plates. Twinning in pyroxene is not uncommon. Different degrees and different types of alteration are clearly exhibited by pyroxene. Alteration stages from
traces of hornblende to complete uralitisation into fibrous hornblende and biotite can be traced out in different pyroxene grains. In plagioclase alteration commonly takes place in the cores and extends outwards, while in pyroxene, during the process of uralitisation, alteration initially commences at the marginal parts and extends inwards until the whole pyroxene grain is transformed into uralite. The pyroxene, suffering alteration, also shows at its marginal parts, biotite with yellow to deep brown pleochroism and in some cases the pleochroism is less pronounced from pale yellow to yellow. Similarly secondary hornblende is either nonpleochroic with green body colour or shows pleochroism from yellow to green.

Magnetite is fairly abundant and occurs as irregular, vermicular, skeletal growths. Sometimes it is seen with fantastic shapes. It is mostly associated with pyroxene. Quartz mostly occurs as intergrowth and also as separate grains. It is irregular or rounded and occurs adjacent to plagioclase grains. It is slightly dusty with opaque ore. Apatite is an accessory included as tiny needles mostly in quartz and plagioclase.

Modal Analyses of Dolerites:

Modal composition of the representative members of dolerite dykes are listed in the table 21 and presented on a cumulative basis in fig. 41.

Plagioclase including its alteration products namely sericite and clinozoisite but excluding chlorite is the abundant constituent in most of the dolerites. Pyroxenes are next in importance, but some of the pyroxenes include their alteration products serpentine, chlorite and iron-oxide dust and stains.
not present. The absence of the spherical shape is due to the
growth taking place from a plane and not from a nucleus.

In Plate XVI, Fig. 3, a plumose growth of feldspar from the
trace of a plane and on either side of the plane is found. As
the size of the feldspar stringers increases from the growth
plane they are found interlaced by more and more of quartz rods.
Thus, what is, to begin with, a simple fine fibrous growth of
feldspar, becomes a parallel growth between feldspar and quartz.
Feldspar is highly altered and hence occurs as turbid brown
stringers interspersed with colourless quartz rods. The plumose
growth becomes coarser and coarser away from the contact and in
grade on to micropegmatitic and graphic intergrowth. With the
increase in the size of the constituents of the intergrowth,
the micropegmatitic intergrowth merges with the even grained
granitic texture of the granite. Whereas the granite contains
microcline, the feldspar of micropegmatite is orthoclase as
revealed by lower 2V of 65°.

Another usual type of growth in this micropegmatite is
revealed in Plate XVI, Fig. 4. The growth, in this case, starts
apparently radially from a nucleus constituted of a square-
shaped crystal of altered orthoclase. The growth of the feldspar
is perpendicular to the sides of the square at the centre.
As the growth from each side continues laterally, they impinge
on the extended diagonals of the square and the growth appears
to start from these diagonals. The plumose growth of the micro-
pegmatite, seen in plenty in the rock, is often a sector of one of
these diagonals. The fibres are straight and continuous making
an angle of 45° with the extended diagonals while being perpendi-
cular to the sides of the square. This type of growth, when the
stringers meet the diagonals at 45°, is responsible for imparting "Herringbone structure" to the micropegmatitic intergrowth. At the extremities, the outgrowths which are continuous become disconnected, being cut up due to increase in the grain size, and pass into a graphic intergrowth. Thus in one single intergrowth a gradation from spherulitic to plumose, parallel intergrowths to graphic texture is seen in Plate XVI, Fig.5. Shand quotes a similar case of micropegmatitic intergrowth in an aplite which has become under the influence of adjoining granodiorite. This aplite at its margins and in contact with the granodiorite is micropegmatitic, showing fan-like growth of quartz and feldspar, the growth being outward from the granodiorite.

The author believes that the silica of the liquid generated by the melting of granite has manifested as a constituent of micropegmatite. This acid material, with its strong contrast with the rest of the dolerite is considered to be the result of contamination of dolerite magma by the granitic liquid. In other words the dolerite has assimilated or dissolved a portion of the granite at its contact. It indirectly throws light on the existence of siliceous feldspathic liquid corresponding to the granitic magma.

Interaction of the dolerite with the Acid veins in granite:

Dolerite occurs in contact with granite. At certain places, granite, in contact with dolerite, contains minor veinlets, essentially composed of andesine and quartz which are sometimes intergrown in a myrmekitic fashion. Some of these veinlets are seen to cut the dolerite, thereby indicating that the veinlets are younger than granites and dolerites.
The minor veinlets, at the contact with the dyke, contain mainly andesine and quartz. Andesine is invariably pink in colour, owing to the presence of innumerable microscopic inclusions of ferric oxide. The inclusions are so numerous that the mineral appears almost opaque in thin section (Plate XVII, Fig 1). The mineral occurs either as tabular grains or as small rods, intergrown with rods of quartz in a myrmekitic fashion. Quartz is fresh and is practically free from inclusions. In addition to its occurrence in myrmekitic intergrowths, it also occurs as large, anhedral discrete grains. In some places secondary epidote of green colour has developed at the expense of phenocrystal plagioclase, presumably as a result of later hydrothermal activity. It is interesting to note that the plagioclase involved in myrmekitic intergrowths has not been involved in saussuritisation. Epidote is variegated, showing different tints in green or yellow, and is feebly pleochroic to non-pleochroic. This observation indicates marked compositional variation in epidote from grain to grain. Epidote mainly occurs as a chain of small crystals, more or less enveloping the tabular grains of plagioclase on all sides. In almost all cases, where epidote rims occur around plagioclase, a mantle of secondary albite, nearly free from inclusion of iron oxide, separates the two minerals. Albite makes usually a sharp contact with andesine (Plate XVII, Figs 1 and 2). In a few cases, the transition from andesine to albite is gradual as indicated by optical study and by gradual variation in the density of inclusions of iron oxide (Plate XVII, Fig.3).
### Mode of EAV 1 D/2511

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<tr>
<th>Component</th>
<th>Percentage</th>
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<td>Quartz-feldspar intergrowth</td>
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<tr>
<td>Quartz</td>
<td>6.80</td>
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<tr>
<td>Andesine</td>
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<tr>
<td>Albite</td>
<td>2.96</td>
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<tr>
<td>Epidote</td>
<td>5.40</td>
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<td>Sericite</td>
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<tr>
<td>Opaque ore</td>
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<td>Chlorite</td>
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<td><strong>Total</strong></td>
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**Albite-andesine-epidote-quartz association of the above section.** (EAV 1 D/2511.)

<table>
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<tr>
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<td>Andesine</td>
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**Mode of the successive shells of Andesine-Albite-Epidote:**

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<th>EAV 1 D/2577</th>
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</thead>
<tbody>
<tr>
<td>Epidote</td>
<td>38.75</td>
<td>24.95</td>
</tr>
<tr>
<td>Andesine</td>
<td>34.92</td>
<td>63.43</td>
</tr>
<tr>
<td>Albite</td>
<td>26.33</td>
<td>11.62</td>
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</table>
Relative proportions of Andesine and Albite.

<table>
<thead>
<tr>
<th></th>
<th>Andesine</th>
<th>54.71</th>
<th>68.37</th>
<th>85.63</th>
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</thead>
<tbody>
<tr>
<td>Albite</td>
<td>27.59</td>
<td>45.29</td>
<td>31.63</td>
<td>14.37</td>
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</table>

It is believed that the nucleation of epidote has taken place mainly along the grain boundaries of tabular crystals of plagioclase by consuming a portion of plagioclase, presumably as a result of hydrothermal activity. The material required for the formation of epidote has been obtained in part from the plagioclase it has replaced and in part from the neighbouring plagioclase. As result of this, ions like sodium and silicon are mainly released into the structure of neighbouring plagioclase and ions like calcium, aluminium and iron, from the neighbouring plagioclase, enter into the structure of epidote. These chemical changes make the plagioclase, in immediate vicinity of epidote, to become albited and to get rid of the inclusions of iron oxide. The above hypothesis for the origin of albite rims around intermediate plagioclase may provide an explanation for the origin of mantled-albite even in rocks where epidote rim is absent, if it is assumed that relatively mobile epidote is removed from the rock in solution. Epidote is a relatively mobile mineral which can be easily removed from the place of its formation by solution.

The occurrence of bleached calcium-poor plagioclase among epidote can be compared with the occurrence of bleached iron-poor
zones sometimes found around porphyroblast of almandine or staurolite as reported by Rømberg (1952, p.212). While discussing the origin of pyrite crystals at the expense of hornblende in amphibolite a bleached, iron-poor hornblende is found separating pyrite and iron-rich hornblende (p.76-78). Rømberg (o.cit), while discussing the leached-out aureoles around porphyroblasts, considers such phenomena to be exceptions rather than the rule. He concludes that the growing crystal will normally be able to collect material from more distant places throughout the rock and that the chemical gradients driving these centripetal migrations have often been too small to manifest themselves distinctively as concentric zones around the porphyroblasts. The fact that, in the present case, the epidote has taken material required for its formation only from plagioclase that is in immediate contact with it might indicate that the chemical gradients involving the migration of chemical elements under the hydrothermal conditions, responsible for epidote formation, have been sufficiently large to manifest themselves as concentric zones visible under the microscope.

Petrographic variation across the Ramapuram dyke:

Specimens have been collected from the contact towards the centre of the dyke at nearly equal intervals. At the contact and a few inches inside the dolerite, the individual crystalline constituents are not clear and well-defined; owing to the metamorphic and metasomatic effects.

The following petrographic features have been worked out:
a. Grain size: (Table 23, Fig.44):
1. Maximum length of plagioclase.
2. Average length of plagioclase.
4. Average breadth of plagioclase.
5. Maximum length of pyroxene.
6. Average length of pyroxene.
7. Maximum breadth of pyroxene.
8. Average breadth of pyroxene.

b. Modal variation (volume percentage) of plagioclase, pyroxene, micropegmatite and opaque ores (Table 22, Figs.42 and 43).

c. Variation in Specific gravity (Table 24, Fig.45).

d. Variation in the frequency of twinned plagioclase grains. (Table 25, Fig.46).

e. Variation in the frequency of twinned pyroxene grains. (Table 26, Fig.46).

f. Variation in the volume percentage of twinned pyroxene with respect to untwinned pyroxene (Table 26, Fig.46).

CONTAMINATED DOLERITE.

Sivarampet Dyke:

Instances of reaction between granite and dolerite-magma of dolerite and granitic magma, are frequently mentioned in geologic literature, though details are often lacking. Mennell (1911), has described dolerite dykes which cut granite in Southern Rhodesia and incorporate masses of the granite itself or of quartz and feldspar. He shows that there has been some solution
Table 22.

Modal variation (volume percentage) across the Dyke(Figs. 42 & 43).

<table>
<thead>
<tr>
<th>Mineral</th>
<th>ELR 1</th>
<th>ELR 2</th>
<th>ELR 3</th>
<th>ELR 4</th>
<th>ELR 5</th>
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<tbody>
<tr>
<td>Plagioclase</td>
<td>37.75</td>
<td>39.15</td>
<td>41.18</td>
<td>40.98</td>
<td>43.02</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>44.66</td>
<td>42.09</td>
<td>35.18</td>
<td>35.57</td>
<td>32.12</td>
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<tr>
<td>Micropegmatite</td>
<td>12.01</td>
<td>13.08</td>
<td>18.11</td>
<td>17.54</td>
<td>19.10</td>
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<tr>
<td>Opaque Ores</td>
<td>3.80</td>
<td>3.99</td>
<td>4.18</td>
<td>4.41</td>
<td>4.13</td>
</tr>
<tr>
<td>Accessories</td>
<td>1.78</td>
<td>1.69</td>
<td>1.35</td>
<td>1.50</td>
<td>1.63</td>
</tr>
</tbody>
</table>
# Table 23

Variation in the grain size of Plagioclase and Pyroxene (Fig. 44)

<table>
<thead>
<tr>
<th>No.</th>
<th>Plagioclase</th>
<th>Pyroxene</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average length</td>
<td>Average breadth</td>
</tr>
<tr>
<td>ELR - 5</td>
<td>961.54</td>
<td>446.26</td>
</tr>
<tr>
<td>ELR - 4</td>
<td>793.60</td>
<td>371.20</td>
</tr>
<tr>
<td>ELR - 3</td>
<td>589.90</td>
<td>191.00</td>
</tr>
<tr>
<td>ELR - 2</td>
<td>501.70</td>
<td>168.90</td>
</tr>
<tr>
<td>ELR - 1</td>
<td>432.20</td>
<td>132.40</td>
</tr>
</tbody>
</table>

ELR - 5: 1199.33 675.61 1861.26 921.54
ELR - 4: 1038.71 528.93 1568.05 741.08
ELR - 3: 794.30 392.00 1250.93 624.27
ELR - 2: 429.22 226.53 715.78 415.42
ELR - 1: 328.38 161.13 518.85 289.44
Table 24. (Fig.45).

Variation in Specific Gravity.

<table>
<thead>
<tr>
<th>ELR 1</th>
<th>ELR 2</th>
<th>ELR 3</th>
<th>ELR 4</th>
<th>ELR 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.103</td>
<td>3.074</td>
<td>3.051</td>
<td>3.019</td>
<td>2.985</td>
</tr>
</tbody>
</table>

Table 25

Petrographic variation in dolerite from near contact towards the centre:

Relative proportions of twinned and untwinned grains of plagioclase and pyroxene.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>ELR 1</th>
<th>ELR 2</th>
<th>ELR 3</th>
<th>ELR 4</th>
<th>ELR 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twinned plagioclase</td>
<td>89.22</td>
<td>85.47</td>
<td>81.66</td>
<td>80.15</td>
<td>78.82</td>
</tr>
<tr>
<td>Untwinned plagioclase</td>
<td>11.78</td>
<td>14.53</td>
<td>18.34</td>
<td>19.85</td>
<td>21.18</td>
</tr>
</tbody>
</table>
Table 26. (Fig.46).

<table>
<thead>
<tr>
<th></th>
<th>Twinned pyroxene</th>
<th>Untwinned pyroxene</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of twinned pyroxene grains in %</td>
<td>Volume percentage relative to untwinned grains</td>
</tr>
<tr>
<td>ELR-1</td>
<td>40.00</td>
<td>57.07</td>
</tr>
<tr>
<td>ELR-2</td>
<td>44.70</td>
<td>55.14</td>
</tr>
<tr>
<td>ELR-3</td>
<td>53.30</td>
<td>62.32</td>
</tr>
<tr>
<td>ELR-4</td>
<td>58.60</td>
<td>66.43</td>
</tr>
<tr>
<td>ELR-5</td>
<td>66.40</td>
<td>64.51</td>
</tr>
</tbody>
</table>
...opaque ore

...accessories.
of the enclosed material and some crystallisation of micropegmatite in the dolerite. Krockstrom (1936) gives a full account of the Hellefors dolerite dyke in Sweden. Near its contacts with granite, this rock holds inclusions of granite and is itself greatly enriched with quartz and alkali-feldspar which form micropegmatite intergrowths. Similar instances of dolerite dykes incorporating the adjoining granitic materials are recorded in the M.P.R. area. One such case is found near Sivarampet village, and the other is about 20 feet away from the fault zone II, the location of which is given in page (Plate XVIII, Figs, 1 and 2).

In both cases, the dykes involved are about 50 feet in width, cutting through the medium to coarse grained grey granite. The second contaminated dolerite is actually a part of the dolerite running along the Ramapuram Ridge.

Such contaminated dolerite gives the appearance of intrusion breccia, occurring at the contacts between the granite and dolerite, spread for a distance of 30 to 50 feet. Beyond this zone, the granite is normal foliated rock and the dolerite is reddish brown, massive rock. These zones are restricted in their occurrence, but do not occur all along the dolerite run. It appears to be produced by movement of the dolerite along the pre-existing fracture planes by pressure of fluid dolerite magma. This sort of contamination appears to be related to and caused by magmatic pressure and movement.

Under the microscope, the thin sections of dolerite, which have incorporated the quartz and/or plagioclase from granite, spherulitic structure is observed in the dolerite surrounding...
the quartz inclusions. These spherules form an extinction cross parallel to cross hair. They vary in size from minute growths to larger sheaf-like aggregates resembling plumose growths. Beyond these inclusions, the texture is doleritic with small rounded grains of augite interlaced by microlites of plagioclase feldspar giving an ophitic texture. Interpenetration twins of plagioclase are common. In the spherules the intergrowth is between plagioclase fibres and between plagioclase and pyroxene. These spherules indicate sudden chilling undergone by the dolerite magma surrounding the quartz inclusions. The selvages are glassy with only microlites of plagioclase. The dolerite has been altered to an aggregate of hblorite and hornblende.

Even in the more crystallised portions, the microlites are far in excess to that of pyroxene. As the microlites of plagioclase increase in size, a number of crystallites developed in the ground mass. These occur as needle-like aggregates lying irregularly in all directions. The growth of the crystallites is often radial. There are a number of centres from which radial growth of crystallites has developed. Thus each centre has its own radial growth of aggregates. The radial growth from each centre interfere with the growth from the other centres, so that each crystallite of a radial growth resembles a ray of a star colliding with the crystallites from the adjoining radial growths.

Some sections consist partly of granitic and partly of doloritic material. The granite consists of plagioclase feldspar which is large in size and polysynthetically twinned and mostly exhibits albite laws. It has low anorthite content. The plagioclase of the dolerite is lath-shaped with simple twinning. A crude ophitic or sub-ophitic texture is seen in the dolerite portion.
In contrast to the above section, in the slide ELP.S-8/2439, there are no spherules, though inclusions of granitic materials are seen in this section.

The dolerite in which spherules are seen, are those taken from the chilled borders wherein inclusions of granite are seen. So here the spherulitic texture is a chilled phenomenon and not an effect of granitic intrusion, because such spherules should be seen wherever granitic material is found as inclusion if granite has actually intruded into granite.

In the section ELP.S-7/2434, there are large areas consisting of quartz aggregates. Each aggregate consists of a number of grains of quartz having irregular boundaries and showing undulose extinction. Each inclusion of quartz aggregate, as a whole, has rounded outline indicating resorption due to magmatic reaction. The dolerite portion in this slide is essentially composed of sharp laths of plagioclase with a little amount of magnetite and pyroxene. It is also partly glassy and fine grained.

Thin veins are found in dolerite portion of the admixed rock. The vein consists of colourless mineral and very small in size showing aggregate polarisation colours. The mineral is flaky, small in size and its extinction position is difficult to decipher. Within these veins are found unaltered relics of amphibole. The course of change here appears to be the conversion of pyroxene into uralite and plagioclase into saussurite but the new colourless mineral filling up the crack as a vein appears to be talcose having clear borders. This vein material transects the minerals along the walls. During this transection, it has incorporated the minerals from the walls, namely uralite and saussuritised plagioclase.
Ramapuram Dyke:

Here the zone is near the fault zone No. 2 and the boulders of dolerite "embedded" with granitic material lay scattered.

The plagioclase feldspar of the dolerite is elongate and lath shaped, most of it showing simple twinning after albite and carlsbad laws. A few are also zoned, zoning being oscillatory. Between the areas formed by the laths of plagioclase are uralitized pyroxene. This simulates intergrowth texture. In this area found large grains of plagioclase feldspar and quartz derived from the granite. There is an intimate admixture between dolerite and granite portions. Clots of large grains of plagioclase of granite are found. They show multiple twinning. The constituents of the dolerite wrap round these large plagioclase grains of the granite. Often islands of doleritic portions are found surrounded by large grains of plagioclase of granite. Within these islands have developed long sheaf-like aggregates of plagioclase of dolerite as variolites. The anorthite content of the plagioclase of granite and dolerite appears to be more or less the same. The plagioclase of the granite appears to blende itself with the plagioclase laths of the dolerite at its border. At the periphery of the plagioclase of the granite, the twin lamellae of the plagioclase of the granite, wherever it is parallel to the twin lamellae of the plagioclase of the dolerite, appears to merge with the later.

Quartz and plagioclase show evidence of intense crushing. Quartz shows granulation at the periphery and strongly developed strain shadows. The twin lamellae of the feldspar are highly bent and fractured. Along the fracture planes of feldspars are found
veinlets of fine grained dolerite material. Pyroxene alters to amphibole, chlorite and epidote. There is a very intimate admixture between dolerite and granite. Plagioclase feldspar is highly altered to a turbid, greyish brown material. Twin lamellae are very narrow and bent and shows strain shadows as in quartz. Quartz grains vary in size from very tiny granules to very large ones indicating intense crushing that his zone has undergone. The plagioclase feldspars are only those derived from granite whereas the dolerite is devoid of plagioclase.

In Elp-45 b/2424 micropegmatitic intergrowth between quartz and feldspar is observed. It is both coarse and fine intergrowth. This growth usually starts in a nucleus or from the border of a large plagioclase or the quartz grains as the growth starts outwards from the margin. The grains of the minerals involved in the intergrowth becomes larger. However numerous centres of micrographic intergrowths are found scattered throughout.

There are also large clots of quartz grains surrounded all round by micropegmatite. Thin microveins and veinlets consisting of epidote and calcite are seen traversing the section. The quartz grains are highly crushed so that the extremities of the quartz grains are surrounded by numerous small tiny granules of quartz.

Elp 40-1-1/2408 is also a section of contaminated dolerite with inclusions of quartz and feldspars in fine grained dolerite. The plagioclase feldspars are saussuritised, pyroxene is converted into amphibolite. There are veinlets of quartz and epidote cutting through both dolerite and granitic portions. A single vein is seen cutting through grains of plagioclase of dolerite and also large grains of quartz and feldspar of the granite.
There are thin needle-like inclusions in the quartz of the veinlet. In p-2/2100, the micropegmatite occurs as the reaction rim around quartz and plagioclase grains.

Elp-42/2423: The evidences where, on account of interaction between granite and dolerite, an intermediate rock, diorite has been formed with the conversion of pyroxene to amphibolite included between the plexus of feldspar arranged as in basaltic texture. The feldspars are lath-shaped with simple twinning arranged in all directions. The hornblende thus formed has been further converted into chlorite retaining the original shape of the hornblende as pseudomorphs. In most cases the six-sided outline of the basal sections of hornblende is still retained whereas the mineral has actually been converted into chlorite. The ultramarine blue colours of the chlorite is very characteristic.

In Elp 45-A/2422, both granite and the admixed dolerite together have undergone intense crushing. The dolerite portion has undergone flowage, the flowage bands being contorted, whereas the quartz and feldspar have been crushed and elongated into lenticular clots parallel to flowage banding. Between the grains of quartz and feldspar are found contorted bands of the altered doleritic material. These bands are darker in colour consisting of iron ore, chlorite, actinolite and fine granules of feldspar. This section is also a clear example of the effect of crushing. Twin lamellae of the feldspars of granite are bent round the lenticles of quartz and parallel to the flowage bands. Quartz is also crushed into fine granules and these granules get mixed up with the altered dolerite material. The section is full of the micropegmatite whose grain size varies from spherulitic intergrowths of the feldspar into larger graphic growths. The growth
of the spherules is around a nucleus or along a line or from the margins of quartz and feldspar. The micropegmatite at their outer boundaries are in coarser intergrowths. Similar occurrences are recoded in the section 'interaction with the country rock' and the details are death with in page .

Elp 46/2412 is a rock which is the product of assimilation of granite and dolerite of this is completely assimilated and recrystallised. It is a typical diorite, equigranular with yellowish brown hornblende and pale green actinolite.

Such a thorough and extensive assimilation between granite and dolerite in this particular zone lends support to the view of the assimilation of dolerite by the granite magma. In this region there are cases where dolerite has intruded into granite with little or no effect on the granite. At best there is a narrow zone on the border of the dolerite in contact with granite where the granite has melted to form a micrographic texture as in Ramapuram dyke near the Ramapuram temple. At other places the contaminated dolerite is seen wherein the dolerite by forceful intrusion has incorporated the broken fragment of quartz and plagioclase with a more or less thorough admixture and mineralogical transformation. The dolerite by incorporating the granite material has been converted into diorite. In a single slide (ex., Elp 58/2439) are found two varieties of plagioclase feldspars, one large polysynthetically twinned \( (An_{26}-An_{30}) \) and another small, lath-shaped with simple twinning derived from dolerite \( (An_{35}-An_{38}) \). So, in this case (Sivarampet dolerite) the hybrid variety diorite is due to the incorporation of granitic material into dolerite; but in the case of the dolerite found at the dam site near the Fault zone 2 which is part of the Ramapuram temple
dyke there is not only incorporation of granite by the dolerite, but also intense movements of the blocks along the dyke fracture similar to faulting movement. It is evidenced by the intense crushing both the granite and dolerite matrix have undergone. The crushing of the grains of quartz and feldspar of the granite, their thorough admixture in the dolerite material, flowage of doleritic material, the parallel veinlets cutting through both doleritic and granitic portions are all evidences for slippage along the dyke fracture. Moreover adjoining this dolerite and just about 50 feet away is a zone of faulting showing slicken-sliding and brecciation in the ferruginous quartzites found along the schistose planes of the chlorite schist. The chlorite schist in this area admixed with the ferruginous quartzite has also been interpreted as due to dislocation metamorphism. That means the chlorite schist zones may, at places, be the zones of faulting which are responsible for converting the high grade amphibolite into chlorite schist. The fault plane indicated by the chlorite schist and which is parallel to the dolerite dyke may closely follow the dyke fracture, it may be possible that the dyke itself as intruded along the fault plane incorporating the granitic material. Further movement along this fault plane, after the intrusion of the dyke, has been responsible for converting the pyroxene into hornblende and chlorite rendering thereby as smoother and more plastic surface for faulting movement.
MINERALOGY

Feldspars:

Plagioclase is invariably the most common and abundant constituent and it always shows polyhedral twinning. Grains with two sub-individuals are also common.

Plagioclase generally occurs as laths. Square-shaped grains are also not uncommon. There is general increase in the dimensions of the plagioclase laths from the contacts towards the middle of the dykes, and this is due to the rate of cooling and crystallisation of the magma. The average ratio of length to breadth is about six to eight in coarse grained dolerites, about five in medium dolerites, while in the phenocrysts of the chilled phases it falls down to about three. The idiomorphy of the feldspar laths is often perfect.

In olivine dolerite and oliving-free dolerite plagioclase is commonly fresh and clear while in dolerites with micropegmatite they are turbid due to alteration.

The anorthite content varies from seventy eight to thirty five percent and they are mostly twinned according to albite-carlsbad, carlsbad and albite laws. The highest An. content is observed in the olivine bearing dolerites and the An. content has been found to decrease through olivine-free dolerite to dolerite with quartz and micropegmatite.

Twin Laws:

Twin laws of 271 plagioclase grains in 42 rock slides of different varieties of M.P.R. dolerites have been determined.
The frequency of each twin law in the plagioclase of these rocks is given in table 27, and is also represented in Suwa's diagram (Fig. 47).

Carlsbad law is the most abundant twin law (92) followed by albite-carlsbad law (76) and albite law (66). Other laws are much less and all of them together account for 37. The albite ale B twinning in the plagioclases of the composition range of these dolerites \((\text{An}_{35}-\text{An}_{78})\) is negligible. Only three grains out of 270 grains are encountered whereas the sodic plagioclases of granites have a remarkably higher frequency (198 out of 387) of albite ale B twins. This additional observation made on the plagioclase twins in dolerites irrefutably points to the influence of composition over the development of albite ale B twinning--the more basic the plagioclase is, the less is the incidence of albite ale B twinning and vice versa.

**Zoning:**

Continuous diffuse or oscillatory zoning or undulatory extinction are seen in some cases. In some cases zoning is seen in large crystals and in some cases it is seen both in large and small crystals. The most basic core is \(\text{Ab}_{50}\text{An}_{70}\) and the rims of the grains vary in composition from \(\text{An}_{38}-\text{An}_{48}\). Commonly the variation of anorthite content is about 10%–14%, from core to rim. The general trend is normal even in the oscillatory zoning. A plagioclase grain showing oscillatory zoning is shown in the Figure (Fig. 48) and the variation with anorthite content of the grain is shown in figure 49 representing the relationship between the anorthite content and widths of the lamellae. The curve (Fig. 49) shows oscillatory zoning though the general trend is normal. Phemister (1934) and Hills (1936)
Fig. 47

1. Olivine Dolerite
2. Vitrophyric Dolerite
3. Dolerite
4. Dolerite with micropegmatite
5. Quartz Dolerite
6. IPT: Interpenetration Twins.
ascribe the oscillatory zoning in plagioclase to rhythmic changes in composition of a melt around a growing plagioclase crystal. Bowen (1928), Fenner (1926) and Homsa (1932) attribute it to the movement of crystals within a magma and the mixing of the magmas themselves. Petrographic features of the M.P.R. dolerites support the views of Phemister and little regarding the origin of oscillatory zoning.

Clouding:

The plagioclase feldspars are found to be clouded in the dolerites with micropegmatite. The clouding is mainly due to the presence of dusty and needle-like inclusions of magnetite which are strikingly seen with a high power objective. In other varieties of dolerites the plagioclase is devoid of such clouding. Mac Gregor (1930) attributes clouding to thermal metamorphism. Sargent (1918, p.19) and Sutton and Watson (1951) ascribe it to autometamorphism. Poldervaart and Gilkey (1954) state that cloudiness may be produced either by the incorporation of the materials during crystallisation or by introduction without after consolidation. In the former case clouding results due to exsolution, and in the latter case owing to diffusion. According to them thermal metamorphism aids the first, and regional metamorphism the latter, provided the temperature is maintained for a long time and there is enough supply of water and iron-bearing materials. This is in accordance with the observations made by Naidu (1960, p.27). The M.P.R. dolerites in which the plagioclase is clouded are medium to coarse grained and they occur in the central parts of the dykes which are slowly cooled. The presence of micropegmatite, quartz, hornblende and mica in the dolerites
with clouded plagioclase reveal the presence of enough water. The abundance of opaque ores reveal the source material necessary to impart clouding. Therefore the clouding in the M.P.R. dolerites is believed to be brought about by diffusion of rion ions during the deuteric stage of evolution of these dykes. As clouding in plagioclase is not observed in all the dykes of the area, the clouding cannot be attributed to the regional metamorphism. This is in accordance with the observations made by Sargent (1918) and Sutton and Watson (1951) and Neidu(1960,p.26-27).

In dolerites with micropegmatite the marginal parts of the plagioclase crystals are often intergrown with quartz or pass into plagioclase with less of anorthite content in which case micropegmatite occurs interstitial to plagioclase laths. The dolerites with micropegmatite are considered to be the youngest of the M.P.R. hypabyssal suite.

Orthoclase is present sparingly intergrown with quartz in dolerites with micropegmatite. The optic axial angle varies from 52° to 60° in the plane perpendicular to (01).

**Olivine:**

Olivine occurs as colourless perfect euhedral crystals or as stubby, poorly terminated crystals. Some are fresh and some are corroded. It occurs as separate grains or as glomeropheno- crystals associated with pyroxene; and in a few cases it occurs as granules in the ground mass. Most of the grains are traversed by irregular cracks which are invariably filled up by iron oxide materials and by films of chlorite and yellowish green serpentine. In some grains both fresh olivine and altered oliving are encountered in thin sections. In some grains, opaque ores, bowlingite
and talc occur as patches; sometimes the former presence of olivine is indicated by fibrous pseudomorphs of serpentine and magnetite which retain the outline of original olivine crystals. In some thin sections small relict centres of fresh olivine are surrounded by fibrous areas of serpentine and chlorite and such other alteration products. Some such olivine grains have granular and vermicular magnetite. In some cases the olivine crystals are stained by yellowish red or dark brownish red iron oxide and the crystal borders are altered to Iddingsite (?).

Olivine shows wide variations in size with an average diameter of 0.42 mm. In these grains the long axis is parallel to the C-axis. Zoning has not been observed but within one section they show range in optic axial angle 86°-88°. The composition of olivines obtained for these values on Földvára's curves (1950, p.1073) varies from Fo95 to Fo85.

Orthopyroxene:

Bronzite represents the orthopyroxene and occurs as colourless and subhedral plates and anhedral grains. In a few cases, in olivine dolerites, it is seen to carry relics of pigeonite. In some other cases it shows a peculiar patchy extinction. Hess and Phillips (1938, p.450-456) offer alternative explanations for the development of such intergrowths. They can result either due to inversion of early crystallised pigeonite on slow cooling to orthopyroxene or owing to the unmixing of CaSiO3 from orthopyroxene on slow cooling. Walker and Földvára (1949, p.636) attribute it to the graphic intergrowth of ortho- and clino- pyroxene on a sub-microscopic scale and adduce similar reasoning as Hess and Phillips. This holds good for the patchy extinction of bronzite in the M.P.R. dolerites.
Clinopyroxene:

The clinopyroxenes present in the M.P.R. dolerites are pigeonite, augite and subcalcic augite.

Magnesium-rich pigeonite occurs in the groundmass pyroxenes of the chilled phases of dolerites. They also occur as relics in the plates of bronzite in olivine dolerites. They are zoned with a core of pigeonite, surrounded by a mantle which is subcalcic augite. Pigeonite is either uniaxial or show low optic axial angle. Augite and sub-calcic augite occur as euhedral crystals and ophitic and subophitic plates.

Alteration of the augite to uralite and serpentine may occur, but is not very pronounced, the orthopyroxenes generally being much more susceptible to alteration than their calciferous counterparts. Both varieties of pyroxene may change into greenish-brown clouded pseudomorphs composed of very finely dispersed iron ore dust and an indeterminable flaky substance. Sometimes the very fine lamellae of these alteration products follow the original (110) cleavages as well as the dome planes and are intergrown with minute layers of relatively fresh pyroxene.

Tomita's diagram showing the variations of the optic axial angle and the extinction angle Z C is shown in figure 50, unchanged except for the addition of plots marking the position of the optical constants ($2V_X$ and Z C) of the pyroxenes of M.P.R. dolerites. In this diagram $2V_X$ values for only pyroxenes with two directly observed optic axes are plotted. It is clearly seen that this diagram does not fit at all closely, the values for pyroxenes of M.P.R. dolerites. The discrepancies, as pointed out by Deer and Wager (1940) are probably due to the fact that
these values are very sensitive to variations in the amounts of the other constituents occurring in natural pyroxenes.

Amphiboles:

Uralitisation of the pyroxenes gives rise to the development of secondary amphiboles. The uralitisation of pyroxene forms fringes of radiating or irregular threads around the pyroxene grains. The spatial distribution of the uralitised areas in thin sections is rather irregular. Green and bluish green hornblende occur as secondary amphiboles. The bluish green hornblende occur along the margins of green hornblende. The green hornblende has the pleochroic shheme, $X = \text{Yellow}$; $Y = \text{pale green}$; and $Z = \text{green}$. $2V_x = 78^\circ - 84^\circ$. $\angle C = 16^\circ - 17^\circ$.

$N_m = 1.668$. Blue-green hornblende is pleochroic with, $X = \text{yellowish green}$; $Y = \text{pale blue green}$; and $Z = \text{blue green}$. $2V_x = 70^\circ$. $\angle c = 15^\circ$. $N_m = 1.676$.

Biotite:

Two types of biotite occur in the deuterically altered dolerites. Biotite pleochroic from brown to stray yellow is present as the marginal alteration products of green hornblende and blue-green hornblende. Green biotite is rare and occurs as peripheral alteration products of the brown variety; Hell (1941, p.30) ascribes the change from brown to green biotite to an increase in FeO content accompanied by a decrease in MgO. Green chlorite sometimes occurs as an alteration product of biotite.

Opaque Ores:

Primary crystals of opaque ore occur as euhedral to subhedral grains. A good deal of the iron oxide found in the dole-
rite is also of secondary origin. The secondary iron oxide occurs in widely varying habits-fillings in cracks of olivine and sometimes in pyroxenes, as dust, and stains on pyroxenes. In olivine dolerites, they occur as pseudomorphs, after olivine and pyroxene. Small and regularly arranged specks and granules of ore occur in some olivine and pyroxenes. Probably it represents the exsolved iron ore. Together with titanomagnetite there locally occur interstitial small and sparse grains of pyrrhotite and ilmenite with or without alteration to leucoxene are observed.

The bulk of the opaque ore is present in dolerites with micropegmatite when the iron enrichment of the magma has reached the maximum. The bulk of the ores is titaniferous magnetite and therefore the TiO₂ increases with the iron content of the rocks.

CERTAIN ASPECTS ON THE TWINNING OF PLAGIOCLASE AND PYROXENE:

Thin sections of the rocks taken from the chilled contacts of the dykes showed certain interesting features of which interpenetration twins are the most conspicuous. Interpenetration twins of the plagioclase, pigeonite and augite are recorded. Of these the interpenetration twins of plagioclase are common, but that of pigeonite and augite are very rare, being recorded only one each. Besides these a peculiar intergrowth between augite and plagioclase resembling that of a penetration cross is also recorded.

Interpenetration Twins of Plagioclase:

The following features of the interpenetration twins of plagioclase are observed in the M.P.R. dykes:
1. Well developed penetration twins are prominently displayed in the border zones where the ground mass is aphanitic in which plagioclase occurs as phenocrysts. Away from the contacts, that is towards the centre of the dykes where it is coarse grained, the interpenetration twins are rare or absent, when developed they are imperfect and the free and perfect development of the cross seems to be inhibited by the growth of the adjacent feldspar laths and augite plates.

2. Interpenetration twins are well developed in the pilo-taxitic types. They are found to be absent or rare in the micropegmatitic phases.

3. Wherever they are developed they look fresh and least altered.

4. The angle between the composition planes of the two arms of the cross which may be termed as the "angle of divergence" is always nearly perpendicular. However angles between 35° and 80° are also encountered but are not common. In majority of the cases each arm of the cross is a simple twin. In a few cases one arm is a simple twin while the other is polysynthetically twinned with 2 or 3 composition planes, but never exceed 3.

5. Penetration between an untwinned lath and twinned lath is not encountered. In some cases both twinning and zoning are found in the cross, in such cases the zoning is either progressive or oscillatory. In a few cases one or both the arms are zoned. Penetration between zoned and untwinned grains is never met with.

6. Though in many cases two laths form the cross, but in a few cases three or four laths are seen to penetrate and such twins may be termed as "multiple penetration twins".
7. In some cases iron oxide material, either magnetite dust or haematite staining, is seen along the composition planes of the cross. Minute cracks roughly in a radial pattern are seen at the point of penetration.

Details for two of the crosses are setforth in the following table:

<table>
<thead>
<tr>
<th>Table 28</th>
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<tr>
<td><strong>Interpenetration Twins of Plagioclase.</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Individuals in each arm</th>
<th>Dimensions in microns</th>
<th>Twin Law</th>
<th>Anorthite content (in percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. 1 &amp; 2</td>
<td>672.4 82.0</td>
<td>Albite law</td>
<td>52-53</td>
</tr>
<tr>
<td>Fig. 3 &amp; 4</td>
<td>820.0 131.2</td>
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<td>53</td>
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<tr>
<td>50. 2 &amp; 5</td>
<td>- -</td>
<td>Albite law</td>
<td>50-52</td>
</tr>
<tr>
<td>II. 1 &amp; 1'</td>
<td>262.4 65.6</td>
<td>Carlsbad law</td>
<td>55</td>
</tr>
<tr>
<td>Fig. 1' &amp; 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51 3 &amp; 4</td>
<td>147.6 82.0</td>
<td>Albite law</td>
<td>55</td>
</tr>
</tbody>
</table>

From a study of 28 interpenetration twins of plagioclase, it is observed that only three types of twin laws are involved. They are albite law, carlsbad law and albite-carlsbad complex law. The frequency of twin laws is as follows:

- Albite law 15 - 20%
- Carlsbad law 24 - 32%
- Albite-carlsbad complex law 36 - 48%

Total (28 penetration twins) 75
The pole of the planes of association marked AP in Fig. 50 of the four arms in some cases falls on (021) curve of plate 2 of Reinhard; therefore the plane of association may be said to be parallel to (021). The pole of the plane of association in some other cases do not fall on any curve of Reinhard, and may be said to be not having any crystallographic orientation and may be concluded as being parallel to some irrational pyramid.

Interpenetration twins of both plagioclase and pigeonite have been observed in the section of a small chilled dyke about 10 feet wide occurring about 2 miles northwest of Sivarampet village. In this plagioclase and pyroxene occur as phenocrysts in a fine grained matrix. These two minerals occur as glomeroporphyritic clusters and also as individual grains. The plagioclase is labradorite, averaging about 58% of the anorthite content. Pyroxene is sub-calcic augite and pigeonite. In this the interpenetration twin of pigeonite is observed.

The interpenetration twin of clinopyroxene has been reported by Jaffe (1953) but reported occurrence of interpenetration twin of pigeonite has not been found in literature accessible to the author.

Of the pigeonite cross, one arm is 0.45 mm. in length and 0.15 mm. in breadth while the other is 0.45 mm. in length and 0.125 mm. in breadth. It has the following optical characters:

Colourless, non-pleochroic, positive elongation;

\[ XZ \ 010; \quad Z \ C = 32^\circ; \quad 2V_z = 8^\circ-10^\circ; \quad N_z - N_x \ 0.025. \]

Both twinned grains forming the cross are contact twins with (100
as twin plane and the angle between (100) of one arm and the (100) of the other is 80°. The interpenetration twin has (101) as the twin plane.

In this section is also found an interpenetration twin of plagioclase. It has as its arms two simple twins. One arm is twinned after albite law, while the other is twinned after Carlsbad law, and the angle between the two composition planes of the two plagioclase grains forming the cross is 35°.

From a petrological point of view, Gorai (1951) divides the plagioclase twins into four types of which the interpenetration twins are grouped under the type 4. According to Gorai, the interpenetration twins include twins according to the laws that are restrict to, or characteristic of, the volcanic and plutonic rocks.

But in the above observations, pigeonite which is a product of rapid crystallisation and is restricted to lavas and other relatively quickly chilled rocks occur as interpenetration twin together with the interpenetration twin of plagioclase. Therefore the interpenetration twin of plagioclase which is associated with untwinned and twinned pigeonite appear to be restricted to and characteristic of volcanic rather than plutonic rocks. The complete absence of plagioclase interpenetration in granites supports this view. Therefore, the chilled nature, basaltic texture, occurrence of pigeonite and the presence of the interpenetration twins of both plagioclase and pigeonite suggest that the dykes under study have developed under conditions similar to those attained in the volcanic mode of origin.

An interpenetration twin of augite (Section pl-63), has been recorded, having the following characters:
The two grains penetrating into one another are two stout-twinned grains and the angle between the two composition planes is nearly perpendicular.

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<th>Length (mm.)</th>
<th>Breadth (mm.)</th>
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<tr>
<td>I twinned grain:</td>
<td>1.274</td>
<td>0.273</td>
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<tr>
<td>II twinned grain:</td>
<td>2.048</td>
<td>0.410</td>
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</table>

Colourless, non-pleochroic.

$\mathbf{b = Y; \quad Z \ C = 41^\circ-44^\circ. \quad 2V_z = 38^\circ-41^\circ.}$

$N_z - N_x = 0.0247, 0.0234, 0.0257.$

**Behaviour of Plagioclase and Pyroxene Twins:**

Petrographic variation of the specimens taken across the dyke near Ramapuram temple is shown in tables 22 to 26 and figures 42-46. Table 26 and figure 46 are relevant in the present discussion. The detailed petrographic study of the plagioclase and pyroxene twins have been made in all the sections taken at nearly equal intervals across the dyke from the contact to the centre.

The most striking and consistent feature in all the thin sections of the dyke examined is that the twinned grains occur in clusters. The individual twinned grains in any cluster may all be parallel (Plate XIX, Fig.1, 6), sub-parallel or randomly oriented (Plate XIX, Figs. 2, 3, 4); in a few cases two twinned grains are nearly perpendicular each in touch with the other or partly penetrating into the other (Plate XIX, Fig.5). A few interpenetration twins are observed but are rare. When they occur as parallel or sub-parallel groups they appear as bundles.
(Plate XIX, Fig. 1). They appear to be "pressed" against two "rigid" masses which are plagioclase grains. In such cases the long prisms of pyroxene appear slightly curved or wavy together with the twin planes. The cleavages may become obliterated or may appear to be dwindled off at such portions where they are "pressed".

Twinned grains always occur much larger than the untwinned grains. Clusters of untwinned grains are rare.

A twinned grain may be in contact with an untwinned grain and in such cases the contact may become a twin plane with alternate illumination and extinction of the untwinned grain and one sub-individual of the twinned grain which is in contact with it.

The twin planes are curved in the bent crystals (Plate XIX, Figs. 6 and 7). In a few cases the twin plane is found to be "terraced" or step-like (Plate XIX, Fig. 8).

In a few cases the twin plane appears to be "branched"; that is a twin plane will be straight and continuous and then becomes bifurcated within the grain (Plate XX, Figs. 1 and 2).

The individual twins, most commonly, show only two sub-individuals (Plate XX, fig. 3); occasionally three and rarely four lamellae are seen. In such lamellar twinning the lamella in the middle shows different interference colour while the other two lamellae on either side will have the same interference color but different from that of the middle lamella. Further the middle lamella, has a uniform width but abruptly stops half the way without reaching the other end of the grain, or the middle lamella has a uniform width for some distance and then the width increases or decreases and maintains the uniformity with that changed
Twinning may be developed about a crack, with alternate illumination and extinction of the two parts on either side of the crack. Thus a crack may become a twin plane and it may be straight, curved, sinuous, or irregular.

Twin planes in some grains are marked with yellow or light yellowish brown iron oxide staining, due to which the twinned nature of the grain becomes very emphatic. The untwinned plates are fragmented into a crystal aggregate. The individual grains present sutured and serrated borders with the surrounding grains. Clusters of twinned pyroxene are figured in Plate XX, Fig. 4.

From the figure (46) it is evident that there is a general and progressive decrease in the incidence of plagioclase twinning from nearer the contact of the dolerite dyke with the country rock towards the middle portion. The observation made, in this respect, is in conformity with that made by Ingerson (1952) who explains as follows:

1. Early formed crystals appear to have a greater tendency to twin than do the latter crystals of the same minerals. This is primarily due to the mechanical disturbance and also due partly to the higher temperature;

2. There is a higher incidence of twinning near the contact, which may be brought about by the greater differential stresses to which the growing crystals are subjected.

Ingerson also points out that the same above interpretations hold good in the case of twinning frequency in quartz also and suggests that these interpretations can be extended to different mineral species. But the observation made in this study with respect to pyroxene is exactly opposite of what it is with respect
to plagioclase, as there is a general increase in the incidence of pyroxene twinning towards the middle portions of the dyke. So it is evident that the interpretations made from a study of twinning frequency in plagioclase, and extended to twinning frequency in quartz, do not hold good to twinning frequency in pyroxenes, and hence cannot be generalised to all mineral species.

According to a summarising article by Smith (1962), the following factors make for abundance of twins in feldspar:

1. high temperature of crystallisation;
2. growth from liquid (magma) rather than in solid (in a metamorphic rock);
3. rapid growth;
4. small size of crystals; and
5. euhedral crystals.

All of these factors are consistent with the situation in the dyke under study. The author has been unable to find comparable generalisations concerning the control of the twinning in pyroxene. However with its quite different structure, one can think of no a priori reasons why pyroxene should respond to the above mentioned factors the same way that feldspar does. Most of the twinned pyroxene grains have two sub-individuals. Few grains show irregular polysynthetic twinning with three or the most four lamellae. Plagioclase invariably exhibits very high relative frequency of twinning. Further twinning in pyroxene contrasts very strikingly with the variety and complexity of twinning exhibited by plagioclase. The factors which control the formation of plagioclase twinning are connected with physical, chemical and physico-chemical circumstances which differ obviously in controlling the formation of twinning in pyroxene.
This interpretation at once raises, however, the question why pyroxene twins occur, sometimes abundantly in some rocks, and are rare or absent in others. According to the French theory, as mentioned by Donnay (1943), differences in twinning behaviour or similar minerals are much more probably due to differences in space-lattice structure than to direct influence of external conditions such as temperature. Donnay (1940, 1943) assumes that twinning in plagioclase is a phenomenon of crystal growth and is controlled mainly by the geometry of the space lattice. Exactly the opposite view that the twinning in pyroxene is essentially a secondary phenomenon holds good as is evidenced from the petrographic features of the twinned grains of pyroxene. Of course, it is not known whether the twinning in plagioclase is primary or secondary, and in spite of the investigations by several earlier workers, it is still an open question.

The secondary nature of pyroxene twinning is upheld, because:

(1) there is no regular relation between the distribution of twin lamellae and external morphological form (Figs. 1 and 6 in Plate XIX);

(2) they are associated with bending, twisting or fracturing of the crystal as is so common with secondary twinning (Figs. 1, 6, and 7 in Plate XIX);

(3) the lamellae are not regular and one or two lamellae (of the 3 or 4 lamella present in polysynthetically twinned pyroxenes) terminate abruptly within a crystal independently, without showing any systematic distribution;

(4) the twinned grains clearly indicate stress or strain directed at certain portions and the crystals are disturbed not all along their projected continuation (Figs. 1 & 6, Plate XIX);
(5) the gross outer form of the individual grains, or the aggregate of twinned crystals also clearly reveal the secondary nature of the pyroxene twinning.

In the case of the lamellar twinning in hypersthenes, Henry (1941) observes two types of bending:

(1) simple gliding, with only a movement of molecules in one direction, sometimes accompanied by bending round an axis;

(2) gliding resulting in the twinning of the individuals.

Similarly the polysynthetic lamellae in the hypersthenes of charnockites have been explained by Naidu (1954) as glide twins.

Thus the twinning in pyroxene is regarded as secondary.

Again secondary twinning includes three types, namely,

(1) gliding twins;

(2) transformation twins (Buerger, 1945, p.477); and

(3) "synneusis twins" or the "combination twins" of Ross (1957, p.650).

The third type is much less widely appreciated and is not reported in pyroxenes in the literature accessible to the author; but this genetic type is clearly revealed and prominently displayed by the pyroxene twins in the dyke under study. In the thin sections examined the separate twinned grains are rare or absent. Invariably they occur in glomeroporphyritic clusters with individual twinned grains being in parallel, sub-parallel, or random orientation. It appears that twinning behaviours, crystal habit and the nature of the crystal boundaries are affected differently by crystallisation of pyroxene in an essentially solid medium. The occurrence of pyroxene twins in clusters again
suggests that the pyroxene crystals in a solid state have undergone drifting together in an essentially fluid medium and combination of crystals to form twins. The abundance of Carlsbad twins in igneous plagioclase and their contrasted rarity or absence in metamorphic plagioclase is explained by Vance (1961) as due to their development by synneusis, a process operative exclusively in a fluid medium where free movement of crystals is possible.

Besides synneusis twins, secondary twinning of pyroxene is also represented by glide twinning. The pyroxenes with well-developed deformational fabric, represented by the stress-strain pattern of the pyroxene aggregates with bending, twisting and fracturing of individual grains as well as aggregates, and strongly developed strain shadows, resulting from continuous deformation proceeding simultaneously with crystallisation of the magma, have given rise to the development of secondary twinning. In this the glide twinning is believed to be formed by the stresses set up during contraction with cooling; on slow cooling and with deformation, the atomic layers in the two sub-individuals of the simple twin would have sheared and formed polysynthetic twins, besides their formation by the process of synneusis. The two processes of formation of secondary twinning are mutually exclusive and both processes appear to have operated either simultaneously or one followed by the other. Thus, in contrast to the frequency of plagioclase twinning, a general increase in the frequency of incidence of pyroxene twinning progressively towards the middle portion of the dyke is accounted for. In proposing the above working hypothesis, the author is
aware of the breadth of the problem and the limitations of the data presented. Consequently the conclusion arrived at is tentative and merits scrutiny in the light of more detailed investigation.

PETROCHEMISTRY

The author has made an attempt to discuss the petrogenesis of the M.P.R. dolerites in this section based on the petrochemical evidences. For the last three decades, much work has been done and is also in progress, both on the chemical and experimental side. Since it is difficult to present extensive data for comparison, the author has made a reference to almost all the available literature.

Five chemical analyses of the representative specimens of the members of the dolerites have been made and listed in Table 29, together with their norms and Niggli values.

Graphical Representations:

Thornton and Tuttle (1956) suggested a differentiation diagram in which oxide weight percentages of the various elements are plotted against sum of normative quartz, albite, orthoclase, nepheline, leucite and kaliophylite. This sum is called the "differentiation index" and expresses, numerically the extent to which a rock has approached petrogeny's residue system and also marks the degree of fractionation. It is a useful co-ordinate for variation diagrams and is a measure of the "basicity" of a rock (Thornton and Tuttle, 1960). The method can be used equally well for magmatic series as well as for metasomatic series (Eckelmann and Foldervaart, 1957, p.1255).
Table 29

Chemical Analyses of the Components of Dolerites, their Norms and Niggli Values.

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<td>SiO₂</td>
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<td>48.98</td>
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<td>TiO₂</td>
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<td>Al₂O₃</td>
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NORMS

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#### NIGGLI VALUES.

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1. Olivine dolerite.
   **Locality:** 1 mile West of Ramapuram.

2. Vitrophyric dolerite.
   **Locality:** 1 furlong NE of Sivarampet.

3. Pyroxene dolerite.
   **Locality:** 1 furlong north of Sivarampet.

4. Quartz-dolerite.
   **Locality:** 4 furlongs south of Ramapuram Temple.

5. Micropegmatitic dolerite.
   **Locality:** 2 furlongs south of Ramapuram.

**Analyst:** E.A.V. Prasad.
Fig. 52 is a differentiation index (D.I.) diagram, constructed for the M.P.R. dolerites, which displays some instructive features. Depending on the differentiation index, the M.P.R. dolerites are divided into early, middle, and late-stage dolerites with differentiation index divisions at 20, 30, and 50, as suggested by Wager (1956) and Wilcox and Poldervaart (1958). Na₂O and K₂O show a gradual increase, whereas TiO₂, Al₂O₃, FeO and CaO show decrease from olivine dolerite to dolerite with micropegmatite; with increase in the differentiation index, Fe₂O₃ shows a steady increase up to the middle stages, wherefrom it shows a decline. This curve is convex upward, indicating moderate iron enrichment. MgO curve is steep at the basic end and gradually flattens at the acidic end. SiO₂ gradually increases from early- to middle-stage members, and thereafter shows an abrupt rise in the late-stage dolerites. All the curves are smooth and continuous and the variation of the elements are normal (Nockolds and Allen, 1954) with near-linear increase in SiO₂, Na₂O, K₂O and near-linear decrease in TiO₂, Al₂O₃, FeO, MgO and CaO.

To show the variation in the major elements, Larsen's (1938) variation diagram modified by Nockolds and Allen (1953) has been constructed (Fig. 53), by plotting the metal atoms on the ordinate and the function \((1/3 \text{Si} + \text{K})\cdot(\text{Ca} + \text{Mg})\) along the abscissa. The function varies from -5.810 to +5.977. Si gradually rises up to the intermediate members, wherefrom it shoots up into the acid members. Al shows a decline in the early stages, but later it becomes normal. Same is the case in the Fe also. At the basic end, Mg curve is steep but gradually flattens in the intermediate and acid members. Fe shows a decrease in the early stages, but a sudden decline in the later
CHEMICAL VARIATION DIAGRAM OF M-P-R DOLELITES

DIFFERENTIATION INDEX (Gd+Ad+Gt+Né+Le+Kl) →

Fig. 52
LARSENS CHEMICAL VARIATION DIAGRAM
MODIFIED BY NOCKOLDS (1953)

Fig. 53
stages. Ca also behaves in the same manner. Alkalies increase slowly in the series from the basic to acidic end, with increase in acidity. The Fe curve is slightly above the Ca curve, which is characteristic of the calc-alkaline series. There is only moderate enrichment of iron, followed by silica enrichment in the late stages of differentiation, which is evidenced from the figure 53.

To show the differentiation of suites, Simpson (1954) suggested a diagram in which mafic index, 100 \( \frac{(\text{FeO} + \text{Fe}_2\text{O}_3)}{\text{(MgO + FeO + Fe}_2\text{O}_3)} \) is plotted against the felsic index, 100 \( \frac{(\text{Na}_2\text{O} + \text{K}_2\text{O})}{(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})} \). Wrenn and Poldervaart (1958, p.96) modified this diagram by using atomic weight percent instead of oxide weight percent, and it is shown in Fig.54 for the M.P.R. dolerites. The trend of the M.P.R. dolerites compares favourably with the general trend of average igneous rocks. The plots of olivine- and vitrophyric- dolerites fall in the region of early stage basalts, while pyroxene-dolerite and quartz-dolerite fall in the middle- and late-stage basalts respectively. The plot of the micropegmatitic dolerite falls far away from this trend. The micropegmatitic phase might belong to a later stage in the differentiation series than that reached by the parent rock. Such an explanation was offered by Walker and Poldervaart (1949, p.662), while discussing the petrogenesis of the dolerite pegmatites related to the Karroo dolerites. Simpson's diagram seems to be much useful in establishing the different stages of differentiation.

In order to compare the differentiation trend to the M.P.R. dolerites, with those of other similar suites, \( \text{MgO} - (\text{Fe}^{+2} + \text{Fe}^+) - (\text{Na} + \text{K}) \) diagram (Fig.55) has been constructed which displays
25 OF THE M.P. DOLERITES ON A DIAGRAM OF FELSIC INDEX AGAINST MAFIC INDEX.

Fig. 54
Mg-Fe'' + Fe'' - Na + K DIAGRAM

TREND OF M.P.R. DOLERITES

FIG. 55
the fractionation trend of basaltic magma. This diagram has been useful because of the three components. \( \text{Mg}^{2+} \) is the significant element of the more refractory minerals; \( \text{Fe}^{2+} \) + \( \text{Fe}^{3+} \) the significant element of the medium refractory minerals and \( \text{Na} + \text{K} \) are the significant element of the less refractory minerals. It is evident from the figure that the trend of differentiation of the M.P.R. dolerites is convex upward, displaying moderate enrichment of iron in the middle stages of differentiation, although not to the extent as in Skaergaard.

The trend of the M.P.R. dolerites resembles the Karroo dolerites and dolerites of the Palisades provinces (Walker and Polderwaert, 1949; Hotz, 1953; Hess, 1960). This diagram also displays alkali enrichment in the late pegmatitic phases, termed selic differentiates by Neverberg and Gronger (1960, p.771).

Fig.56, is an alkali enrichment ternary diagram constructed in the three components Ca-Na-Ka. All the plots fall on the sodic side of the median. The trend of the M.P.R. dolerites compares favourably with that of the Skaergaard trend.

Brannmal (1933, p.120) suggested a triangular diagram of normative constituents, Or + Cor - Ab - An + Fem, to express the syntaxis and differentiation. When normative values of the components of the M.P.R. dolerites are plotted in the Brannmal's diagram (Fig.57), the trend follows the trend of Daly's average calc-alkaline rocks.

**Magmatic History of the M.P.R. Dolerites:**

**Parental Magmas:**

Richey and Thomas (1930) and Kennedy (1933) have recognised two fundamental basaltic magma types—tholeiites and olivine
Ca\textsuperscript{2+} - Na\textsuperscript{+} - K\textsuperscript{+} Diagram

Trend of M.P.R. Dolerites.

Fig. 56
ANALYSES OF THE M.P.R. DOLERITES & THEIR TREND ON A TRIANGULAR DIAGRAM
OF NORMATIVE COMPOUNDS (EXCLUDING QUARTZ)

© plots of the M.P.R. dolerites

Fig. 57
basalts, the former giving rise to quartz-bearing members, and the latter to alkaline rocks. For the last three decades, remarkable experimental work is in progress at the Carnegie Institution of Washington and Bowen (1928) is the first to apply physico-chemical principles to magmatic crystallisation.

It is chiefly through the work of Tilley (1950) and Kuno (1957, 1959), tholeiites and alkali-basalts have been distinguished by petrographic means from each other to a fairly reasonable degree. Recently Yoder and Tilley (1962, p.355) have suggested that all the elements for chemical definition and distinction of the two basaltic magma types are present in the system silica-nepheline-forsterite-diopside and redefined alkali-basalts and tholeiites as nepheline-normative and hypersthene-normative basalts respectively.

Fig.58 is a silica-alkalies variation diagram, used by Tilley (1950, p.42) to distinguish the tholeiites and alkali basalts. The M.P.R. dolerite trend coincides with that of the Hawaiian tholeiites. When the M.P.R. dolerites are plotted on the soda-silica variation diagram (Fig.59), the trend coincides with that of the Hebridean tholeiitic series.

Murata (1960) has suggested a new method of plotting the chemical analyses of basaltic rocks by utilising the $\frac{Al_2O_3}{SiO_2}$ ratio as the abscissa and MgO as ordinate. He has demonstrated from this diagram that the two types of basalts- tholeiitic and alkali types- can be effectively separated, forming two separate parallel trends. When the analyses of the M.P.R. dolerites are plotted in the Murat's diagram (Fig.60), the plots fall close to the tholeiitic series.
SILICA : ALKALIES DIAGRAM (AFTER TILLEY 1960)

O Plots of the M.P.R. Dolerites.

Fig. 58

SiO₂ - Na₂O DIAGRAM

O Plots of M.P.R. Dolerites.

Fig. 59


\[
\frac{Al_2O_3}{SiO_2} - M_{2O} \text{ DIAGRAM (AFTER MURATA 1966)}
\]

\( O \) plots of the dolerites of the M-P-R area

**Fig. 60**
High SiO$_2$, low Na$_2$O, K$_2$O and MgO, micrographic intergrowth of alkali feldspar and quartz, high per cent of iron ores, coupled with the definite chemical trends point toward tholeiitic affinities. This view is further substantiated by the presence of unzoned olivines, augite and orthopyroxene. This is in accordance with the observation of Wilkinson (1956, p. 735, 737-738).

**Differentiation:**

Fractional crystallisation is by far the most important process which plays an important role in the differentiation of M.P.R. dolerites.

The mineral constituents that participate in the process of differentiation may be described under two heads:

1. Felsic group comprising of calcio-plagioclase, quartz and orthoclase;
2. Mafic group comprising of olivine, orthopyroxene, pigeonite, clinopyroxene, iron ore, amphibole and biotite.

Olivine and pyroxene are the early minerals that separate from the crystallising magma of the tholeiitic type, giving rise to a residual liquid enriched in silica and alkalies, and the FeO/MgO ratio increases notably. As such, the olivine and pyroxenes are enriched with iron, whereas the early formed plagioclase is enriched in calcium, whereby the residual liquid shows impoverishment in MgO, CaO and Al$_2$O$_3$. Due to the early crystallisation of olivine, generally in excess of the stoichiometric proportion, has brought about a sharp increase in SiO$_2$, a sharp decrease in MgO and a gradual decrease in FeO as crystallisation
has proceeded. From the felsic group, lime-soda feldspar separates early in the crystallisation sequence, as is evident from Bowen's (1913) experimental studies. This brings about a gradual increase in SiO₂, Na₂O, K₂O with a decrease in CaO and Al₂O₃.

Among the felsic group, quartz and orthoclase and among the mafic group, hornblende and biotite appear late in the crystallisation sequence.

The appearance of iron ore twice in the crystallisation sequence demands explanation. It appears as early picotite and as late titano-magnetite or ilmenite, which reflects in the chemical composition. In the early stages, there is a decrease in FeO and Fe₂O₃, followed by a prolonged and gradual increase in FeO, Fe₂O₃ and TiO₂ during the middle stages. A sharp fall appears in these constituents during the late stages of crystallisation.

It may be quite probable that high proportion of volatiles have played an important role in the formation of the dolerite pegmatities. Presence of hornblende and chlorite may furnish an evidence in support of the presence of high water content, in the late stages. The liquid which is enriched in volatiles would reduce the viscosity and may in turn crystallise as a coarse rock. Similar explanation has been offered by Tomkeieff (1929), Walker and Poldervaart (1949) and Mc Dougall (1962) in respect of dolerite pegmatites of the Whin Sill, the Karroo dolerite pegmatites, and Tasmanian dolerite pegmatites respectively.

The presence of quartz and iron ore in the late stage micro-
pegmatitic dolerites needs explanation. Walker (1953, p.58),
while dealing with the quartz-dolerite sills of central Scotland, attributes the granophyric phase in the end stages to the elimination of iron-oxides and titania during the earlier stages. Phemister (1934) attributes that the oxidised state of the iron in the dolerite pegmatite prevented much of it from forming pyroxene and thereby led to the crystallisation of considerable amount of quartz and iron ore. This explanation may seem to be reasonably applicable to the M.P.R. micropegmatitic dolerites.

The trend of M.P.R. dolerites resembles the Skaergaard trend (Wager and Deer, 1939), Karroo dolerite and Palisades province dolerite trends (Walker and Folderveart, 1949; Hotz, 1953; Hess, 1960).

To sum up, it may be concluded that there is moderate iron enrichment for the major part, followed by enrichment of silica and alkalies, which crystallises as sodic micropegmatite. This has been evidenced from Fig. 55, which has already been alluded in page 157. It may also be pointed out that crystallisation fractionation was more pronounced in the ferro-magnesians than in the plagioclase series for a major period.

Thus fractional crystallisation may be responsible for the formation of the M.P.R. dolerites, whose trend is similar to that of tholeiitic magma type. The ultimate source of the magma is not known.