A CHEMICAL AND PETROLOGICAL STUDY OF SOME DYKE ROCKS IN THE PRE-CAMBRIAN (CUDDAPAH TRAPS)*

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INTRODUCTION

The suite of traps that forms the subject of this paper occurs as intrusions in the Vempalle limestones and the Tadpatri shales of the Lower Cuddapahs in the Pulivendla taluk of Cuddapah, the Tadpatri taluk of Anantapur and the Dhone taluk of Kurnool. They were collected from a large area in the Cuddapah basin extending from Betamcherla in the Kurnool district to near Vempalle in the Cuddapah district, so that they are representative of the numerous sills that traverse the area. The collection includes also two or three specimens of trap rocks intrusive into the Archaean gneisses near Tiruttani in the Chittoor district. Judging from petrological characters the Tiruttani rocks are probably of the same age as that of the Cuddapah traps, but we have no stratigraphical data to determine the relationship between these two.

These traps form numerous sills and are occasionally lenticular though generally regular and of uniform thickness. The thicker sills often contain intercalations of Vempalle limestones or Tadpatri shales. They are fine-grained and of uniform grain, being composed generally of labradorite feldspar, augite and micropegmatite with subordinate biotite, magnetite, epidote, glass and secondary alteration products. It is only rarely that they exhibit any difference in the grain-size between the centre and the margins. Such a sill, composite in nature, is seen passing through Pulivendla as noted by Dr. C. S. Fox. The central portion of the sill is very basic and contains coarse grains of abundant olivine, augite, enstatite, serpentine, a little feldspar, iron ore and brown mica and thus differs from the layers above and below it, which are dolerites without olivine. The trap sills are fairly conspicuous because of their forming dark low ridges which are marked by brown coloured soil and thorny shrubs. In some places the rocks show the presence of amygdaloidal cavities filled up with secondary infillings and

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are also traversed by veins of epidote which shows up well because of its marked green colour.

The Cuddapah traps have not been studied by any one so far in any detail. As early as 1890, P. Lake described briefly the olivine-bearing traps of Juturu. Subsequently (Sir) T. H. Holland (1897 B) classified "some dykes of basic igneous rocks which break through the 'pyroxene granulites' and which he regarded as the dyke-representative of the Cuddapah lava flows" and gave a mineralogical description of these rocks. More recently (Sir) C. S. Fox (quoted by A. L. Coulson, 1934) and A. L. Coulson (1933, 1934) have referred to these traps only incidentally in their description of asbestos and barytes occurrences in the Cuddapah formations. No chemical data are available except for the two modern analyses given by A. L. Coulson in his memoir on asbestos (1934) and the two much earlier analyses given by Holland in 1897.

In the following pages are described the petrographic and chemical characters of these trap rocks. The chemical analyses were done in the Geology Department of the Presidency College, Madras. The analytical results are subjected to the petrochemical studies introduced by Prof. Dr. P. Niggli of Zürich. The plagioclase feldspars and pyroxenes have been studied by the Universal Stage methods, which include the twinning laws and other optical characters. The textural relationship exhibited by the rocks has also been studied in detail, which showed that these minerals have crystallised simultaneously to a large extent.

It has been possible from these studies to trace the chemical characters of these traps, the trends of differentiation of the magma in the evolution of the various types, and the sequence of crystallisation of these traps in the differentiation history. The general results show that the magma which gave rise to the Cuddapah traps is of calc-alkali or tholeiite type. The Cuddapah traps are similar in many respects to the 'Newer dolerites' of Singhbum, Keonjhar and other areas in the Iron ore series of Orissa and Singhbum. They are also similar to the Gwalior traps in the nature of their pyroxenes, but are lower in alkalis and higher in alumina. They differ from the Deccan traps, the Karroo dolerites, the Tertiary dykes of the Island of Mull, the Whin Sill and the Palisades diabase in containing no pigeonite.

MINERALOGY

Although uniform in their mineralogical characters and chemical composition the trap rocks under study may be divided into three textural groups.
1. **Fine-grained variety.**—This varies from dolerite to basalt and is usually dark in colour, compact and also highly vesicular.

2. **Medium-grained variety.**—This type is mostly black to dark-grey in colour and is represented by quartz dolerite.

3. **Coarse-grained variety.**—This type, formed by the slow cooling of the magma, is found to occupy mostly the middle portions of the dykes or sills. It includes olivine dolerites and quartz dolerites.

   The grain-size of the minerals composing the rock varies on the average from 0.2 mm. to 0.5 mm. in the fine-grained varieties, and 0.5 mm. to 1 mm. in the medium-grained rocks, to more than 1 mm. in the coarse-grained types. The petrological characters of the various specimens collected are fairly uniform, but some of the vesicular basalts differ from the normal types in containing much palagonite, often to the exclusion of pyroxene.

**Microscopic characters.**—One striking feature observed under the microscope is the relationship between feldspar and pyroxene. Small laths of feldspar are enclosed either partly or wholly in elongate or stumpy prisms of augite or the augite may be developed in irregular form in the interstices of the penetrating plagioclase laths. Besides this marked doleritic and subophitic development of plagioclase and augite, ophitic, inter-granular and intersertal textures are also noticed. In the olivine-bearing types, olivine is enclosed by large prismatic crystals of pyroxene. Micropegmatite and quartz occur occasionally in the interstices of the feldspars and augites. In the fine-grained types these are represented by a vague mesostasis of weakly refracting glass with grains of opaque magnetite and imperfectly developed microlites of feldspar. Generally the magnetite is distributed evenly throughout the rock. Biotite and hornblende occur as alteration products. Apatite and specks of pyrite are the usual accessories. The rocks have been subjected to secondary alteration such as palagonitisation, sericitisation, serpentinisation and kaolinisation.

   The vesicular and amygdaloidal basalts have their vesicles filled up by palagonite and calcite and occasionally also by quartz instead.

   In the following paragraphs the feldspars, pyroxenes, micropegmatite and other minor constituents are described.

**Plagioclase.**—Plagioclase is the dominant constituent of all the normal rocks examined, except in the olivine-bearing type in which it is subordinate in amount to olivine and pyroxene. Megascopically the feldspars are bluish to dark-grey in colour. The crystals exhibit generally polysynthetic twinning,
but simple twinning is also met with and occasionally untwinned plagioclase laths are found in association with quartz pieces.

\[ k = \frac{2 \text{ alk}}{\text{al} + \text{alk}} \]  

Fig. 1

The composition of the plagioclase feldspars and the twinning law obeyed by them were determined on the Federov Universal Stage. The anorthite content of the feldspars is found to vary from 75 to 30 per cent. Zoning is developed rather inconspicuously in most of the larger laths, being represented by a slight variation in the extinction angle towards the interior. In some cases, however, prominent zoning is observed, the composition passing from labradorite with about 60 per cent. anorthite to a thin external layer of andesine or oligoclase. The average composition of the plagioclase
is deduced to be near about 55 per cent. anorthite and the first plagioclase to crystallise from the melt of this composition would contain about 75 per cent. anorthite. The feldspar phenocrysts found in the vesicular basalt (Type D, which is described later) do not show any marked zoning, the composition of these and of the groundmass feldspars being more or less the same. It is probable, therefore, that the early formed plagioclase has been ‘made over’ to the composition of the later feldspars with the result that zoning has disappeared. The plagioclases exhibit predominantly twinning on (010) as the composition plane of different lamellae with Albite and Carlsbad laws occurring frequently.

The composition of plagioclase can also be deduced from the chemical analysis of the rock, if the calculated $k$ and $\frac{2alk}{a_l + a_k}$ values (Table V) are plotted in Niggli’s diagram (Fig. 1). It will be seen from the diagram that the nature of plagioclase deduced from the chemical composition of the rock agrees fairly well with optical determinations. It may be pointed out that the average falls close to 55 per cent. anorthite which is also the average arrived at from optical investigations. A and E have a higher anorthite content than the rest, but from the description of these rocks given elsewhere it will be seen that A is a highly basic rock belonging definitely to an earlier period in the history of consolidation, while E, if not so very basic, is highly feldspathic and also altered, which is reflected in the higher anorthite content of the rock.

Pyroxene.—The pyroxenes are found to belong mostly to the monoclinic variety. In the olivine-bearing types, however, rhombic pyroxenes were also noted in addition. The monoclinic pyroxene is usually augite with large optic axial angle; the other variety of monoclinic pyroxene, pigeonite with small optic axial angle was not detected in any of the analysed specimens but was present in slide No. 8 (1 mile east of Vemula) in small amount.

The monoclinic pyroxene is generally colourless in thin sections, but shows a slightly yellowish or greenish tinge; some grains are also pinkish, indicating that they are titaniferous. The mineral occurs in elongated or stumpy prisms generally twinned on (100) showing sometimes salite and herringbone structures. It may also be irregular in shape, with two sets of cleavage. The optic axial angle varies from $40^\circ$ to $56^\circ$ and $Z \wedge C$ from $36^\circ$ to $46^\circ$.

In the olivine-bearing types the rhombic pyroxene occurs in irregular form, intergrown with olivine and monoclinic pyroxene and is colourless.
The optic axial angle (negative) in the plane parallel to (010) varies from 79° to 85°. From this value a composition of $\text{En}_{81} \text{Fs}_{19}$ is deduced from Burri's diagram (p. 181, 1941) for the rhombic pyroxene.

Comparative study of the pyroxenes found in this ancient intrusive rock with those in the basic rocks from India and from other parts of the world is interesting. Dr. L. A. N. Iyer (1932) who investigated the 'Newer dolerites' of Bihar and Orissa found that the pyroxenes in them have a larger optic axial angle, varying from 56° to 68° but has not recorded any pyroxene of small optic axial angle. Dr. M. S. Krishnan (1936) in his studies of the 'Newer dolerites' of Keonjhar State, Bihar and Orissa, did not report the presence of pigeonite in the dolerites and basalts, whereas in the norite dykes he was able to distinguish pyroxenes of small optic axial angle. In his paper on the Gwalior traps M. P. Bajpai (1935) has not reported the optic axial angles of augites seen in the slides. P. R. J. Naidu* found that the 'abnormal' dolerite dykes cutting the charnockite areas of Halagur and Doddkanya, Mysore, contain pigeonite. The pyroxenes of the Deccan traps have generally a small optic axial angle and belong to the pigeonite group as pointed by H. S. Washington (1922) and L. L. Fermor (1925). The Whin Sill (Holmes and Harwood, 1928), the Karroo dolerites (Daly and Barth, 1930, and Walker and Poldervaart, 1940) and the New Jersey diabases (Walker, 1940) exhibit characters similar to each other in having all the three pyroxenes—hypersthene, augite and pigeonite. In all these cases, there is a complementary relationship between hypersthene and pigeonite. In his latest paper on the 'Pyroxenes of common mafic magmas' H. H. Hess (1941) has come to the interesting conclusion that the complementary relationship is due to the inversion of the lime-poor ortho-pyroxene to pigeonite at $\text{En}_{70} \text{Fs}_{30}$, so that for any ratio less than 7:3, pigeonite takes the place of the ortho-pyroxene.

This study shows that the Cuddapah traps contain predominantly monoclinic pyroxenes with large optic axial angle. The dolerites of later ages appear to contain all the three pyroxenes, pigeonite being dominant in the normal Deccan traps. In view of the nature of the pyroxenes in these rocks, it would be pertinent to compare the normative composition and the metasilicate proportion of pyroxene, calculated from the average chemical composition with those of other rocks and see how this important difference can be accounted for (see Table I). The diopside and hypersthene molecules of the average Cuddapah traps and 'Newer dolerites' are similar except

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* Current Science, 1943, 12, 115.
for a slightly higher content of these in the latter. The Karroo dolerites are also similar to the above dolerites in their containing more hypersthene than diopside. But, in contrast to this, the Deccan trap shows equal amounts of both these molecules. The Whin Sill, though containing more hypersthene than diopside, shows less of both these molecules than the other rocks.

### Table I

The normative composition of Pyroxenes in the Cuddapah traps and other dolerites and basalts

<table>
<thead>
<tr>
<th></th>
<th>D</th>
<th>H</th>
<th>CaSiO₃</th>
<th>MgSiO₃</th>
<th>FeSiO₃</th>
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<tbody>
<tr>
<td>A</td>
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<td>20.91</td>
<td>14.5</td>
<td>67.8</td>
<td>17.7</td>
</tr>
<tr>
<td>B</td>
<td>13.82</td>
<td>13.74</td>
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<td>24.26</td>
<td>12.36</td>
<td>17.16</td>
<td>21.24</td>
</tr>
<tr>
<td>E</td>
<td>12.32</td>
<td>23.09</td>
<td>16.45</td>
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<tr>
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<td>41.8</td>
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</tr>
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<td>44.1</td>
<td>28.4</td>
</tr>
<tr>
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<td>46.6</td>
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A to G. Cuddapah traps.

I. Average of 8 analyses of Cuddapah traps.
II. Newer dolerite. Average of 3 analyses of Newer dolerites, Singhbhum (L. A. N. Iyer, 1932) and 2 of Keonjhar State (M. S. Krishnan, 1936).
III. Average of 11 analyses of Deccan traps (H. S. Washington, 1922).
IV. Average of 5 analyses of Karroo dolerites (Daly and Barth, 1930).
V. Average of 6 analyses of Whin Sill (Holmes and Harwood, 1928).
VI. Average New Jersey basalt (Anderson, 1940).

The metasilicates in the averages of these rocks are remarkably uniform in showing a lower proportion of CaSiO₃ and higher proportion of MgSiO₃, while FeSiO₃ is intermediate between these values. On a careful scrutiny it would appear that there is a reciprocal relationship between MgSiO₃ and FeSiO₃, for a decrease in MgSiO₃ results in the increase of FeSiO₃ but such a notable change is not observed in CaSiO₃. The explanation for this can be had from Fig. 2 which shows that pyroxenes of mafic magmas become enriched in iron and correspondingly impoverished in magnesium.

Thus, in view of the absence of any marked difference in the normative composition of the pyroxenes of the various rocks compared with the Cuddapah dolerites, the metasilicate proportions of the rocks analysed were plotted in the above figure. All except type A fall above the cotectic line.
This type is rich in olivine and carries rhombic pyroxene. A study of the thin section goes to show that the rhombic pyroxene was the first to crystallise. The clino-pyroxene joined later and both crystallised out before the rhombic pyroxene reached the composition En_{70} Fs_{30}. In all the other rocks only one pyroxene was distinguished and the points for these rocks lie above the cotectic line. To account for the presence of only one pyroxene it could be reasonably supposed that the degree of reaction obtained between the melt and the crystals suspended in it was such that the melt never reached the cotectic line and this process might have been greatly assisted by the volatile constituents of the magma.

**Pyroxene-Feldspar Relations and the Order of Crystallisation**

To describe the different types of textural features in relation to the pyroxenes and feldspars various names have been proposed by different writers. Kroksström (1933) has proposed four names, namely, ophitic, sub-ophitic, doleritic and sub-doleritic. The ophitic and sub-ophitic textures in basaltic rocks indicate that the feldspars are of earlier crystallisation while...
the doleritic and sub-doleritic textures point to the simultaneous crystallisation of these minerals.

In the Cuddapah traps, the pyroxenes are generally larger in size than the plagioclases. The shapes of these pyroxenes are to a great extent determined by those of the adjacent feldspar laths. Sometimes the pyroxenes are also sub-idiomorphic with a roughly prismatic habit. Besides these, in some slides ophitic and sub-ophitic textures in the restricted sense of Krokström are also found, the pyroxenes then filling narrow interstices between two neighbouring feldspars, and different pieces over wide areas showing simultaneous extinction, with similar orientation or optical continuity. The pyroxenes also enclose completely numerous small laths of plagioclase showing that they are definitely later than the plagioclase in crystallisation.

Barth (1936) has discussed the crystallisation process of basalt and suggested that the initial composition of the magma determines whether pyroxene or plagioclase is the first mineral to crystallise. When crystallisation of the first mineral is going on, the melt moves towards the boundary surface where simultaneous crystallisation of both minerals would take place. Barth has deduced, from a study of the plateau-basalts which show unequivocally simultaneous crystallisation of pyroxene and plagioclase, this boundary surface in a tetrahedron with the normative minerals $ab$, $an$, $di$ and $hy$ at the corners. The position of the boundary surface is got from the sum of $ab' + 2di' + 2.3hy'$, which is called the $f(norm)$. If the $f(norm)$ is near about 123 the basalt falls on or near about the boundary surface and simultaneous crystallisation is to be expected. If the norm is smaller or greater than 123 the basalt lies in the plagioclase field or in the pyroxene field respectively. The $f(norm)$ values for the Cuddapah traps and for the other basalts compared with them are given in Table II.

It will be seen from Table II that the $f(norm)$ is around 123 for all types except A, B and E which have a higher or lower value. Type A is a rock of ultrabasic composition and from an examination of the thin section it is clearly seen that olivine and pyroxene are earlier than the plagioclase which is subordinate in amount and occupies the interstices between these minerals. In the rock designated B the pyroxenes are intergranular and interstitial to the feldspars which penetrate the former so that we can conclude that the feldspars crystallised earlier. The high percentage of alumina in this rock results in an excess of feldspar which causes crystallisation in the feldspar field itself. As has already been mentioned, the rock E shows high alumina percentage and the feldspars are extensively kaolinised so that the high per-
### Table II

$f'(\text{norm})$ for Cuddapah and other traps

<table>
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<tr>
<th></th>
<th>$a'%$</th>
<th>$b'%$</th>
<th>$c'%$</th>
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<td>E</td>
<td>23.8</td>
<td>32.5</td>
<td>24.2</td>
<td>117.0</td>
</tr>
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<td>F</td>
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<td>27.3</td>
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</table>

A to II. Cuddapah traps.

II. Average of B to II.

III. Average of 11 analyses of Deccan traps (Washington, 1922). As given by Barth (1936), Tab. 3, p. 332.

IV. Average of 11 analyses of Deccan traps (Washington, 1922). As given by Barth (1936), Tab. 3, p. 332.

V. Newer dolerite. Average of 3 from Singhbhum (L. A. N. Iyer, 1932) and of 2 from Keonjhar State (M. S. Krishnan, 1936).

VI. Whin Sill. Average of 6 analyses by Harwood (Holmes and Harwood, 1928).

VII. Karroo dolerite. Average of 4 analyses (Daly and Barth, 1930). As given by Barth (1936), Tab. 3, p. 332.

VIII. Average New Jersey basalt (Anderson, 1940).

Percentage of alumina may partly be due to alteration. But from the nature of the rock it can be said that even though some feldspars may have been precipitated first the bulk of them crystallised approximately simultaneously with the pyroxenes.

From these studies we can conclude that during the earlier stages of crystallisation—excepting in type A—the feldspars crystallised to begin with, but were very soon joined by the pyroxenes so that in all the normal types the two minerals have crystallised simultaneously.

**Micropegmatite.**—There is some acid material in these basic dykes in the form of micropegmatite, quartz and acid glass, which are found in the interstices, forming a mesostasis to the earlier formed feldspars and pyroxenes; sometimes they may also form mesoscopic patches.

This acid material is considered by most petrologists as the last phase in the consolidation of the magma. It is present in many basic rocks in India and elsewhere. As early as 1897, Holland discussed the origin of
microppegmatite in the basic dykes of the Madras Presidency including those of Cuddapah age and concluded that the microppegmatite "is really original, the last phase in the consolidation of the rock" (p. 34, 1897 A).

Bowen (pp. 70-74, 1928) considers that quartz or acid residue in basic rocks is due to the early separation of olivine in excess of its stoichiometric proportion. But Fenner (1929 and 1931) objects to this theory on the ground that the earlier ferromagnesian silicates contain an excess of magnesia, while the residual liquid gets enriched in iron so that magnetite, pyroxene and feldspar crystallise during final stages. So he concludes that microppegmatite does not normally result from the process of crystallisation-differentiation, but is a secondary product of hydrothermal activity after the rock has completely solidified. Kennedy (1933) advocates two distinct types of basaltic magmas, viz., tholeiitic and olivine-basaltic types, and considers that the tholeiitic magma, represented by most plateau-basalts gives rise, on differentiation, to a liquid of acid composition and that the olivine-basalt (oceanic basalt) magma gives rise always to a liquid of feldspathoidal composition poor in quartz. The Cuddapah trap would fall under the tholeiitic type as will also be pointed out later. The tholeiitic type does not seem to have any significance in space and geological time as it is found in various ages in both fissure and central eruptions.

Minor Constituents

The other constituents seen in these rocks are biotite, amphibole, glass, chlorite, magnetite, hematite, epidote and clino-zoisite, apatite and pyrite with such secondary products as sericite, kaolin and calcite. A short description of the more important of these is given below.

Glass.—In all the fine-grained types the glass forms a mesostasis to the main constituents. It is colourless, light brown or dark in appearance and in almost all cases wholly devitrified, containing acicular crystals and microlites as also small rounded grains of magnetite.

Chlorite.—Both penninite and delessite are distinguishable. Penninite is greenish or bluish green in colour and weakly birefringent with 'ultra blue' interference colours. Delessite occurs in fibrous sheaves with positive elongation of the fibres, straight extinction and low birefringence. It is pleochroic according to the general scheme:

\[ Z = Y = \text{Green}; \quad X = \text{Straw yellow} \]

Iron ores.—Magnetite is found in all the rocks as an accessory mineral. It is in the form of large grains, sometimes with crystal contours and sometimes in granular clusters. The great part of this mineral is of an earl
generation, but in some cases evidence of late crystallisation is also found. The presence of leucoxenic material in some of the sections shows that part of it may be titaniferous.

_Epidote and Clinozoisite._—The epidote aggregates consist of minute grains recognised by their high refringence and birefringence. They are strongly pleochroic, from very pale green to yellowish green. The clinozoisite is colourless to pale green and similar to epidote but shows very low birefringence. It forms granular aggregates mostly derived from the alteration of feldspars.

**Petrographical Description and Chemical Analyses of the Cuddapah Traps**

Seven representative specimens of traps from different localities in the area were chosen for chemical analyses so as to cover the general types encountered. The analytical results and norms are given in Table III. The rocks are arranged in the order of increasing silica percentage but not necessarily in the order of increasing acidity as represented by saturation. The analysed types are briefly described below.

A. **Picrite (Hornblende-peridotitic).**—The rock is coarse-grained and dark in colour and is very largely made up of olivine and pyroxene. Olivine (0.2-0.9 mm.) is colourless and mostly rounded in appearance with characteristic 'mesh' structure having an optic axial angle (2V) of +84° to +88°. Both ortho-pyroxene and clino-pyroxene are encountered. The ortho-pyroxene is enstatite occurring as large individuals (1 to 2·1 mm.) of irregular shape. The interference colours are 1st order grey to white and the optic axial angle (2V) in the plane perpendicular to b-axis is −82° to −84°. The clino-pyroxene (1 to 2·3 mm.) is intergrown with ortho-pyroxene and is mostly colourless, often with a yellowish tinge. The optic axial angle is about +50° to +55° while the angle Z/A C varies from 36° to 38°.

The plagioclase which is subordinate in amount is largely altered and could not be determined, though showing broad lamellae. From Niggli's diagram and from the norm, the composition is deduced to be 62 per cent. anorthite.

There are, in addition, alteration products, such as magnetite, serpentine, brown mica, sericite, kaolin and chlorite.

The mode of the rock is given below:

<table>
<thead>
<tr>
<th>Olivine</th>
<th>34.3</th>
<th>Chlorite and serpentine</th>
<th>17.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxene (ortho &amp; clino)</td>
<td>20.3</td>
<td>Biotite</td>
<td>4.4</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>18.6</td>
<td>Magnetite</td>
<td>4.3</td>
</tr>
</tbody>
</table>
When the mode is compared with the norm, it will be seen that the amount of olivine actually present in the rock is less than the normative amount. The pyroxene and feldspar are also less than the normative percentages. But the modal magnetite is higher. Chlorite, serpentine and biotite make up this deficiency between the mode and the norm.

B. Pyroxene dolerite (Normalgabbroid, c-gabbroid).—This rock is medium-grained and compact and bluish to dark-grey in colour and is made up of bluish plagioclase, dark dull pyroxenes and magnetite. The plagioclase is seen in small slender laths (0·2 by 0·8 mm.) developed in sub-ophitic relationship to pyroxenes. The feldspar is mostly labradorite with an anorthite content of 60 to 70 per cent.

The augite is always irregular in shape and faintly pinkish in colour with very weak pleochroism in yellowish or greenish tinges. The optic axial angle varies from + 41° to + 45° while the angle Z A C varies from 39° to 43°.

Chlorite, magnetite and sericite and kaolin occur as alteration products. Apatite is rarely found.

The mode of the rock is as follows:

| Plagioclase | 44·2 | Magnetite | 9·2 |
| Pyroxene   | 22·5 | Sericite  | 5·5 |
| Chlorite   | 18·8 |

When the mode is compared with the norm it is seen that the amounts of feldspar and pyroxene are lower in the mode than in the norm. This we can expect from the alteration of the minerals.

C. Dolerite (normalgabbroid; c-gabbroid).—The rock is dark-grey in colour, composed of greyish feldspars, dark ferromagnesians and a few pieces of magnetite. The plagioclase feldspars make up the bulk of the groundmass in the form of small laths (0·15 to 1·4 mm.) developed in sub-ophitic relationship to the pyroxenes which they penetrate from the edges and make the pyroxenes angular. A composition of about 55 per cent. anorthite is deduced from both Niggli's diagram and the norm. They could not be determined on account of the alteration suffered by them.

The augite is colourless, occurring as large crystals twinned on (100) and encloses small laths of twinned plagioclase in addition to showing a marked doleritic structure. The optic axial angle (2V) in the plane parallel to (010) varies from + 44° to + 47° while Z A C in the same plane is 40° to 42·5°.
Micropegmatite and quartz pieces are also seen in the slide. As secondary minerals, magnetite, chlorite, kaolin, sericite and calcite are seen.

D. Vesicular basalt-porphyry (Natronlamprosyenitisch).—This is a dark-coloured rock with porphyritic crystals of feldspar embedded in a groundmass of chlorite and small feldspars of the same character. The rock is highly vesicular and the vesicles are filled up by dark, friable, chloritic material which has a dirty-green colour. Inclusions of calcite and a dark-green or yellowish green mineral, not scratched by pen-knife, are seen in the chlorite.

The porphyritic plagioclases twinned according to Albite-Ala and Ala (Es) are found either as rectangular tables or as thick elongated prisms. The groundmass plagioclases are in the form of small laths and exhibit twinning after the same laws. The composition is 33 to 40 per cent. anorthite.

Clinozoisite and calcite are found associated with chlorite as they are the result of the alteration of feldspar. Clinozoisite, embedded in palagonite, is twinned on (100) showing the characteristic section of crystals of monoclinic symmetry. The extinction angle with reference to c-axis varies from 4° to 8°.

E. Quartz-dolerite (Miharaitisch).—This is a medium-grained rock composed of greyish plagioclase and dark ferromagnesian minerals.

Plagioclase is the most abundant mineral in the rock, giving lath-shaped sections. It is usually much altered to kaolin and sericite.

The pyroxenes, often twinned on orthopinacoid, are irregularly shaped and sometimes prismatic and short. They are pale greyish yellow to colourless. The optic axial angle (+2V) in the plane parallel to (010) is from 52° to 56°. The angle between the axis of minimum elasticity and the vertical crystallographic axis is about 39°. Some of the pyroxenes are altered to serpentine.

Quartz and micropegmatite are intergrown with the feldspars. Some of the quartz may be of secondary origin on account of kaolinisation of feldspars. The minor constituents are magnetite, biotite and chlorite.

F. Fine-grained Basalt (Melagabbrrodioritisch).—This is a fine-grained cryptocrystalline dark-coloured rock composed of minerals indistinguishable even with the help of a good pocket lens. The rock is merocrystalline under the microscope with imperfectly developed microlites of plagioclase embedded in a mosaic of pyroxene, palagonite and glass. Twinning is imperfectly developed. The composition is deduced as 39 per cent. anorthite from Niggli’s diagram. The pyroxenes are seen as small rounded or rectangular,
Chemical & Petrological Study of Dyke Rocks in Pre-Cambrian

pale yellow to colourless pieces with a tendency to be grouped in aggregates. Some rectangular prisms show simple twinning.

Magnetite occurs as relatively larger grains and enclose feldspars and pyroxenes. They are distinctly later than these minerals in consolidation. A few pieces of dichroic haematite are also seen.

The interstices of all these minerals are filled up by palagonite, ill-defined glass and chalcedony. A few pieces of zoisite and calcite are also noticed.

G. Quartz-dolerite (Miharaitisch).—This is a medium-grained dark-grey trap composed of grey plagioclase and dark ferromagnesian minerals. It shows two thin veinlets perpendicular to each other, consisting of palagonite which pass from one piece of chlorite or amphibole to another through feldspathic and micropegmatitic portions. It appears to have been formed as veins from magmatic fluids during the late stages of activity.

The plagioclases occur as laths 3 to 7 mm. in length with ill-defined relationship to pyroxene. They show twinning after Albite, Carlsbad or Albite-Carlsbad law and contain between 54 and 70 per cent. of anorthite. Zoning as well as secondary alterations are observed.

The augite is colourless and non-pleochroic often exhibiting simple twinning on the orthopinacoid. The optic axial angle is $+49.5^\circ$ and $Z \cdot A \cdot C$ is $46^\circ$.

Micropegmatite generally fills the interspaces between pyroxenes and feldspars and is composed of quartz and feldspar, intergrown micrographically. The quartz carries inclusions of bluish crystals, probably patite and numerous minute dark inclusions.

As secondary alteration products, hornblende, biotite, iron ore and chlorite are noticed.

The mode of the rock is given below:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>37.6%</td>
</tr>
<tr>
<td>Chlorite and Amphibole</td>
<td>16.9%</td>
</tr>
<tr>
<td>Micropegmatite</td>
<td>8.3%</td>
</tr>
<tr>
<td>Magnetite</td>
<td>2.5%</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>33.5%</td>
</tr>
<tr>
<td>Biotite</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

The modal feldspar and pyroxene are less than the normative amounts on account of the alteration of these minerals to secondary products.

General Review of Chemical Composition

Having made a petrographical study of the traps we can proceed to review their general chemical characters and compare them with well-known types such as the plateau-basalts and tholeiites from India and elsewhere.
Considering the analyses A to II (Table III) it is seen that type A is distinctly different from the others. Its silica content is lowest and alumina is less than in the other rocks. The iron-oxides present are about normal to basalts, with ferrous oxide dominating over ferric; magnesia is decidedly high while

### Table III

**Analyses of the Cuddapah Traps**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
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<tr>
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| Sp. Gr. | 29.5* | 29.5* | 29.0* | 29.6* | 29.3* | 29.5* | 30.75* |
| Temp. C | 100-17 | 100-35 | 100-05 | 100-46 | 100-47 | 100-49 | 100-78 | 100-05 | 100-29 |

**Basis**

- **Cp** .. 0.55 .. 0.29 .. 0.29 .. 0.56 .. 0.29 .. 0.28 .. 0.29 .. 0.29 .. 0.29
- **Kp** .. 1.00 .. 1.38 .. 2.44 .. 2.43 .. 2.41 .. 4.21 .. 2.04 .. 0.70 .. 2.47 .. 2.08
- **Ne** .. 5.98 .. 14.65 .. 12.16 .. 20.87 .. 10.44 .. 17.26 .. 13.91 .. 15.33 .. 17.74 .. 14.59
- **Ca** .. 10.47 .. 18.32 .. 16.08 .. 14.09 .. 23.39 .. 11.81 .. 17.53 .. 13.07 .. 14.80 .. 16.27
- **Cs** .. 3.33 .. 5.28 .. 6.17 .. 8.27 .. 6.63 .. 6.98 .. 7.91 .. 12.90 .. 5.98 .. 6.25
- **Fe** .. 1.50 .. 4.14 .. 3.13 .. 6.09 .. 1.35 .. 6.15 .. 2.38 .. 4.18 .. 3.17 .. 3.81
- **Fα** .. 13.48 .. 11.48 .. 14.59 .. 9.37 .. 7.75 .. 12.03 .. 16.13 .. 14.03 .. 16.38 .. 12.02
- **Fβ** .. 45.27 .. 14.76 .. 13.88 .. 15.04 .. 16.76 .. 10.71 .. 12.08 .. 12.12 .. 14.12 .. 15.95 .. 13.88
- **Fe** .. 0.28 .. 1.32 .. 1.10 .. 0.81 .. 0.45 .. 1.17 .. 0.21 .. 1.16 .. 1.23 .. 0.98
- **Q** .. 18.39 .. 27.70 .. 29.47 .. 29.01 .. 32.29 .. 30.25 .. 22.93 .. 24.92 .. 31.47 .. 29.75

**Kata Norm**

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<th>E</th>
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### Chemical & Petrological Study of Dyke Rocks in Pre-Cambrian

**Table III—Contd.**

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<td>2.60</td>
<td>1.46</td>
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</tr>
</tbody>
</table>

| **Total** | 99.81 | 100.10 | 100.42 | 100.06 | 100.58 | 100.29 | 100.53 | 100.82 | 99.86 | 100.28 |

* Total includes 0.36 CO₂. † Total includes 0.93 Cc. ‡ Total includes 0.93 Cc and 0.81 Ru. ¶ Total includes 0.80 of CaCO₃.

**A. Picrite**

(No. 5): From the middle of the composite sill near 35 miles 289 furlongs on the Cuddapah-Pulivendla road. Analyst N. A. Vemban.

**B. Pyroxene dolerite**


**C. Dolerite**

(No. 9): From near the village Vemula on the Cuddapah-Pulivendla road. Analyst N. A. Vemban.

**D. Vesicular basalt—Porphyry**

(No. 46): 7th mile on the road from Betamcherla to Kalwa. Analyst N. A. Vemban.

**E. Quartz-dolerite**

(No. 4): From upper portion of the sill, 35 miles 2 furlongs on the Cuddapah-Pulivendla road. Analyst N. A. Vemban.

**F. Fine-grained basalt**

(No. 49): Eastern end of Brahmanapalle asbestos zone, Pulivendla taluk, Cuddapah district. Analyst N. A. Vemban.

**G. Quartz-dolerite**

(No. 2 b): From the hillock west of Tiruttani, Chittoor district. Analyst N. A. Vemban.

**I. Dolerite**


**II. Quartz-dolerite**

below asbestos zone, a quarter of a mile south-west of Malkapuram, Dhone taluk, Kurnool district. *Ibid.*

**III. Average of 8 analyses of Cuddapah traps B to II.**

CaO, alkalis and titania are low. This rock comes under the peridotite-picrite group.

The most striking feature in the series of analyses is the uniformity in composition of the dolerites and basalts with the silica percentage varying from 46.92 to 52.02 per cent. Alumina is present in about the usual amount expected in basalts, except in E which is highly feldspatic. The iron oxides
are usually high except in E and G. Ferrous oxide predominates over the ferric in general but the high ferric oxide content in D and F can be accounted for by the considerable amount of palagonite present. Manganese is low. Compared to the combined iron oxides the amount of MgO is lower. The CaO is about normal. Soda dominates over potash, but in D and F soda is notably higher. Titanium and phosphorus are both in about the normal amounts.

A comparison of the mean analysis of the Cuddapah traps (Table IV) with the average Deccan traps shows that they are closely akin to each other. There is also a close resemblance between the ‘Newer dolerites’ of Bihar and Orissa and the Cuddapah traps. In comparison, the Gwalior trap contains less alumina and more alkalis. The average analyses of the Karroo dolerites, the Whin Sill and the New Jersey basalts compare closely with that of the Cuddapah traps, as all of them come under the normal tholeiitic types.

PETROCHEMISTRY

For the present study seven analyses of Cuddapah traps were made by the writer and two previous published analyses have been added. This form of expressing the composition (weight percentage of the chief oxides) is not by itself quite suitable for petrographic classification and comparison or for understanding the chemical characters of the rocks and their evolution. For such a study, various new values were calculated by grouping together allied oxides having the molecular proportions of the various oxides as the basis of calculations according to the method of Niggli, which is very helpful in the study of differentiation and of magmatic affinities of rocks. The various calculated values are given in Table V.

Differentiation Trends in the Cuddapah Traps

The rock types under study are all basic in character with the silica content varying from 45 to 52 per cent. (by weight). This small range in silica percentage goes to show that the magma that gave rise to the various types did not undergo extensive differentiation and that most of the rocks represent more or less the composition of the magma itself. Though the silica expressed as weight percentage has a very small range, we can see from the Niggli values that ‘si’ varies from 81 to 128 units and that there is a well-marked gap of 22 units between si 81 and 103; but there is every gradation from si 103 to 128. This gap is significant for study of the nature and evolution of this magma. In Fig. 3 a generalised differentiation diagram has been drawn from the Niggli values with si as abscissa and the other
TABLE IV
Average Analyses of the Cuddapah Traps and other basic rocks
compared with them

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>40.20</td>
<td>50-01</td>
<td>52.11</td>
<td>50.18</td>
<td>50-52</td>
<td>52.25</td>
<td>50-66</td>
<td>48.78</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>14.59</td>
<td>15.68</td>
<td>14.35</td>
<td>11.73</td>
<td>13.75</td>
<td>14.00</td>
<td>14.28</td>
<td>15.85</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3-50</td>
<td>3.19</td>
<td>1.38</td>
<td>2-02</td>
<td>3.67</td>
<td>0.84</td>
<td>3.41</td>
<td>5.37</td>
</tr>
<tr>
<td>FeO</td>
<td>9.57</td>
<td>9.02</td>
<td>9.94</td>
<td>11.94</td>
<td>8.50</td>
<td>9.39</td>
<td>8.58</td>
<td>6.54</td>
</tr>
<tr>
<td>MnO</td>
<td>0.40</td>
<td>0.16</td>
<td>0.18</td>
<td>0.50</td>
<td>0.16</td>
<td>0.45</td>
<td>0.12</td>
<td>0.29</td>
</tr>
<tr>
<td>MgO</td>
<td>6.33</td>
<td>5.46</td>
<td>6.73</td>
<td>5.45</td>
<td>5.42</td>
<td>6.05</td>
<td>6.02</td>
<td>6.03</td>
</tr>
<tr>
<td>CaO</td>
<td>9.45</td>
<td>9.45</td>
<td>8.85</td>
<td>10.05</td>
<td>9.09</td>
<td>9.71</td>
<td>8.60</td>
<td>8.91</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.64</td>
<td>2.60</td>
<td>2.97</td>
<td>4.47</td>
<td>2.42</td>
<td>2.21</td>
<td>2.92</td>
<td>3.18</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.63</td>
<td>0.72</td>
<td>1.15</td>
<td>0.55</td>
<td>0.96</td>
<td>0.72</td>
<td>1.63</td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
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<td>1.91</td>
<td>0.80</td>
<td>1.59</td>
<td>2.39</td>
<td>1.10</td>
<td>1.30</td>
<td>1.39</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.17</td>
<td>0.39</td>
<td>0.24</td>
<td>0.74</td>
<td>0.26</td>
<td>0.22</td>
<td>0.17</td>
<td>0.47</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>2.68</td>
<td>1.70</td>
<td>2.08</td>
<td>0.81</td>
<td>1.61</td>
<td>0.72</td>
<td>2.28</td>
<td>1.76</td>
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<tr>
<td>H₂O⁻</td>
<td>0.39</td>
<td>0.43</td>
<td>0.17</td>
<td>0.81</td>
<td>0.76</td>
<td>0.32</td>
<td>2.28</td>
<td>1.76</td>
</tr>
</tbody>
</table>

Sp. Gr. 100-29 100-12 99-05 100-43 100-31 100-21 99-96 100-09

* Total includes 0.58 CO₂ and 0.11 Incl.

I. c-gabbroid V. c-gabbroid
II. c-gabbroid VI. c-gabbroid
III. Normalgabbrodioritisch VII. Normalgabbroid
IV. Normalgabbrotheralitisch Normalgabbrodioritisch
VIII. Normalgabbrodioritisch

I. Average of 8 analyses of Cuddapah traps B to II given in Table III.
II. 
   Deccan Trap : Average of 11 analyses including 1 Rajmahal trap. 
   * Bull. Geol. Soc. America, Vol. 33, p. 774, 1922, 
   Analyst H. S. Washington

III. 
    Newer dolerite : Average of 3 of Singhbhum. 
    * Rec., G.S.I., LXV, p. 528, 1932 and 2 of Keonjhar 

IV. 
    Gwallor trap : Average of 6 analyses. 

V. 
    Whin Sill : Average of 6 analyses. 

VI. 
    Karroo dolerite : Average of 5 analyses. 

VII. 
    Average New Jersey basalt : Quoted from C. A. Anderson. 

VIII. 
    Daly's average basalt : Quoted from Washington, 
TABLE V

Niggli, QLM and γ values of the Cuddapah Traps

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>I</th>
<th>II</th>
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<tbody>
<tr>
<td>Si</td>
<td>...</td>
<td>80.7</td>
<td>107.4</td>
<td>153.4</td>
<td>121.8</td>
<td>115.2</td>
<td>127.6</td>
<td>125.7</td>
<td>102.8</td>
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<tr>
<td>Al</td>
<td>...</td>
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<td>22.1</td>
<td>24.5</td>
<td>19.1</td>
<td>21.6</td>
<td>16.0</td>
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<tr>
<td>FM</td>
<td>...</td>
<td>77.1</td>
<td>48.3</td>
<td>61.0</td>
<td>52.7</td>
<td>42.3</td>
<td>49.9</td>
<td>42.9</td>
<td>49.1</td>
</tr>
<tr>
<td>K</td>
<td>...</td>
<td>17.7</td>
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<td>9.3</td>
<td>6.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Ti</td>
<td>...</td>
<td>0.55</td>
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<td>2.7</td>
<td>2.1</td>
<td>1.1</td>
<td>3.0</td>
<td>1.3</td>
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<tr>
<td>P</td>
<td>...</td>
<td>0.21</td>
<td>0.14</td>
<td>0.14</td>
<td>0.15</td>
<td>0.28</td>
<td>0.15</td>
<td>0.14</td>
<td>0.13</td>
</tr>
<tr>
<td>K</td>
<td>...</td>
<td>0.14</td>
<td>0.09</td>
<td>0.17</td>
<td>0.10</td>
<td>0.18</td>
<td>0.20</td>
<td>0.13</td>
<td>0.04</td>
</tr>
<tr>
<td>Q</td>
<td>...</td>
<td>0.76</td>
<td>0.49</td>
<td>0.44</td>
<td>0.49</td>
<td>0.65</td>
<td>0.37</td>
<td>0.50</td>
<td>0.44</td>
</tr>
<tr>
<td>M</td>
<td>...</td>
<td>63.7</td>
<td>36.5</td>
<td>38.5</td>
<td>32.4</td>
<td>31.0</td>
<td>36.2</td>
<td>33.5</td>
<td>45.3</td>
</tr>
<tr>
<td>N</td>
<td>...</td>
<td>0.66</td>
<td>0.54</td>
<td>0.53</td>
<td>0.38</td>
<td>0.65</td>
<td>0.25</td>
<td>0.53</td>
<td>0.45</td>
</tr>
<tr>
<td>γ</td>
<td>...</td>
<td>0.65</td>
<td>0.15</td>
<td>0.16</td>
<td>0.03</td>
<td>0.15</td>
<td>0.19</td>
<td>0.24</td>
<td>0.27</td>
</tr>
</tbody>
</table>

FIG. 3 Differentiation diagram of the Cuddapah Traps

Fig. 3a. Differentiation diagram of the calc-alkali series (After Niggli)
constituents as ordinate. There are three curves which are roughly mutually sympathetic, but antipathetic to the $fm$ curve. The curve $c$ rises more rapidly than the $al$ curve but it becomes sympathetic to $fm$ curve at about $si$ 112. The $alk$ curve, on the other hand, rises only very gently. The $fm$ curve is steep from $si$ 81 to 110, the value of $fm$ changing rapidly for a small variation in $si$, but it becomes flatter afterwards.

The Niggli differentiation diagram does not give us an idea of the individual behaviour of soda and potash, or of magnesia which are grouped together in the $alk$ and $fm$ values. To study this, the values $k$ and $mg$ can be plotted, with $k$ as abscissa and $mg$ as ordinate. The relationship between these two components during the progress of differentiation can be understood from Fig. 4. It is seen that there is comparatively little variation in $k$.

![Diagram](image-url)

**Fig. 4**

$k$–$mg$ diagram for the Cuddapah Traps. The maximum being 0.16, while the $mg$ values have a range of as much as 0.39. The points occupy a small linear zone which is nearly vertical in position to the abscissa, this being found commonly in potash suites. The reciprocal relationship which is characteristic of calc-alkaline suite is not clearly seen in the diagram.

The normative mineral composition of a rock can be estimated from its Niggli values. When there is enough silica and when $al$ is less than the sum ($alk + c$), the value $2 alk$ gives the proportion of the alkali-feldspars, $2 (al - alk)$ that of the anorthite content, and $(100 - 2 al)$ that of the melanocratic (ferromagnesian) minerals. The sum of these three values is
always equal to 100 and can be represented by a single point in a trilinear co-ordinate diagram in which the three corners represent 100 per cent. of the three values.

When these values are plotted on a trilinear co-ordinate diagram (Fig. 5), a clear idea is gained of the basicity of the rocks and also of the general trend of consolidation of the magma, which conforms to the theory of crystallisation-differentiation, viz., the progressive enrichment in alkali feldspar.

From the diagram the magma can be regarded as having followed three different lines of development during the evolution of the various types.

1. The impoverishment in ferromagnesians with constant alkali-feldspars.

2. The enrichment in alkali-feldspars with constant dark minerals.

3. The enrichment in alkali-feldspars with constant anorthite content.

From the point A the first trend operated and, during the progress of this, the second and third courses have given rise to the other types. We cannot say definitely which type is the result of these two differentiation
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tendencies as the points can be joined either way, but we can regard the types E and D as resulting from the enrichment of alkali-feldspars with constant anorthite content. Of these two, the type D has higher alkali-feldspars while E is richer in anorthite content.

The QLM-Diagram

The QLM-diagram is very important in tracing the magmatic affinities of the rocks and the sequence of formation of the various types and also the order of crystallisation of the minerals composing the rocks. As the role of quartz is important in the formation of different rocks, the behaviour of quartz in the differentiation history can very well be followed in this diagram.

When the QLM values (Table V) of the Cuddapah magma types are plotted in the diagram (Fig. 6) prepared by Niggli (1938, Figs. 2a, 20 and 21), it is seen that all the points except A fall below the line PF (saturation line) and above PL in the area of 'Normal basalt' within the main basalt field. The point A, representing a peridotitic type falls outside the above field. All the so-called 'primary basalts' of all parts of the world (such as tholeiite, ophiolith, norite, plateau-basalt and olivine-basalt) fall within the borders of 'Normal basalt'.

Most petrologists now regard all igneous rocks as derived generally from a basaltic magma, though such a magma may not necessarily be considered the starting point in all cases. In this connection Bowen has written (p. 5, 1928):

"To Daly, in particular, we owe the demonstration, apparently satisfactory, that basaltic magma is a constant member of all these associations and that there is no essential difference in the basaltic magma of the various associations. Partly for this reason and partly on geologic grounds he considers that basaltic magma is the parental magma of all igneous-rock series, except certain pre-Cambrian rocks. The facts are not such as to enforce belief in the parental nature of basaltic magma but they are sufficiently definite that many petrologists now entertain the belief favourably and include it in their general scheme of rock derivation. In the present discussion the parental nature of basaltic magma is taken as a fundamental thesis and other rock-types are developed principally by fractional crystallisation. The reasons for preferring a thoroughly basic, presumably basaltic, parental magma are, however, strong and will become apparent as the discussion proceeds."

Thus Bowen derives the various rock types from basic and basaltic magma, supported by his experiments on liquid melts in the laboratory.
To him crystal fractionation is the chief cause of the diversity of rocks. He believes that basaltic magma generally gives rise to quartzose late differentiates but under certain conditions a liquid deficient in silica may be filter-pressed before reaction with early-formed crystals such as pyroxenes; or the liquid may be rich in silica if filter-pressed during peritectic reaction, leaving behind feldspathoids. Daly, on the other hand, considers that ‘primary basalt’ magma is capable of giving rise to various rock-types but he attributes the formation of alkaline rocks primarily to the desilication of basaltic magma by wide-spread assimilation of limestones and calcareous sediments. Thus both the authorities view the alkaline rocks as abnormal and derived under exceptional circumstances from the ‘primary basalt’ magma. Contrary to the views of Bowen and Daly, W. Q. Kennedy (p. 256, 1933) basing his conclusions on the investigations of the authors of the Mull Memoir, says:

“Study of individual rock bodies and regional magmatic provinces leads to the conclusion that there exist two great primary basalt magmas, the olivine-basalt type and the tholeiitic basalt type, each of which gives rise normally to its own particular line of descent. The former is the parent of the alkaline rock suite and the latter is the parent of the calc-alkaline suite as follows:

<table>
<thead>
<tr>
<th>Common Parent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olivine-Basalt Magma-Type-? - Tholeiitic Magma-Type</td>
</tr>
<tr>
<td>Trachyandesite</td>
</tr>
<tr>
<td>Trachyte</td>
</tr>
<tr>
<td>Phonolite</td>
</tr>
</tbody>
</table>

There is no evidence that either of these “primary” magmas is a derivative of the other nor can we point to any common parent from which they could have been derived. Any such relationship is too far removed from the scope of the present investigation to merit discussion, and all that seems certain is that both types of basaltic magma have been available throughout geological history in immense amounts and over immense areas. We are justified, therefore, in regarding them, for the purposes of petrogenesis, as primary magmas.”

Thus Kennedy maintains that a particular late differentiate is determined only by the nature of the primary magma and is not the result of the physico-chemical conditions obtained during solidification.

Niggli (1938) prefers to assume two or even a larger (yet limited) number of well-defined basaltic ‘Stammagmas’ (“Zwei oder einer kleinen Zahl
wohldefinierter basaltischer Stammagmen," p. 653, 1938) for the derivation of rock-types of petrographic provinces. Niggli uses the terms 'Ausgangs' or 'Stammagma' instead of 'primary magma' since there is a great variation in the composition of the basic magma, as is shown by the large basaltic field in the QLM-diagram (Fig. 6).

Basing his observations on his molecular values, Niggli has found that the olivine-basalt or 'plateau-basalt' type is essentially of normalgabbroid to hornblenditisch and that the tholeiitic type varies from normalgabbro- dioritisch to miharaitisch. He says that the theory of Kennedy holds often, but on a careful investigation one can observe all possible intermediate members in between these two types; as the chemical difference itself is relatively small, so that normalgabbroid types are found also in typical Pacific provinces and gabbro-dioritisch in the Atlantic. On a comparison of the molecular values of tholeiite and norite and of 'plateau-basalts' and tholeiites, and from the association of hornblenditisch and hornblendeperidotitisch
types with 'plateau-basalts' and tholeiites, he concludes that tholeiite was derived from completely fluid magmas of hornblenditisch and hornblende-peridotitisch composition and that, as these magmas give rise to heteromorphous rock-types with such monomineralic rocks as amphibole picrite and hornblendite which exhibit similar composition included in them, the further course of differentiation depends entirely upon the predetermined primary molecular constitution of the early formed crystals combined with the trend of diffusion.

H. Kuno (1937), after a chemical study of many basalts, quite different from that of Niggli, arrived at a similar conclusion (p. 208), namely, that "these rocks are differentiates of more basic magmas by fractional crystallisation" and that "the ultimate primary magma from which these rocks have been derived are supposed to have had the composition of an olivine-rich eucrite." He expressed the general trend of differentiation of this primary eucrite magma in the following tentative scheme:

```
Primary Olivine-eucrite magma

Olivine-basalt Magma-type

Mugearites, Trachyandesite, etc.
(Saturated Olivine-basalts, such as those of Hawaii and Iceland)

Trachytes and other acid alkaline rocks

Tholeitic Magma-Type

Pyroxene-andesites

Rhyolites
```

Even though there is agreement between Niggli and Kuno in considering the plateau-basalts as derivatives from a more basic magma, Niggli conceives of a magma of ultrabasic composition while the 'primary magma' of Kuno is gabbroidal or noritic. This latter according to Niggli is derived from a more basic magma; but the attractiveness of Kuno's theory lies in considering the tholeiite type as the derivative of olivine-basalt which is an amplification of the observations of Niggli.

In conceiving of the plateau and olivine-basalt magmas as derived from liquid ultra-mafics, we have to face the objection raised by Bowen. Bowen (1927 and 1928) denies the existence of peridotitic magma and concludes that monomineralic rocks such as dunite, anorthosite, etc., do not represent the composition of the magma from which they were formed but are accumulations of early-formed crystals which separated from the liquid by crystal fractionation. He supports his view by experimental work on liquid melts which indicates that ultra-mafic magmas can be liquid only at prohibitively high temperatures. But C. N. Fenner (1938) and H. H. Hess (1938) consider
that hyperfusible constituents would have a controlling effect on the temperature. C. N. Fenner states (p. 399, 1938):

"This leads to the conclusion that, contrary to inferences reached in the theory of crystal fractionation, wholly liquid magmas of ultrabasic composition exist."

The views of Fenner and Hess may perhaps be verified in a few localities, but it may not follow that all peridotites represent direct product of solidification from the magma of the same composition. On the other hand, Bowen has clearly shown that certain peridotites are the result of accumulations of early-formed crystals from a basaltic or noritic magma. In the case of the peridotites of Skye he pointed out that the chilled marginal facies of the ultra-mafics carried phenocrysts of olivine in a fine-grained basaltic matrix, indicating that the core is the result of accumulations of early crystals from which the residual liquid was filter-pressed. We should, therefore, look for positive proof in the field regarding the origin of such types as the trap from which the (analysed) specimen A was collected. In this connection it may be worth noting that C. S. Fox (quoted by A. L. Coulson, p. 150, 1934) describing the occurrence and field relations of this trap, states:

"The ridge (west of Pulivendla Inspection Bungalow) appears to consist of a composite sill (three separate sills) of dolerite, the middle one, a dark, coarse, scoriaceous-weathering rock being rich in olivine, while the layers above and below it are dolerites without olivine."

A. L. Coulson comments thus on the statement of Fox:

"These observations of Dr. Fox have great interest and deserve amplification. The author collected specimens of the sill which bear out Dr. Fox's remarks. Thus the uppermost part of the sill is best described as a quartz-dolerite. It is very similar to a specimen of what is undoubtedly the same sill collected near the 38th milepost on the Cuddapah-Pulivendla road, 1½ miles WNW of Vemula."

"The central portion of the sill is very basic and contains abundant augite, olivine, (?)hypersthene, serpentine, a little feldspar, iron-ore and brown mica. It is a picrite. It also has its counterpart in a similar specimen collected near Vemula.

The lowest portion of the compound sill is intermediate in basicity between the uppermost and central parts, being best described as a dolerite."

From his own field and laboratory studies the present writer is quite in agreement with the above description. The upper and lower dolerites do
not appear to be the border facies formed as the result of filter pressing of
the residual liquid, nor do they contain any olivine phenocrysts to warrant
such an assumption; but they do represent quite separate phases of intrusion.
It is suggested, therefore, that type A represents the primary magma of the
composition of picrite from which other types were possibly differentiated.

In Fig. 6 is shown the main basalt field in which are distinguished 'Normal
basalt' and 'alkali basalt' and a well marked area of calc-alkaline rocks.
It can be seen that the major portion of the 'Normal basalt' represented by
tholeiite, ophiolith and 'plateau-basalt' is occupied by calc-alkaline field.
When the $QLM$ values of the Cuddapah traps are plotted, it is seen that all
the normal types occupy the region of 'Normal basalt' while A and I which
are distinctly earlier in the differentiation series are found towards the side M.
There is only one trend of differentiation, from picritic composition towards
the calc-alkaline field as shown below:

\[
\begin{align*}
\text{Picrite} \quad \text{hornblendeperidotitisch} \\
\text{dolerites} \quad \text{normalgabbroid or c-gabbroid} \\
\text{quartz dolerites} \quad \text{normalgabbrodioritisch or miharaitisch}
\end{align*}
\]
The same trend of differentiation is also indicated when we study the interrelation between the three Basis molecules Kp, Ne and Cal, which is brought about by \( k \) and \( \pi \) values themselves, on a triangular diagram whose corners are Kp, Ne and Cal, in which the three generalised diagrams constructed by Niggli (Figs. 2b, 3b and 4b, 1938) for the three petrographic suites are included in a simplified form. When \( k \) and \( \pi \) values for the Cuddapah traps are plotted in the diagram (Fig. 7) it is seen that except for the points D and I all the others fall within the field of the Pacific suite.

It is evident from these studies that the Cuddapah intrusive belongs to the calc-alkaline suite.

**SUMMARY AND CONCLUSION**

The traps of Cuddapah age mark an important period of volcanic activity later in age than the Dharwars and probably earlier than the Cambrian. The chief character that distinguishes the Cuddapah traps from those of Dharwar age is the marked freedom of the former from metamorphism as the Peninsula was free from major earth movements after their intrusion.

In the present work an attempt is made to study the petrography and petrochemistry of these basic rocks collected from several sills intrusive into the Vempalle limestones and the Tadpatri shales in the Ceded districts.

These trap rocks are composed of colourless, non-pleochroic pyroxenes and labradorite feldspars with sub-ophitic to doleritic textural relationship between these two minerals indicating that they crystallised more or less simultaneously. This is also confirmed by the \( f(\text{norm}) \) values. The pyroxenes belong mostly to the monoclinic variety, augite, the other monoclinic pyroxene, pigeonite being rare or absent; in the olivine-bearing types there is also the rhombic pyroxene, enstatite. The optic axial angle of the augite varies from 56° to 40° and the extinction angle from 46° to 36°. The enstatite is optically negative (\( 2V = - 83° \pm 2° \)) and is rich in magnesium.

The Cuddapah traps, the Newer dolerites and the Gwalior traps are similar to each other in their pyroxenes being mainly augite with a large optic axial angle. They differ from the Deccan traps, the Karroo dolerites, the Whin Sill and the New Jersey diabases in the absence of pigeonite which characterises those rocks. The average composition of the plagioclase, deduced from both Universal Stage determinations and chemical analyses is found to range from bytownite with 75 per cent. anorthite to oligoclase or andesine of 30 per cent. anorthite with a mean value of about 55 per cent. anorthite.
From a study of the analyses, six distinct magma-types (Niggli's) have been recognised:

1. Melagabbrodioritisch
2. Miharaitisch
3. Normalgabbroid
4. c-gabbroid
5. si-pyroxenitisch
6. Hornblendeperidotitisch.

Petrochemical studies, using Prof. Niggli's methods, show that the rocks are basaltic in nature with only a limited range of differentiation. The differentiation diagram based on the Niggli molecular values, $QLM$ values and $k/e$ values show that the Cuddapah magma belongs to the 'Normal basalt' of Niggli (= Tholeiite type) and that the trend of differentiation is similar to that of the calc-alkaline suite of rocks.

These conclusions are only of a limited validity as the number of specimens analysed is small. As these traps occur extensively and over large areas, there is scope for the extensive collection and study of much material which will lead to a wider understanding of the nature and history of these rocks.

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