Past I: a petrological study op the prinsen af wales bjaerge lavas, East Greenland II: the two granphyres of meall dears, skye, with a special study of the clinopyroxene contained in one of them

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PART I : A PETROLOGICAL STUDY OF THE PRINSEN AF WALES BJAERGE LAVAS, EAST GREENLAND.

PART II : THE TWO GRANOPHYRES OF MEALL DEARG, SKYE, WITH A SPECIAL STUDY OF THE CLINOPYROXENE CONTAINED IN ONE OF THEM

By

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Being an account of the work carried out at the Geology Department, Durham University (Durham Division) during the period 1948 - 1950 under the direction of Professor L.R. Wager, M.A., Sc. D., F.R.S.

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PART I.

PART I.

CONTENTS.

INTRODUCTION.

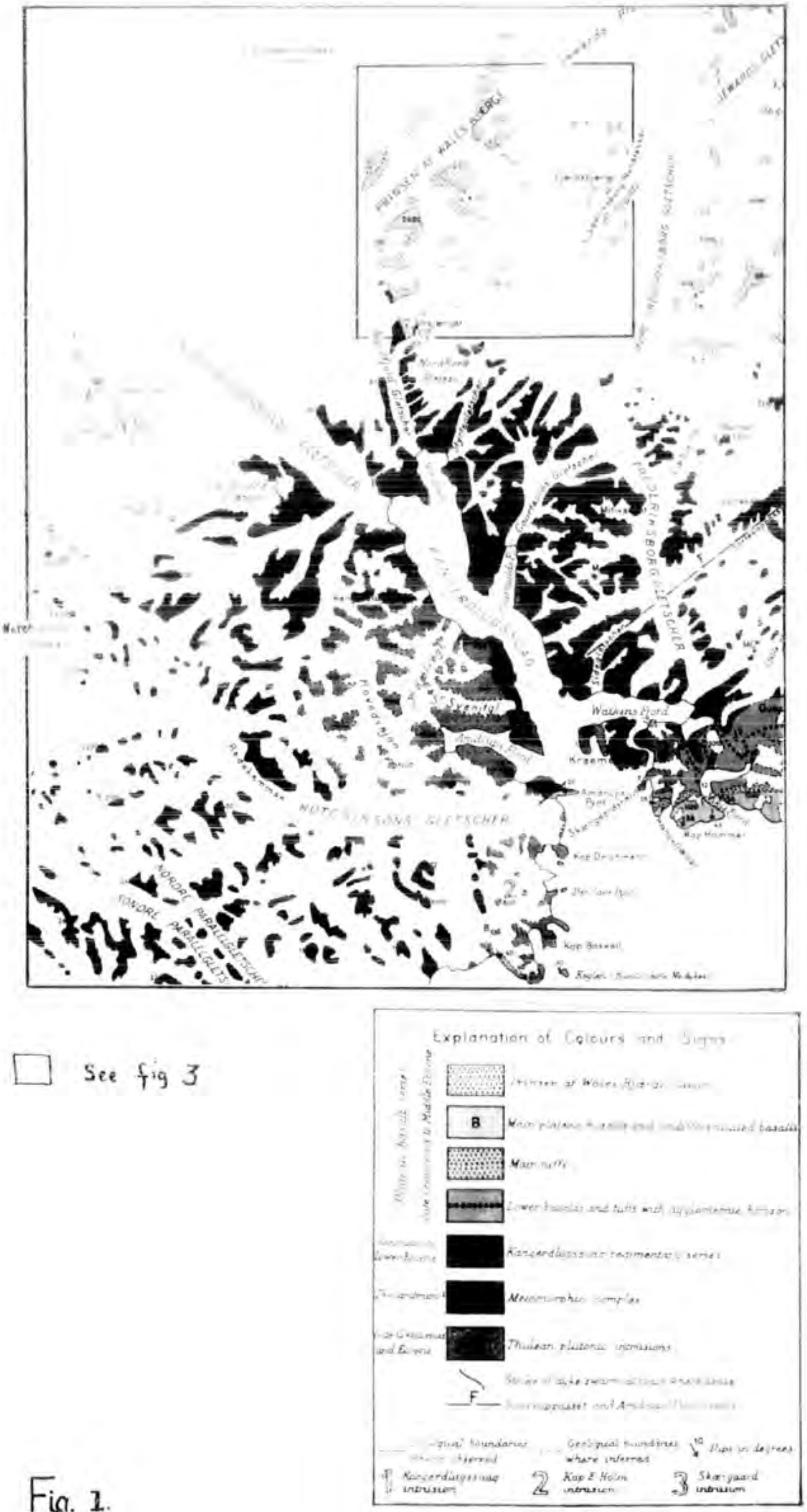
During the British East Greenland expedition 1935-36 geological studies were made in the coastal and inland regions round Kangerdlugssuaq (Wager 1947). It was found that the basalts in both the inland and coastal regions, with the exception of the higher series of Prinsen af Wales Bjaerge, had the general parallel arrangement characteristic of Plateau Basaltsregions. There the lavas displayed a new feature; from a distance they seemed to have been tilted, perhaps by laccolithic intrusion, but on close examination it was found that overlying the wide-spread horizontal plateau basalt, there occurs a group of lavas in which the individual flows are inclined at 20° to 30° to the horizontal as seen in the mountain sides. The term Prinsen af Wales Bjaerge lavas has been since assigned to these upper series.

As far as can be ascertained no petrographical literature dealing with the Prinsen af Wales Bjaerge Lavas has been published, except a brief general description by L.R. Wager (1947, P.26).

The present investigation is mainly concerned with the petrography of these upper inclined series, but a brief description of the Plateau Basalts Series in the Prinsen af Wales region is also given for comparison. These upper inclined series are revealed to ~~be~~ have of special mineralogical, chemical and textural features not met with in the widespread Plateau Basalts.

The rock specimens for this study were provided by L.R. Wager from a collection made during the British East Greenland Expedition (1935-36). Five new chemical analyses for the Prinsen af Wales Bjaerge lavas were made by the author for this paper.

As a reference map to this work, the geological map published by L.R. Wager (1947, Pl. 6) has been repreduced as fig 1.



PRINSEN AF WALES BJERGE
HUTCHINSONS GLETSCHER
FREDERIKSBORG GLETSCHER
Watkins Fjord
Amdrups Fjord
Kap Deichmann
Kap Boswell
Kap Hammer
NORDRE PARALLELGLETSCHER
SØNDRE PARALLELGLETSCHER
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Main tuffs
Lower basalts and tuffs with agglomerate horizon
Kangerdlugssuaq sedimentary series
Metamorphic complex
Thulean plutonic intrusions
Lower Eocene
Late Cretaceous and Eocene
F
Geological boundaries where observed
Geological boundaries where inferred
10
Dips in degrees
1
Kangerdlugssuaq intrusion
2
Kap E Holm intrusion
3
Skærgaard intrusion

Fig. 1.

I - FIELD RELATIONS.

A - GEOLOGICAL SETTING.

The map (fig 1) illustrates the setting of the Prinsen af Wales Bjaerge Lavas in relation to the geology of the region. The region is in the general form of an elongated dome whose main axis runs E - W through Domkirkbjaerget to the east of Kangerdlugssuaq fjord. On the northern flank of this anticlinal structure, the basalt lavas show a decrease in dip to 2° - 5°. Further to the North the lavas are nearly horizontal or lie in a shallow syncline running from Seward Nunatakker through the upper part of Christian Den IV's Gletscher. On the southern flank of the domal structure the dip increases from 2° - 3° to high dips as the coast is approached.

The following account gives a brief survey of the rock formations in the Kangerdlugssuaq region based on published papers by L.R. Wager in 1934, 1935, 1939 and 1947. In fig. 2 the broad variations in rock types at the different localities are illustrated by vertical sections.

The main rock types in the region covered by the map are as follows:-

1. Metamorphic Complex.

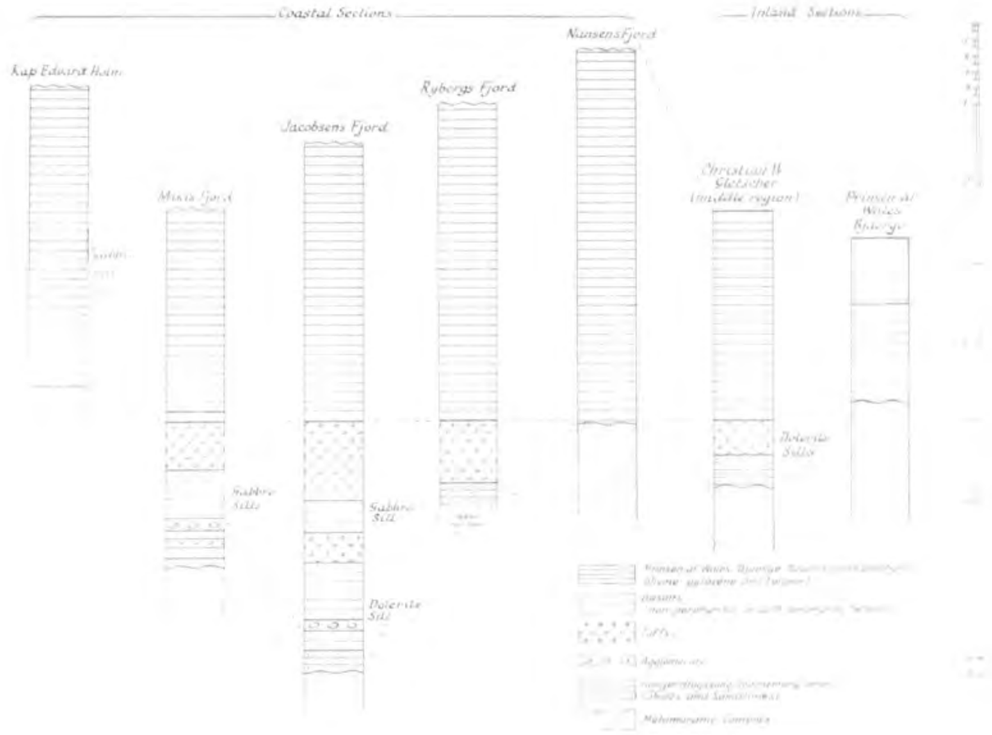


Fig. 2.

Vertical sections illustrating the variation in rock types at the different Localities in Middle East Greenland (Reprinted from, Wager 1947, P21)

2. Kangerdlugssuaq Sedimentary Series.
3. Plateau Basalt Series.
4. Tertiary Plutonic Centres intruded into the previous formations.
5. Coastal Dyke Swarms.

1. The Metamorphic Complex.

The oldest formation in the region is a Precambrian substratum which consists chiefly of grey acid gneisses. Plagioclase Amphibolites enclosed in the gneiss form about one-tenth of the whole complex. Ultrabasic masses and porphyroblastic schists are also present in the gneiss, but are of rare occurrence. These rock types present in the complex have been interpreted as being of an earlier age than the enclosing gneiss. From the study of the rock units in the metamorphic complex it would seem to indicate that more than one period of magmatic and tectonic activity took place during the Precambrian time. This is based on the presence of transgressive sheets of plagioclase amphibolite which injected the gneiss and were themselves subsequently injected by the gneiss (Wager 1934, P. 9-10) and by the dominance of an easterly direction of strike, the result of a Precambrian orogeny. This prevailing direction is nearly at right angles to that due to the Caledonian orogeny, in the formations to the North of Scoresby Sound.

2. Kangerdlugssuaq Sedimentary Series.

Towards the end of the Mesozoic era, the land lay almost at sea level. A limited marine transgression of Senonian age took place in the form of an arm stretching round and north of Jackobson's Fjord to Isfaldgletscher. The sediments in that region contain belemnites. These sediments were laid unconformably over the metamorphic complex. Estuarine conditions followed over a large area of Middle East Greenland, extending to the West about Kangerdlugssuaq and to the N.E. about Nansens Fjord. The absence of sediments, and the fact that plateau basalts rest directly on the metamorphic complex at the Prinsen af Wales Bjaerge, Trikantnunatakker and Hutchinson's plateau would indicate that the sedimentation basin did not extend far to the north. On Urbjaerget, north of Kangerdlugssuaq, there are no thick and constant sedimentary series. In Christian Den IV's region, the sediments form the mountains extending for 60 Kms. from the head of Rybergs Fjord to Ispaldgletscher. These sediments consist of shales, sandstones and conglomerates, with occasional cappings of basalt-tuff series. Leaf impressions and fossil fruits are found in the sandstone. In the conglomerates abundant well-rounded ~~shaped~~ basalt pebbles were found, which indicate the commencement of the Tertiary volcanic activity elsewhere whilst sedimentation continued in this area.

3. Plateau Basalt.

In early Eocene the sedimentary period over Middle East Greenland ended and an intense and wide-spread volcanic activity took place by outpouring of the plateau basalts.

The term plateau basalt includes both the whole pile of basalts and the interbedded tuffs. It is accordingly divided into two series (fig. 2) :-

(a) Lower basalts with tuffs and volcanic agglomerates and with a thick upper main tuff horizon.

(b) An upper uninterrupted series of basalt flow.

(a) Lower Basalt Series.

The extent of the lower series is not great, which indicates that basalt extrusion was not always accompanied by an explosive phase. Where they are found, they lie conformably on the sedimentary series.

The main occurrences of lavas and tuffs are in the country between Kangerdlugssuaq and Mikis Fjord, and further east in I.G. Jacobsens fjord. The agglomerates forming the base of this series are interbedded with basalt and tuffs, occasionally cut out by dolerite and gabbro sills. The basalts show spilitic alteration as an indication of submarine extrusion, and are followed by the upper main tuff horizon. Further to the N.E.. in Rybergs Fjord, the lower series are formed only of the main tuffs while the lower basalts tuffs and agglomerates are missing. In that region the main tuffs rest on the sedimentary series. In Christian Den IV's region the lower series are found, but from their general features indicate a subaerial formation, as shown by red partings of the basalt flows occurring between the thick upper and lower tuffs.

To the N.E., at Nansens Fjord and to the West at Kap Edwards Holm, the lower series are completely missing and the upper basalt series rest on the Metamorphic complex. The same is also true for Prinsen af Wales Bjaerge and Urbjaerget, North of Kangerdlugssuaq.

(b) Upper Basalt Series.

The thick main tuffs of the upper horizon, in the previous series, represent a definite period of explosive igneous activity. Where the upper series rest directly on the metamorphic complex, they are consequently of later date than the main tuffs.

This wide spread of thick plateau basalts is formed of parallel flows which can be traced in some places over wide areas. The building up of the flows seems to be similar to that shown by Noe-Nygaard (1942, P.70), which briefly shows the flows as being sheets which are thinning outwards and with overlapping edges.

In the inland region and on the northern flank of the anticlinal structure, the plateau basalt shows a dip of 2^{o} from the horizontal. To the south and as the coastal region is approached, the dip increases steadily until the high dip of the coastal flexure is reached.

The thick pile of basalt lavas over the main tuffs vary from porphyritic to non-porphyritic varieties. From a general comparison of the vertical variation of the lavas it seems that the earliest and latest flows are commonly non-porphyritic, whilst felspar phyric flows occur at intermediate horizons. This variation in character seems to be due to a definite time sequence of the types.

Petrographically, the basalts resemble the well-known Tertiary basalts from the North Atlantic province, i.e. the Plateau magma type (Olivine - basalts) and the non-porphyritic central type (Tholeiites - Wager 1934, P.34).

4. Plutonic Centres.

There are four plutonic centres to the east and west of Kangerdlugssuaq (Wager 1934, P. 37-41) which belong to the same igneous cycle as the plateau basalt.

(1) Kangerdlugssuaq complex to the west of the Fjord. This consists of Syenites ranging from quartz to nepheline-bearing types and having gabbroic outer borders.

(2) Kap Edward Holm Complex, south west of the mouth of Kangerdlugssuaq, formed mainly of gabbros, penetrated by the quartz syenite masses of Kap Deichmann and Kap Boswell.

(3) Skaergaard intrusion, on the east side of Kangerdlugssuaq. This consists mainly of gabbros and ferrogabbros (Wager and Deer 1939).

(4) Liloise plutonic complex, 150 Kms. east of Kangerdlugssuaq. From the nature of the erratics carried by glaciers to the coast from the complex, this seems to be formed mainly of Syenites and nepheline Syenites.

These four complexes, though belonging to the same igneous cycle, were found at different periods. Their relative ages had been defined on the basis of two facts:-

(a) The basic intrusion (2) ~~and 3)~~ ~~are~~ is cut through by syenitic masses and consequently a later date is ~~given~~ suggested for the syenitic intrusions (1 and 4).

(b) The coastal dyke swarms cut through the basic intrusions in Skaergaard and Kap Edward Holm, but are absent from the syenitic intrusions.

From their spatial distribution these centres follow the margin of the Greenland Shield in a N.N.E. direction which is the same direction postulated for the extension of the plateau basalts (Wager 1947, P. 29). The acid intrusions mark the close of the main igneous activity in Middle East Greenland except for later small dyke swarms cutting through the Kangerdlugssuaq intrusion.

5. Dyke Swarms.

Along the coast and parallel to its trend dyke swarms are found. In general their strike is trending E.N.E. - W.S.W., and they cut through the basalt lavas approximately at right angles. The dominant dykes are dolerites. The dyke swarm is closely related to the coastal flexure so that where the flexure is intense the dyke swarm is found to be highly developed following the convex part of the flexure.

B - PRINSEN AF WALES BJAERGE LAVAS.

The Prinsen af Wales Lavas occur in isolated patches with a general N.N.E. trend (cf. map, fig. 1). The total thickness of the lavas in that region is about 800 metres, and together with the underlying plateau basalt gives a thickness of two kilometres. (fig. 2).

Although the extent of the present outcrops is not great, it seems that they extended to the south, as large blocks of similar lavas have been found in the syenitic intrusion to the west of Kangerdlugssuaq Fjord, which indicates an older age for the Prinsen af Wales lavas. On the other hand, these lavas are not represented in the coastal moraines of the glaciers draining the inland areas, examined between Nansens Fjord and Kap Dalton, so it is likely that the series did not extend far to the east.

The N.N.E. trend shown by the lavas outcrops is nearly parallel to that taken by the widespread plateau basalt in E. Greenland. It is not unlikely that these limited areas of Prinsen af Wales lavas had been extruded from volcanic vents probably arranged along the original fissures which acted as feeding channels for the plateau basalt. The inclined feature displayed by these lavas is probably due to their extrusion in a highly viscous condition, which would also account for their not extending far beyond their points of extrusion. The existence of a former volcanic vent has similarly been suggested for the limited rock exposures at Tjaelder

Bjaerget (Wager 1947, P.26).

The Prinsen af Wales lavas were particularly examined on the mountains 3 Km. north-west of the point where the 2° dip arrow is marked, 25 Km. North-north-west of Urbjaerget (fig. 1). Porphyritic and non-porphyritic varieties are represented in this group of lavas, and, moreover, the porphyritic types occur as the uppermost series followed by the non-porphyritic types, with occasional thin flows of porphyritic varieties. One of the thickest lavas was non-porphyritic, a feature which has been found to be the reverse of the relation between porphyritic and non-porphyritic lavas of the typical plateau basalt.

As the horizontal plateau basalt on which the tilted upper series rests overlies directly the older metamorphic complex with no sedimentary rocks or tuffs between them, it is considered that these plateau basalt are later than the main tuffs. It seems likely that the metamorphic complex stood above sea level during the period of sedimentation and volcanic activity, and deposited tuffs are assumed to have been washed eastward to Christian Den IV's region.

The plateau basalt in Prinsen af Wales region varies from felspar phyric to non-porphyritic. ~~series~~. The mineralogy and textures of these types (described in the next chapter) closely resemble those described from the plateau basalt of other regions in Middle East Greenland.

C - TECTONICS.

The tectonics in Middle East Greenland seem to be of the simplest, and the events can be summarised as follows:-

(1) Early Crustal up warping with concommitant denudation, as shown by the high grade of the exposed metamorphic complex.

(2) The outpouring of the plateau basalt is taken to indicate a relief of crustal tension. This extrusion of basalt is accompanied by slight flexuring due to differential sinking of the accumulated lavas.

(3) During the middle or upper Eocene period and after the formation of the plateau basalt, a major epeirogenic movement took place associated with coastal flexuring, with dyke swarms where the flexure is intense. The coastal flexure marks the junction of the differential epeirogenic movement which gave rise to the coastal mountain belt and the Denmark Strait. As a result of this continual tension repeated fracturing was produced, following the convex

part of the flexure which is now indicated by the dyke swarm.

(4) Possible later up-warping of the edge of the uplifted area as a result of isostatic adjustments to erosion and to the development of the ice cap.

II - PETROGRAPHY.

A - NOTES ON THE METHODS USED.

1 - Laboratory methods.

The refractive indices were determined by means of standardised immersion liquids. In the case of porphyritic rocks fragments of the phenocrysts were directly obtained from the hand specimen. The groundmass felspar was determined by preparing an uncovered slide of suitable thickness and the desired grains were picked, washed with methylated spirit and treated with immersion liquids. This last method was only used for porphyritic rocks of reasonable coarseness. In the nonporphyritic rocks a sieved rock powder was used, a separation into heavy and light fractions being made by bromoform. The light fraction was used for the felspar and the heavy for the ferromagnesian minerals. The probable accuracy of these determinations is about ± .003.

The optic axial angles for the olivine and the pyroxene were determined on the universal stage. Not less than two determinations for each mineral were made in every slide and the average value was used. The probable accuracy is about ± 2°. The extinction angles for the clinopyroxene were also determined on the universal stage by the Conrad Burri method (Haff 1941).

The mineral composition (volume %) for most of the rocks was determined on the Dollar's integrating stage. The lengths of the traverses in the case of the porphyritic rocks were about 100 times the average lengths of the phenocrysts. The specific gravities of the rocks analysed were determined with the aid of a Walker Steelyard balance.

2 - Determinative diagrams used for the mineral composition.

The composition of the plagioclase felspar was determined from Tsuboi's diagram for the refractive indices Ng' and Np' (Winchell 1927). The nomenclature followed is that suggested by Deer and Wager (1939, P.25).

In case of the pyroxene, the triangular diagram for 2V and γ constructed by Deer and Wager (1938, P.20) was used. The diagram was found to be more reliable than the diagram constructed by Tomita and based on extinction angles. As γ' was the refractive index usually obtained on cleavage plates an amount of .004 was added to the values of γ' to obtain the actual γ (Tomita 1934, P.47).

The composition of the olivine was determined from the optic axial angle using the curve constructed by Deer and Wager (1939, P.21).

B - PLATEAU BASALT.

The plateau basalt in Prinsen af Wales region was briefly studied in order to provide a general petrographical comparison with the upper inclined lavas.

The various types had been grouped according to mineralogical and textural characteristics. In the first place the presence or absence of olivine was considered to be of classificatory importance, and thus two major groups were established, i.e. olivine basalts and olivine free or olivine poor basalts. These two groups were further subdivided according to their porphyritic or non-porphyritic nature. In the porphyritic types plagioclase felspar is the main phenocrystic constituent.

(1) Olivine Basalt.

The basalts under this heading contain about eight volume - per cent. olivine. They have been divided into two groups based on textural features, onewith porphyritic plagioclase and the other is non-porphyritic. With the exception of a few specimens, the olivine is completely pseudomorphed by chloritic material. The optical data for the constituent minerals are determined in the slides 2206 and 2208, which are considered to be representatives of the corresponding groups, the porphyritic olivine basalt and the aphyric olivine basalts respectively.

(a) Plagioclase - Phyric Olivine Basalt.

Megascopically, the rocks contain large glomeroporphyritic groups of plagioclase, of yellowish-white colour. These are scattered in a fine even-grained groundmass of grey to dark grey aspect.

The following specimens are classed as belonging to this group:-

2203, 2206	Lava flows, Urbjaerget.
2250	Lava flow 60' thick, half-way up to the top on Fredericksborg Nunataker.

Owing to the essential similarity of all the specimens a general account of the main characteristics will be given.

The plagioclase phenocrysts form large solitary crystals or glomeroporphyritic accumulations, the largest individual crystal attaining 3 mm. in length. Inclusions of iron ore and olivine or its pseudomorphs are commonly seen in the plagioclase. The latter when appearing are restricted to the peripheral parts. Albite, Carlsbad and pericline twinning are common. As determined by the immersion liquid method, the plagioclase shows a composition of 66 - 68% anorthite, i.e. a basic labradorite. Olivine is represented mainly by pseudomorphs of brown iddingsitic material, which sometimes retain the original crystal form.

The clinopyroxene occurs as microporphyritic crystals, and in subordinate amounts to the plagioclase and the olivine. The grain size is serial, and grades into that of the groundmass. It is generally of brownish tinge. The following optical data were obtained for the pyroxene:-

$2V_{\gamma} = 50^{\circ}$ $c/\gamma = 38$, suggesting $Wo_{34}\ En_{52}\ Fs_{14}$*

In the groundmass, the plagioclase occurs as small laths of .2 mm. length, of divergent orientation. Twinning is mainly on the albite and carlsbad laws. According to maximum symmetrical extinction angle, the plagioclase is labradorite of 55% An. The pyroxene appears in the interstices between the plagioclase laths as small grains of rather irregular outline. It has the same brownish tinge as that of the porphyritic crystals. Its relation to the plagioclase is generally subdoleritic (Krokstrom 1932, P. 199) as the plagioclase laths are not affected by the pyroxene.

Iron ores are abundant, occurring as large lumps and fine grains and indicating an earlier as well as later period of crystallisation.

Abundant brownish chloritic material is distributed

* See page 34.

in the groundmass.

According to micrometric measurements (Dollar stage) the mineral composition is as follows: (vol. - %)

Plagioclase	Phenocrysts	24%
	Groundmass	25
Olivine	Phenocrysts	7
Pyroxene	Phenocrysts	3
	Groundmass	27
Iron Ore		6
Chloritic material and glass		8

(b) Aphyric Olivine Basalt.

This group is represented by the following specimens:-

2190	Prinsen af Wales Bjaerge, at 2° dip arrow (cf. map)
2204	" " " " " " " " " "
2205	Urbjærget
2208	"
2247	Frederiksborg Nunataker.
2246	" "

Megoscopically the rocks are of dark grey colour, and fine grained texture.

In this section, the main constituents are found to be in order of abundance: Plagioclase, pyroxene, olivine and iron ores. Chlorite occurs as a secondary product mostly after olivine. Interstitial glass occurs in variable amounts. Apatite is almost completely absent.

Plagioclase occurs in laths of divergent orientation, and with idiomorphic outlines. They may attain a length of .5 mm., but on the average are about .2 mm. Twinning is mainly on albite and carlsbad laws. The anorthite content is 64% (immersion liquid method). Clinopyroxene is of a brownish grey hue, and occurs as irregular grains enclosing grains and rods of iron ores. In coarse grained rocks, the pyroxene shows an ophitic tendency towards the plagioclase. In fine textured types the pyroxene is in fine grains occurring interstitially between the felspar laths in subdoleritic relationship. Twinning is seen in a few cases, parallel to (100). The following optical determinations were made for the pyroxene:

$$2V_{\gamma} = 49^{\circ} \qquad c/\gamma = 42 \qquad \mathrm{Wo}_{32}\ \mathrm{En}_{50}\ \mathrm{Fs}_{18}$$

$$\gamma' = 1.701\ (\pm .003)$$

consequently the pyroxene belongs to the diopsidic series and not pigeonitic. Moreover, it does not differ greatly in composition from the pyroxene of the felsparphyric olivine basalts.

Olivine occurs as microporphyritic crystals in different stages of alteration. The crystals are generally rounded in outline and rarely show idiomorphic forms. Several shades of colours are shown by the chloritic material which pseudomorphed the olivine. The common type is the brown iddingsite which may completely replace the olivine. Lemon yellow and deep green chlorites are also met with, replacing the olivine. The fresh olivine is generally colourless. It has an optic axial angle ($2V_{\alpha}$) of 89° (Fedorow stage), indicating a fayalite content of 15%.

The mineral composition was determined on the Dollar integrating stage, and gave the following volumes:- (Vol. - %)

Plagioclase	37%
Pyroxene	38
Olivine	8
Iron ores	4
Chlorite and glass	13

(2) Basalts (with subordinate olivine).

This group comprises those basalts with a subordinate or negligible olivine content. The olivine has not been found fresh in any of the specimens studied, but its original presence is shown by its pseudomorphs. As in the previous group, two types have been recognised, based on textural features, viz. plagioclase phyric basalt and aphyric basalts.

among the second types are included tholeiitic basalts.

(a) Plagioclase Phyric Basalt.

This group of lavas is represented by the following specimens:-

2201 Urbjaerget lava blocks 400 feet above lowest flow.

2213 Nn. Nunataks, N.W. of Camp (cf. map), highest lava

2236 Nn. Nunataks, N.N.E. of Camp (cf. map), lowest flow; 50 ft. thick and vesicular throughout.

Megascopically the rocks are distinctly porphyritic with large glomeroporphyritic accumulations of yellowish-white plagioclase crystals embedded in a fine-grained and grey-coloured groundmass. Vesicles are usually met with, filled with dark green chloritic material and zeolites. The vesicles are generally small, about 2 mm. diameter.

In thin section, the main constituents are:- Plagioclase occurs in large tubular crystals which may attain 4 mm. in length. Inclusions of pyroxene and iron ores are commonly seen along cracks and cleavage planes. In most cases the crystals show an idiomorphic habit against the surrounding groundmass. According to maximum extinction angle and immersion liquid method, the anorthite content of the plagioclase is 60-65%, i.e. calcic labradorite. Zoning is not conspicuously developed, only in a few cases is it seen as either patchy extinction or fine multiple zones of the discontinuous type.

The size of the plagioclase phenocrysts shows a gradual transition into that of the groundmass. The average size in the latter is about .2 mm. The plagioclase occurs as thin laths of divergent orientation. The composition is found to be nearly the same as that of the phenocrysts.

Pyroxene occurs as fine granular crystals between the plagioclase laths, in a subdoleritic relationship. It is of brownish tinge and irregular outlines. The extinction angle c/γ is about 39° - 42°. The optic axial angle is about 45°, as estimated from the curvature of the isogyre in an optic axis figure.

Olivine pseudomorphs are mainly composed of chloritic material of brown and dark green varieties.

Iron ores are abundant as grains and elongated thin laths. Ill-defined brownish chloritic material, other than the olivine pseudomorphs is abundant as interstitial infilling between the other constituents. Interstitial brown glass is fairly abundant, and in many cases is accompanied by chlorite material enclosing abundant iron ore dust and skeletal rods.

The mineral composition as determined by micrometric measurement is as follows: (Vol. - %)

Plagioclase	Phenocrysts	18
	Groundmass	27
Olivine pseudomorphs		2
Pyroxene (Groundmass)		31
Iron ore		7
Chlorite and glass		15

(b) Aphyric Basalt.

The following specimens have been classed as belonging to this group:-

2197	Urbjaerget, lowest lava, 30' thick.	
2198	"	a second flow upward from 2197
2199	"	100' above 2197
2200	"	200' above 2197
2202	"	Top flow.
2203	"	second flow downwards next to 2202.
2207	"	sixth lava downwards from 2202.
2211	Nn. Nunataks, 2½ miles N.W. of Camp (cf. map) 20' thick and with platy jointing parallel to flow.	
2214	As 2211, but at higher horizon.	

2234 N.N.E. of Camp in Nn. Nunataks, highest flow of the horizontal plateau basalt.

2235 As 2234, but below it.

2248 South-most of the Frederiksborg Nunataks.

These rocks, megascopically, are all of a greyish dark colour; their grain is generally fine; the vesicles vary in abundance. In some specimens the vesicles are very abundant and their outlines are generally marked by dark bluish-green chloritic material along the borders. Zeolites, calcite and chalcedony are the common materials filling these cavities.

In thin section, the main minerals are found to be in order of abundance: plagioclase, pyroxene and iron ores. In general aspect, these non-porphyritic rocks are quite similar to the groundmass of the felspar phyric basalts both mineralogically and texturally.

The plagioclase as a rule is perfectly fresh, and occurs in laths of .2 mm length. Some laths may attain .8 mm. length, thus showing a microporphyritic tendency. These types may be considered as transitions to the typically porphyritic group (a). The average composition of the plagioclase according to maximum extinction angle is about 55% An. The clinopyroxene occurs as irregular crystals of faint brownish colour, and of a grain size of the same magnitude as the plagioclase. The texture varies; in certain cases the pyroxene - plagioclase relationship approaches ophitic texture, while in other cases it is subdoleritic (Krokström 1923, P. 199). Both relations may occur side by side in the same slide. The extinction angle c/γ for the pyroxene is about $38^{\circ} - 41^{\circ}$.

Iron ores are abundant as irregular grains and lobed individuals. Sometimes the plagioclase laths protrude into the grains of ore, which also may contain pyroxene grains.

Abundant chloritic material is distributed interstitially between other constituents as well as lining vesicles filled with green almost isotropic glass.

The following mineral composition was determined by micrometric measurements on Dollar's integrating stage (Vol. - %) :-

Plagioclase felspar	46%
Pyroxene	30
Olivine	3
Iron ores	10
Chloritic glass	11

Sample 2201 belongs to this group, but with abundant secondary material consisting mainly of zeolites which occur as infillings of cavities.

Compared with the rocks of this group, No. 2207 has a high content of glass and vesicles. The glass is of brownish colour and encloses abundant iron ore dusts and fine rods. This feature is quite similar to the groundmass of the plagioclase phyric rock No. 2201, which occurs in the same locality but at lower level. The vesicles are vermicular in form and are lined with fibrous deep green chloritic material with an outer thin band of light yellow chlorite. The central part of the vesicles is filled with isotropic analcite.

This rock shows a close similarity to an analysed tholeiitic basalt (E.G. 1057) described from Kap Dalton (Wager 1935, P. 15). The mineral composition for both rocks (micrometric measurement), is given below for comparison (Vol. - %) :-

	E.G. 2207	E.G. 1057
Plagioclase	40%	35%
Pyroxene	29	29
Iron Ore	5	7
Glass	15	29
Chlorite	11	

Zeolites.

Apart from the zeolites filling the amygdales in some of the described basalt flows, beautiful specimens have been collected from several localities. In these specimens the zeolites occur in most cases as idiomorphic crystals so that identification of the various members by crystal form was quite possible in handspecimen.

The zeolites are represented by the following specimens:-

2251 Chabasite and heulandite; most southerly of the Frederiksborg Nunataks. They occur in most of the lava flows.

2256 Chabasite; from two porphyritic basalts (2245 - 2295) on Christian IV. It is accompanied by thomsonite.

2264 Chabasite; N.E. Nunatak of Frederiksborg group.

2265 Stilbite; same locality as 2264; top surface of a flow.

Chabasite forms bright well-developed rhombs. Twinned crystals are common. The crystals range in size from about 1 cm. to 3 mm. R.I.(n) between 1.483 - 1.489 (±.002). It may be associated with heulandite and thomsonite.

Heulandite occurs in idiomorphic elongated crystals, with lustrous and bright faces. The crystals may attain a maximum of 3 mm. length. R.I.(n) is between 1.494 and 1.498 (±.003). When associated with thomsonite, the latter

	appears as swellings with pitted surface, with a radiating arrangement in cross section.
Stilbite	is found as white radiating crystals. Large crystals or groups of small crystals of calcite are commonly found in the centre of the radiating stilbite.
Thomsonite	usually accompanies the chabasite and heulandite. It has a botryoidal form and a greenish or brownish white colour. R.I.(n) is between 1.494 and 1.501.

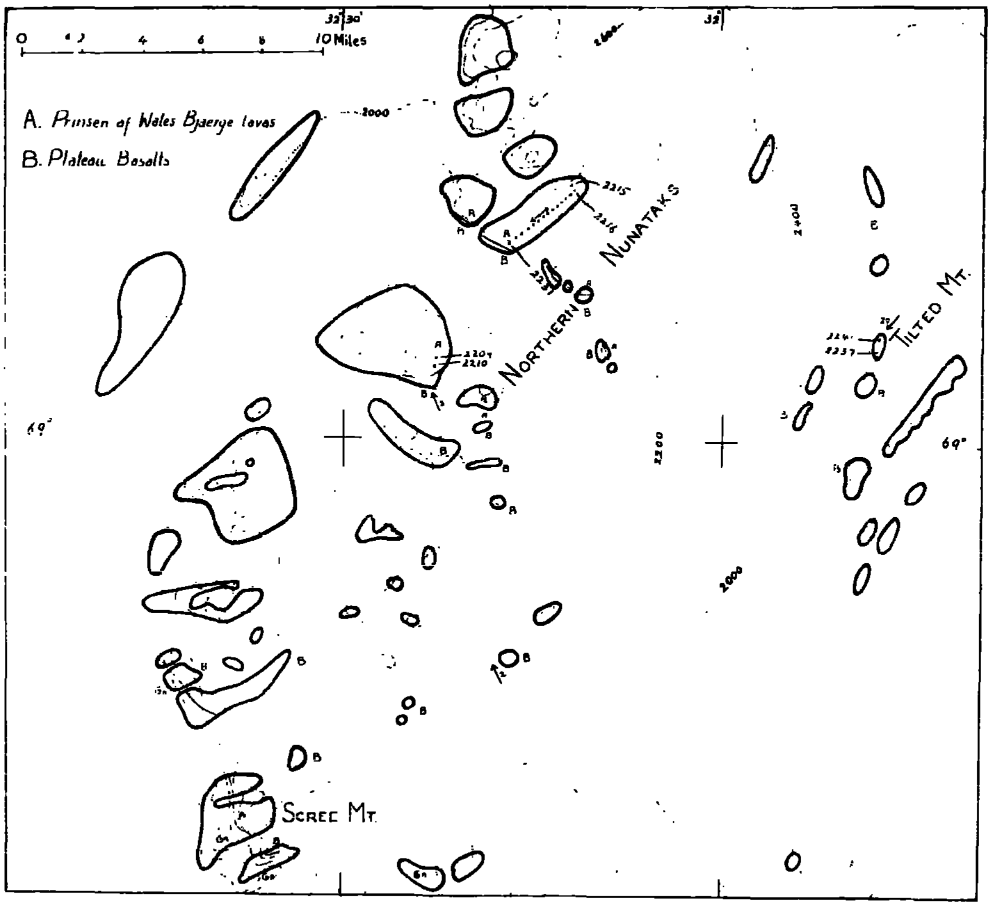


Fig. 3.

Localities of the specimens described from N. Nunataks and Tilted Mt.

C - PRINSEN AF WALES BJAERGE LAVAS.

In the following petrographical description, subdivision has been made into two minor areas, namely the Nn. Nunataks and the Tilted Mountain (fig. 3). This subdivision is thought to be convenient as the two localities are separated by a wide strip of land, and also they show some petrographical differences. The Nn. Nunataks lavas will be described first as they are represented by more specimens and show a greater petrographical variation.

Northern Nunataks.

In the following petrographical description, the rocks were classed into two major groups based on textural features, i.e. porphyritic and non-porphyritic groups.

1 - PORPHYRITIC GROUP.

The rocks of this group are all conspicuously porphyritic and the phenocrysts can be easily detected by the naked eye. In classifying this group it has been found appropriate to use the occurring dominant type of phenocrysts as basis for this classification. The first group (a) is characterised by abundant olivine phenocrysts. In the second group (b) the pyroxene forms the main phenocrysts. In these two groups (a and b) plagioclase

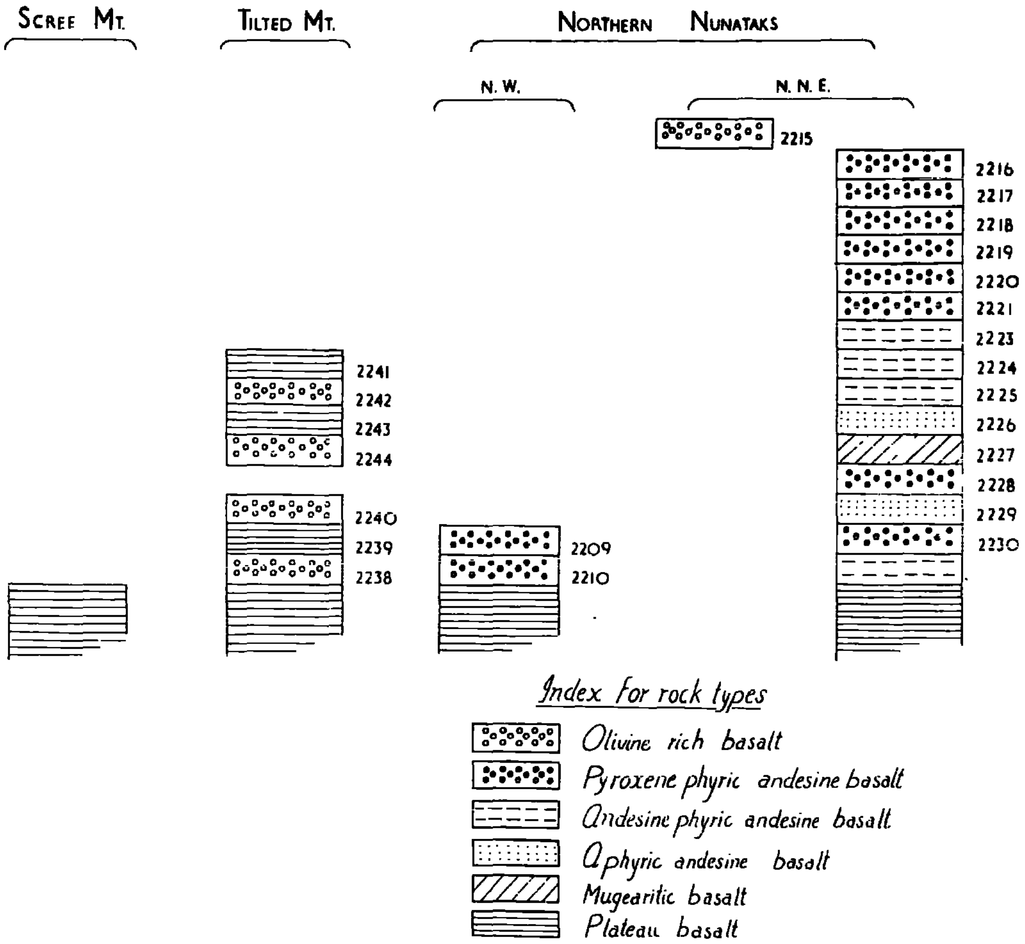


Fig. 4

Diagramatic representation of the order of succession of the Prinsen af Wales Bjaerge Lavas.

felspar is not present among the phenocrysts. For the third group (c) the appearance of the plagioclase is thus characteristic and is accompanied by subordinate amounts of olivine and pyroxene.

The characteristic features of these various types are summarised in the accompanying table 22, and their vertical order of succession is diagrammatically represented in fig. 4.

(1) PORPHYRITIC GROUP.

(a) Olivine-rich Oligoclase Basalts.

This group is represented by a single sample, E.G. 2215, of a top flow on a subsidiary summit N.W. of the locality of the other lavas (see fig. 3).

Megascopically the rock is dark grey in colour with abundant yellow porphyritic crystals of olivine 4 mm. in character, except for rare pyroxene no other phenocrysts are seen with the olivine. The phenocrysts are embedded in a dense aphanitic groundmass. The weathered surface is covered by a thin lustrous serpentinous skin of yellowish green colour. This surface shows olivine phenocrysts coated with brownish alteration products and empty cavities due to their removal.

In thin section, the phenocrysts are seen to be formed mainly of olivine with subordinate pyroxene and iron ore. The groundmass is made for the greater part of pyroxene

Fig. 5

Rock types of the Prinsen af Wales Bjaerge lavas
(Magnification x35)

2215 Olivine rich oligoclase basalt. The groundmass is dominated with pyroxene prisms. Felspar is interstetial, white patches and becomes coarser near the porphyritic constituents.(P33).

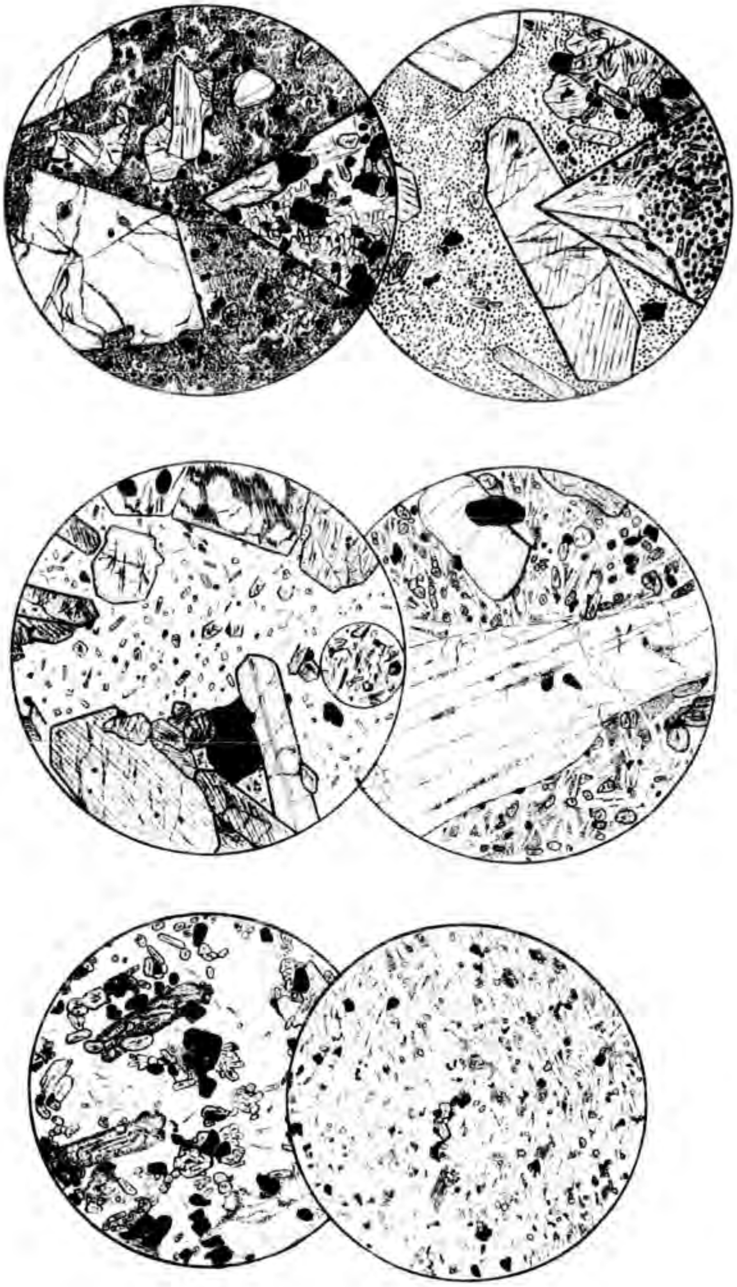
2216 Pyroxene phyric andesine basalt (normal development). Rock shows pyroxene, olivine and iron ore phenocrysts in a fine grained groundmass rich in iron ore. The white interstetial areas are composed of felspar and fine grains of pyroxene. (P43).

2228 Pyroxene phyric andesine basalt (glassy development). The groundmass is formed mainly of glass (white) with microlites of pyroxene. (P57).

2225 Andesine phyric andesine basalt. The minerals present are phenocrysts of: andesine (middle of the field), olivine (upper part), pyroxene and iron ore, in a groundmass of plagioclase and pyroxene. (P71).

2226 Andesine basalt. The field shows chlorite pseudomorphs after olivine, rounded grains of pyroxene and iron ore. The white area is of low double refracting felspar.(P82).

2227 Mugearitic basalt. The constituent minerals are the same as the previous rock, but the rock differs in being of trachytic texture.(P87).



2215 2216

2228 2225

2226 2227

Fig. 5.

and interstitial felspar (Fig. 5 and Pl. I, Fig. 1).

The mineral composition was determined on the Dollar's integrating stage and the following results were obtained (Vol. - %) :-

Phenocrysts	36%	Olivine	29
		Pyroxene	3
		Iron Ore	2
Groundmass	64%	Pyroxene (few olivine)	36
		Leucocratic minerals (felspar analcime apatite)	21
		Iron Ore	9

The olivine phenocrysts occur as fresh well-shaped crystals. Alteration is only seen along borders and cracks where brownish green chloritic material is developed. Cleavage parallel to (010) is distinct. The following optical properties were determined for the olivine:-

$2V_{\alpha} = 88\ (\pm 1)$ (Fedorow stage)

γ' 1.704 (± .004) (Immersion liquid method).

These values correspond to a fayalite content of 17%.

The pyroxene phenocrysts occur as prismatic crystals up to a maximum of 4 mm. in length. It is of brownish colour with a purplish tinge and feeble plechroism (X brownish green $=$ Z $<$ Y slightly darker brownish tinge). Inclusions of rounded crystals of olivine and

and iron ore are commonly seen in the pyroxene. Twinning is sometimes encountered parallel to (100). Zoning is sometimes seen as irregular undulous extinction. When it is regularly developed, the following optical data for the centre and margin were obtained:

Centre $2V_\gamma = 56^\circ$ Margin $2V_\gamma$ 54° (Fedorow stage).

The average composition of the pyroxene was derived by optical measurements for 2V and c/γ in fairly homogenous crystals and the results are given below:

$2V_\gamma$	= 59°	c/γ	$44^\circ \pm 1^\circ$ (Fedorow stage)
	54° (small crystal)		
Average 2V	57°	c/γ =	44°

According to Tomita's determinative diagram these vol~~ume~~ues correspond to a composition of Wo_{45} En_{30} Fs_{25}

Although these determinative diagrams, as well as others concerned with pyroxenes, deal mainly with pyroxene series free from the R_2O_3 group which the present pyroxene may well contain, it is worth using these diagrams to determine the approximate composition. According to Winchell (1935) the presence of Al_2O_3 would tend to increase the extinction angle by $3^\circ - 5^\circ$, so the change in composition will be along a line parallel to the $MgSiO_3 - FeSiO_3$ side of the triangle. According to this displacement the $CaSiO_3$ will be very slightly affected, while the $MgSiO_3 : FeSiO_3$ will show a marked variation.

In the groundmass, pyroxene occurs as fine prismoids and rounded grains varying from .04 - .02 mm. in diameter. They form the dominant constituents among which interstitial felspar occurs. The felspar occurs as interlocking grains rarely twinned and accompanied by analcime in some cases. Near some of the porphyritic crystals, the felspar is seen to develop into laths .2 mm. in length with irregular twinning. Maximum symmetrical extinction angle showed that their composition is around a value of 30% An.

Iron ore is abundant. Magnetite is the dominant ore, present as small grains and octahedra. It has a wide range in size and seems to belong to both early and late periods of crystallisation. Subordinate amounts of skeletal rods, probably ilmenite are also present. Haematite occurs rarely as reddish brown flakes.

From the microscopic study of the mutual relationships of the mineral components, the order of crystallisation seems to be as follows:

Olivine, iron ore, pyroxene and felspars.

Chemical Analysis.

The rock No. 2215 was subjected to a chemical analysis and the results are given in table 1.

Table 1. Analysis 1.

Olivine-rich Oligoclase Basalt. Specimen 2215.

	Weight %			Norm.		
SiO_2	43.26	or.		6.84		
Al_2O_3	5.88	ab.		12.00		
Fe_2O_3	3.66	an.		4.81		
FeO	11.66	np.		1.42		
					Sal	25.07
MgO	17.86					
CaO	8.96	di		28.26		
Na_2O	1.73	$CaSiO_3$	14.78			
K_2O	1.16	$MgSiO_3$	10.43			
H_2O	1.41	$FeSiO_3$	3.05			
H_2O	0.20	ol.		31.35		
TiO_2	3.55	$2MgO\ SiO_2$	23.70			
P_2O_5	0.64	$2FeO\ SiO_2$	7.65			
MnO	0.22	Mt.		5.31		
		Il.		6.73		
	100.19	Ap.		1.51		
S.G.	3.20				Fem	73.16
						1.41
						99.64

IV : 2 : 3 : 2 : 2 (Uvaldose)

Niggli Values.

si	79		
al	6	ti	4.9
fm	72	mg	0.68
c	18	k	0.30
alk	4	p	0.55

Plag.	Ab 71	An 29	
Di	Wo 52	En 37	Fs 11
Ol	Fo 76	Fa 24	

Table 2. Comparisom.

	A	1	2	3	4	5
SiO_2	43.26	45.20	46.57	47.19	48.48	43.27
Al_2O_3	5.88	6.60	7.81	10.95	8.47	7. 54
Fe_2O_3	3.66	5.36	2.40	3.31	2.72	2.22
FeO	11.66	8.01	8.91	10.21	8.66	6.18
MgO	17.86	18.14	19.74	10.52	11.82	17.65
CaO	8.96	8.02	10.65	9.73	10.56	13.72
Na_2O	1.73	1.29	1.70	4.69	3.15	1.26
K_2O	1.16	1.71	0.33	0.93	0.54	1.14
H_2O+	1.41	0.65	0.11	0.17	11.9	0.38
H_2O-	0.20	0.56	0.09	0.07	0.24	0.22
TiO_2	3.55	4.50	1.67	2.27	3.77	1.25
P_2O_5	0.64	0.34	0.34	0.55	0.33	0.38
MnO	0.22	0.19	0.13	0.16	0.11	n.d.
	100.19	100.57	100.45	100.75	100.04	95.21
Sp. G.	3.20		3.164		2.881	

Norm.

	A	1	2	3	4
Or.	6.84	10.01	1.67	5.56	3.34
Ab.	12.00	11.00	14.15	19.91	20.96
An.	4.81	7.23	12.79	6.12	7.23
Np.	1.42	-	-	10.79	3.12
Di.	28.26	21.92	30.26	30.96	41.14
Hy.	-	7.89	00.40	-	-
Ol.	31.35	21.92	34.14	17.29	12.66
Mt.	5.31	7.89	3.48	8.87	3.94
Il.	6.73	7.30	3.19	4.26	7.14
Ap.	1.51	0.67	0.67	1.34	0.67

A. Olivine rich oligoclase basalt (No. 2215).
Iv. 2. 3. 2. 2.

1. Picrite basalt IV. 2". 3. 22 flow. Hawaii (Washington and Keyes 1926, P. 347). Anal. Washington.

2. Picrite basalt, IV. 1. 3. 22. Mouna Kea, Hawaii (Washington 1923, P. 500). Anal. Washington.

3. Chrysophyric oligoclase basalt III. 6. 2. 5. Mouna Kea, Hawaii (Washington 1923, P. 500). Anal. Washington.

4. Olivine oligoclase basalt (III). IV. 2". 2. 2. 2. Mouna Loa, Hawaii (Washington 1923, P. 115 - 116). Anal. Washington.

5. Ankaramite, Ankaramy, Madagaskar (Quoted from Troger 1935, P. 177 - 178).

The rock is characterised by low content of silica and aluminium. Magnesia content is high and is in accordance with the modal composition as shown by abundant olivine and pyroxene. The titanium dioxide is fairly high and it probably exists for the major part as ilmenite and partly in the pyroxene as indicated by its purplish tinge. The low aluminium content corresponds well with the modal percentage of the felspar which is dominantly oligoclase and forms 10% - 15% of the whole rock.

When attempting to classify this rock certain difficulties are encountered. No analysis is found in Washington's tables (1917) under the same subrang that can be said to show satisfactory agreement. The nearest approach to the present rock is in the picrite basalts and olivine oligoclase basalts from the Hawaiian Islands described by Washington (1923, P. 498). The term picrite basalt has been used for olivine-rich rocks with subordinate felspar, 37.5% - 12.5% relative to femic constituents (Cross 1915, Holmes 1916, Washington 1923). Washington in his study on the Hawaiian lavas (1923) recognised another group related to the picrite basalt which he classified as chrysophyric oligoclase basalt. As in the picrite basalts, this group is characterised by abundant olivine phenocrysts but differs in having the salic and femic minerals in about equal amounts. Moreover, the modal and normative plagioclase in the chrysophyric oligoclase basalt ranges from oligoclase andesine to andesine, while in the picrite basalt it is always labradorite.

The picrite basalts (Columns 1 and 2, Table 2) have a general chemical similarity to the Greenland rock, but differ in detail.

The chrysophyric oligoclase basalt, columns 3 and 4, are comparable in many respects to the present rocks.

Both modal and normative plagioclase is the same, being oligoclase. The petrographical description as given by Washington for these rocks also agrees well with the microscopic date for the Greenland rocks.

The rock is also chemically comparable to the ankaramite (Col. 8) described by Lacroix (1923, P.48-50). The comparison is further elucidated by comparing Niggli values for both rocks (Niggli values for the ankaramite are calculated by Tröger 1935, P.178):-

	E.G. 2215	Ankaramite (Col. 8).
si	79	80
al	6	8.5
fm	72	61
c	18	27
alk	4	3.5
k	0.30	0.37
Mg	0.68	0.79

In both rocks the groundmass is dominated by pyroxene while the felspar is subordinate. The ankaramite differs, however, in having labradorite in the groundmass and the phenocrysts are mainly of pyroxene and less olivine.

In view of the above considerations, it is found convenient to designate the present rock by the term olivine oligoclase basalt, as the chemical and modal differences are sufficiently great to distinguish it from picrite basalts.

(b) Pyroxene phyric Andesine Basalt.

The following specimens have been classed as belonging to this group:-

(i) Normal development (crystalline groundmass):-

2216 Nn. Nunataks, highest flow on a subsidiary summit, 200 yds. S.E. of 2215.
2217 Lava flow below 2216
2218 " " " 2217
2219 " " " 2218
2220 " " " 2219
2221 " " " 2220
2230 " " below~~est~~ 2229 flow. In thes locality ~~where~~ the above lavas rests ~~occur~~. on 2231 which ~~It~~ rests on the plateau basalt series.

(ii) Glassy development (glassy groundmass):-

2228 Nn. Nunataks, thin flow among the nonporphyritic flow. Same locality as the above.
2209 From a hill, West of where the other lavas occur.

With the exception of the flow represented by the sample 2209, the lavas belonging to this group are closely associated in the field, forming for the greater part of the successive series of flows.

Normal Development.

The rocks are generally porphyritic, with megaphenocrysts of pyroxene as well shaped crystals in some cases. The pyroxenes are the most common phenocrysts, 4 mm. in average length, although in some rocks they may attain 15 mm. Olivine occurs rarely as brown glassy-looking crystals. The groundmass is dark grey and aphanitic. The grain size may, however, vary, probably indicating different rates of cooling. A few vesicles are present, filled with zeolite material and calcite in some cases. In some of the specimens, flow texture is noticed and shows itself megascopically by the parallel arrangement of the pyroxene phenocrysts.

In thin section, the main phenocrysts are found to be in order of abundance:- pyroxene, iron ore and olivine. These are embedded in a fine-grained groundmass formed of felspar, pyroxene, iron ore, apatite, analcime, zeolite, chlorite and glass (Fig. 5, and Pl. 1, Fig. 2.).

In Table 3 the mineral composition of the rocks belonging to this group is given, as determined by micrometric measurements on Dollar's integrating stage, (Vol.-%)

Table 3. Micrometric Analyses.

Specimens.	Phenocrysts				Groundmass.			
	Pyroxene	Olivine	Iron Ore	Total	Leucocratic Min.*	X Fe-Mg Mins.	Iron Ore	Total
2216	23	5	5	33%	29	4	34	67%
2217	14	8	5	27	38	8	27	73
2218	15	6	3	24	-	-	-	76 ø
2219	24	8	8	40	33	18	9	60
2220	19	9	5	33	44	4	19	67
2221	31	6	3	40	38	19	3	60
2230	5	5	2	12	46	27	14	87

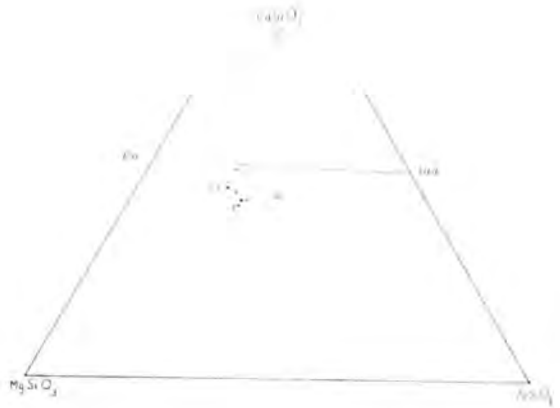
* Leucocratic minerals include: Felspars, analcime and apatite.

X Feromagnesian minerals include: mainly pyroxene and subordinate olivine or its pseudomorphs.

ø The fine-grained nature of the groundmass prevented complete integration.

Owing to the essential similarity of these lavas both mineralogical and textural, a detailed petrographical description will not be given, but instead a general account of their characteristics, stating any special features where necessary.

The pyroxene phenocrysts occur as solitary crystals or in glomeroporphyritic groups. It is of brownish

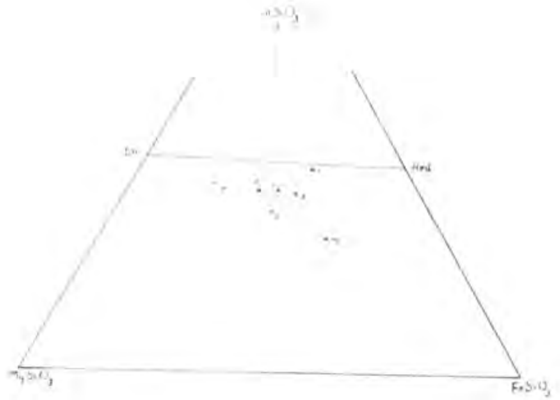


Composition of the clinopyroxenes according to 2V–γ

Fig. 7.

o Querage composition as deduced from fig. 6

× " " " " " 2V–γ



Composition of the clinopyroxenes according to 2V–C/γ

Fig. 6.

c Centre

M Margin

colour with a purplish tinge which is sometimes seen to be stronger at the borders than the centre, where it displays a feeble pleochroism. The crystals are generally subidiomorphic, although in some cases they may show an idiomorphic tendency. Inclusions of olivine and iron ore may occur in the pyroxene which suggest an earlier crystallisation than the latter. Twinning is not infrequent parallel to (100). The trace of the composition plane is often marked by coloured bands. In a few cases regular zoning is found as multiple thin layers, and the following optical date were obtained (Fedorow stage):

Specimen 2216 Centre $2V_\gamma = 57^\circ$ c/γ 44.5

Wo	En	Fs
42	28	30

Margin $2V_\gamma = 52^\circ$ c/γ 46

Wo	En	Fs
31	24	45

In Table 4 the values of 2V, c/γ and γ' for the pyroxenes of the various specimens belonging to this group are given.

Figs. 6 and 7 show their position within the determinative triangular diagrams constructed by Tomita, based on $2V - c/\gamma$, and Deer and Wager, based on $2V - \gamma$, respectively (Tomita 1934, Deer and Wager 1938).

The two types of diagrams, as has been mentioned in previous pages are not strictly applicable to our

Table 4. Optical Date on Pyroxene Phenocrysts.

Specimens No.	2V	c/γ	γ'
(1) 2216	60 - 58 58 57 centre 52 margin	45 45 44.5 46	 1.713 (±.005)
(2) 2217	54 52	 44-45.5	 1.713 (±.005)
(3) 2218	57 55	 45-46	 1.709 (±.001)
(4) 2219	54 54	43 42	 1.713 (±.005)
(5) 2230	56 55	44 -	 1.709 (±.002)
Average	56 (±3)	44 (±2)	1.711 (±.003)

pyroxenes, as they only refer to pyroxenes free from the R_2O_3 group, whereas the present pyroxenes probably contain appreciable quantities. The presence of alumina will tend to increase the extinction angle by 3° - 5°. According to this displacement, the composition will only vary slightly with regard to the Ca SiO_3, while the quotient Mg SiO_3 : Fe SiO_3 will show a marked variation. The refractive indices on the other hand are not affected by the presence of other constituents (Deer and Wager 1938). This fact is brought out in Table 5, which gives the composition (in (Vol. - %) of Ca SiO_3, Mg SiO_3 and Fe SiO_3

according to the two determinative diagrams.

Table 5. Metasilicate Proportions of Pyroxene according to $2V - c/\gamma$ and $2V - \gamma$

Specimens No.	$2V - c/\gamma$			$2V - \gamma$		
	Wo	En	Fs	Wo	En	Fs
2216	47	19	34	50	34	18
2217	37	32	31	40	38	22
2218	41	25	34	44	38	18
2219	42	39	19	41	37	22
2230	42	32	26	44	38	18
Average	42	29	29	43	37	20

From the above considerations it seems rather probable that the actual compositions are better pictured by the refractive index determinative diagrams than by the one based on extinction angles. The average composition of the pyroxene of the whole group may be adequately represented as $Wo_{44}\ En_{36}\ Fs_{20}$

The olivine phenocrysts are subordinate to pyroxene. The crystals are generally subidiomorphic. Alteration in most cases is confined to the borders and cracks where brownish green chloritic material and brown iddingsite are developed. The intensity of alteration is noticed to vary according to the nature of the groundmass. In the extremely fine-grained types the olivine is strongly altered and may be pseudomorphed by iddingsite accompanied by brownish green chlorite. Cleavage parallel to (010) is infrequently developed. Optic axial angles as determined by Fedorow stage are given in Table 6, with the corresponding Fayalite percentage (Winchell 1927). The average composition of the olivine phenocrysts in the whole group may be represented as $Fo_{73} Fa_{27}$

Iron Ore occurs as irregular individuals varying in grain size between phenocrysts and small grains in the groundmass.

Table 6. Optic Axial Angles and Fayalite Content of Olivine Phenocrysts.

Specimens No.	2V	Fa %
2217	86 86-87 } - 86.5	23
2219	82-83 82 } - 82.5	32
2230	85 84 } - 84.5	28

In the groundmass the pyroxene occurs as fine rounded grains and prisms, .02 mm. in length. It is of pale greenish colour and sometimes shows a brownish tint. Cleavage is poorly developed and is in many cases lacking.

Olivine is found in subordinate amounts as small rounded grains, which for the greater part is pseudomorphed by green chloritic material. Felspar dominates over the other constituents. It occurs as irregular interlocking grains and also as fine laths (.04 mm. length), rarely showing perfect twinning. The laths in most cases show a parallel extinction or an angle of a few degrees (4^{o}) indicating an oligoclase composition. In some parts of the slide, the laths may attain .14 mm. in length. This effect is more noticeable in several cases near the porphyritic crystals. Analcime and apatite are abundant among the felspar. Iron ore is generally abundant as isometric grains, octahedra and elongated rods. Few vesicles are found filled with pale brownish zeolitic material, which may be lined with chlorite.

The specimen No. 2221 has a slightly coarser groundmass, but the general mineralogical and textural features described above are retained. In the groundmass the felspar occurs in distinct laths of .2 mm. length, but is also quite common as allotriomorphic grains. According to the immersion liquid method it is seen to be an oligoclase of 13% An. (Np' 1.534, Ng' about 1.542). Abundant apatite needles are enclosed by the felspar. The pyroxene in the groundmass has a brownish tinge and sometimes shows crystal boundaries. The olivine occurs as partially or completely altered rounded individuals. Analcime in noticeable amounts is present interstitially among the felspars. Abundant zeolitic material of yellowish colour occurs interstitially forming irregular patches with sharp angles in some cases. The felspar laths and pyroxene may be seen to have sharp outlines when enclosed in these zeolitic areas.

The flow from which this sample 2221 was collected is cut by a pyroxene monchiquite dyke (2222). In hand specimen the rock is of basaltic nature, grey in colour and fine texture. In thin section it is found to be formed mainly of titaniferous pyroxene analcime and iron ore. The pyroxene occurs as fine prisms and grains and few microporphyritic crystals. Next in abundance to pyroxene is analcime occurring as allotriomorphic interstitial material. It is colourless and isotropic (N 1.487 - 1.49). Abundant apatite needles are enclosed in the analcime, and in many cases the needles show parallel arrangement. Iron ore is abundant as grains and elongated thin rods.

Sample No. 2218 belongs to the same group. Compared with the other rocks previously described, the olivine phenocrysts in this rock are intensely altered and completely pseudomorphed in many cases by iddingsite. Brownish green chloritic material may accompany the iddingsite, but the latter is, however, the dominant alteration product.

The groundmass also shows a marked difference from the previous rocks. It is highly charged with fine iron ore and with mesotasis of greenish colour which can hardly be resolved by the microscope. Under high power fine grains of pyroxene and felspar can be detected, which appear as fine birefringent specks between crossed nicols. These are embedded in a greenish to greenish-brown matrix probably of felspathic composition and glass. This material is also seen wedging between the phenocrysts and encloses abundant rods of iron ore. In some parts of the section this matrix is completely masked by the extreme abundance of iron ore.

Vesicles are commonly seen as small rounded cavities lined with fibrous green chloritic material. Away from the vesicles, the chlorite lining is seen to pass into a dark brown glassy-looking material through different shades of colour. Sometimes light and dark bands with an agate-like structure may be seen in these transitional parts. In several cases this occurrence suggests a replacement of the glass by chlorite at least around these vesicular areas.

Sample No. 2230 is similar in general features to the rest of the group but differs in having a rather coarse groundmass which exhibits in thin section distinct features as described below.

In handspecimen the rock is of dark grey aspect with abundant pyroxene phenocrysts. Reddish patches are abundantly distributed in the groundmass.

Under the microscope the rock is seen to be formed of clinopyroxene olivine and iron ore as phenocrysts. The grain size is, however, serial grading to that of the groundmass. The latter is composed of: felspar, pyroxene, olivine, analcime, apatite and iron ore. (Pl. II, Fig. 2).

The phenocrystic minerals show the same features as the rest of the group, and for which the optical data have been given in previous pages (Table 4). The pyroxene phenocrysts are irregular in outlines and of a rather distinct purplish tinge. The olivine is generally altered along borders and cracks into brownish-green and reddish-brown chloritic matter. The reddish-brown product has not been met with among the alteration products in the previously described rocks. It has a biotite-like appearance and distinct pleochroism. From the descriptions given by Krokstrom for some varieties of iron-rich chlorites, the present chlorite agrees with that referred to as ferrite (Krokstrom 1936).

In the groundmass the felspar appears as a base for the rest of the constituents. It occurs dominantly as clear untwinned allotriomorphic individuals. In a few cases irregular tabular crystals may be seen having lammellar twinning developed in the central part, the outer zone being clear. In both cases the crystals show wavy extinction probably ascribable to some inhomogeneity in composition The maximum symmetrical extinction angle of the twinned felspar is about 11° - 17° $(\widehat{X010})$, indicating an anorthite content of 28% - 34%, i.e. oligoclase andesine. The dominant untwinned felspar is, however, of lower refractive index than Canada balsam, and shows a positive sign indicating an approach to oligoclase-albite in composition. Pyroxene, olivine pseudomorphs and apatite are frequently enclosed in this felspar, in which case they develop idiomorphic forms.

The pyroxene is of the same aspect as the phenocrysts with a purplish tinge. It occurs in variable sizes and forms, with a general tendency towards development of prismatic habit. The idiomorphic crystals are more noticeable when enclosed in the albitic plagioclase which suggests that the pyroxene extended its crystallisation to late stages.

The olivine occurs mainly as pseudomorphs which may retain traces of their original crystal form. The pseudomorphs are generally of dark green chlorite, sometimes fringed with brownish chlorite similar to that seen in the phenocrysts.

Iron ore is abundant, frequently associated with flakes and shreds of the brown chlorite.

Apatite as a rule is abundant in the felspathic groundmass and occurs in the form of elongated needles which are sometimes seen intersecting the olivine pseudomorphs.

Biotite occurs as a few separate shreds of brown colour and distinct pleochroism, with occasional inclusions of apatite and iron ore.

Chemical Analysis:

The rock No. 2216 was subjected to chemical analysis, the result of which is given in Table 7.

The most conspicuous features in the analysis are the low content of alumina, high content of titania and iron oxides, with ferrous dominating over ferric. The percentages of the alkalies are high, soda dominating over potash. As the silica percentage is low, nepheline appears in the norm, although its presence in the section cannot be ascertained. The normative percentage of orthoclase is rather high and it probably occurs partly in solid solution with the plagioclase felspars and partly as a separate constituent in the groundmass. The high titania content seems to exist for the greater part in iron ore. It is also probable that appreciable quantities occur in the pyroxene, as indicated by its reddish tint. The high percentage of normative diopside is connected with the low content of alumina in the rock. As little alumina is left

Table 7. Analysis 2.

Pyroxene-Phyric Andesine Basalt. Specimen 2216.

	Weight %
SiO_2	44.16
Al_2O_3	8.34
Fe_2O_3	5.74
FeO	10.72
MgO	7.80
CaO	11.20
Na_2O	3.26
K_2O	1.75
H_2O	1.07
H_2O	0.40
TiO_2	4.47
P_2O_5	0.83
MnO	0.09
	99.83
S. G.	3.07

Norm.				
Or.		10.34		
Ab.		14.88		
An.		2.89		
Np.		6.87	Sal.	34.98
Di		37.99		
Ca SiO_3	19.72			
Mg SiO_3	13.04			
Fe SiO_3	5.23			
Ol.		6.37		
2 MgO SiO_2	4.41			
2 FeO SiO_2	1.96			
Mt.		8.33		
Il.		8.48		
Ap.		1.23	Fem.	62.40
			H_2O	1.47
				98.85

III. 6. 2. 4 (Monchiquose) Or : Ab : An 36 : 53 : 11

Niggli values.

si	95	ti	7.3	Plag.	Ab 83	An 17	
al	15	mg	0.46	Di.	Wo 52	En 34	Fs 14
fm	54	k	0.26	Ol.	Fo 69	Fa 31	
c	26	p	0.78				
alk	9						

after combination with the alkalies the major part of the lime goes to diopside. The norm in general is in accordance with the modal composition except for the low percentage of normative iron ores which is higher in the mode.

According to the quantitative system of classification which is based on analytical figures and calculated norms, the rock lies in the salfemane class. As the amount of nepheline is lower than that of felspars, the rock lies in the 6th order. The rang is the 3rd, the alkalies and salic lime being equal. With soda dominant over potash the subrang is the 4th, Monchiquose.

Glassy Development.

At a lower horizon than the upper porphyritic series described, a rather thin flow (No. 2228) occurs amongst the nonporphyritic group of lavas to be described later. This flow is also correlated with another flow (No. 2209) west of the locality of the other lavas.

Megascopically the rocks do not differ materially from the normal types, with pyroxene phenocrysts in a black to bluish black aphanitic groundmass.

Microscopically, they may be described as pyroxene phyric rocks in which the groundmass is composed entirely of brownish glass with abundant microlites of pyroxene and iron ore (Fig. 5, and Pl. II, Fig. 1).

The mineral composition of these rocks has been determined by micrometric measurements (Vol. - %) and the following results were obtained:-

		No. 2228.	No.2209.
Phenocrysts:	Pyroxene	15%	10%
	Olivine	5	2
	Iron Ore	4	2
Groundmass:	Glass and pyroxene microlites and iron ore	76	86
Sp. gravity.		(3.063)	(2.843)

The pyroxene phenocrysts are of a brownish colour with a purplish tinge. The crystals are idiomorphic to subidiomorphic with an average diameter of 2 mm. They tend to be in glomeroporphyritic groups with a stellate fashion. Inclusions of olivine and iron ore are occasionally seen in the pyroxene. Twinning is present with the composition plane parallel to (100), along which colour bands are frequently developed. Undulous extinction may be seen in some crystals which seems to be due to a zoning effect. When the latter is regularly developed, it takes the form of multiple thin layers. Estimation of the optic axial angle shows that it varies from 58° at the centre to 53° at the margin and may sometimes reach 46° at the extreme borders (Fedorow stage). This generally indicates an increase in $Mg\,SiO_3 - Fe\,SiO_3$ relative to $Ca\,SiO_3$ as crystallisation proceeds. In the more homogeneous crystals the following optical data were obtained:

Specimen 2228 $2V_\gamma = 55^\circ$ c/γ 45°
54° 43°
56°
Average $2V = 54^\circ$ c/γ 44° $\gamma' = 1.711$ ($\pm$ .003)

Specimen 2209 $2V_\gamma = 58^\circ$ c/γ 46°
57°
60°
Average $2V = 58^\circ$ c/γ 46° $\gamma' = 1.711$ ($\pm$ .002)

In Table 8 the composition of the pyroxene in terms of $Ca\,SiO_3$ $Mg\,SiO_3$ and $Fe\,SiO_3$ is given, according to the determinative diagrams constructed by Tomite and Deer and Wager.

Table 8. Metasilicate Proportion of Pyroxene according to 2V - c/γ and 2V - γ

Specimens No.	2V - c/γ			2V - γ		
	Wo	En	Fs	Wo	En	Fs
2228	42	32	26	43	38	19
2209	45	15	40	50	35	15
Average	44	23	33	46	37	17

The optical data for the present pyroxene are in good accordance with those for the pyroxene phenocrysts in the normally developed rocks.

The olivine phenocrysts are in most cases partially altered to iddingsite of brown and lemon yellow colour. Complete pseudomorphs are sometimes present with original crystal boundaries. In Specimen No. 2209 the olivine is generally much more altered than in Specimen 2228, but to the same alteration products in both cases. When fresh the olivine is colourless ~~with faint pinkish tinge~~ and distinct cleavage parallel to (010).

The following optical data were obtained for the olivine:-

Specimen 2228 $2V_{\alpha} = 84^{\circ}$

" 86°

Average $2V = 85^{\circ}$ Fa_{26}

Specimen 2209 $2V_{\alpha} = 85^{\circ}$

" 86°

Average $2V = 85.5^{\circ}$ Fa_{25}

Iron ore occurs among minerals of early crystallisation as lumps and grains of 4 mm. maximum diameter. They may show octahedral faces in a few cases.

The nature of the glass, however, is found to vary in both rocks. In rock No. 2228 the glass is of dark brown colour with rare vesicles. The refractive index of the glass as determined by the immersion liquid method shows an average value of 1.543 (± .003). According to George's determinative curve for the natural glasses (George 1924, P.365-366) this value corresponds to the following composition (weight-%) :-

SiO_2	55%
Al_2O_3	13.16
$FeO + Fe_2O_3$	9.5
MgO	3.3
CaO	6.3
Na_2O	3.7
K_2O	3.2

This composition lies within the andesitic field as shown by George's curves.

The glass in the rock No. 2209 is seen to be formed of two kinds; one is dominant of dark brown colour similar to that of the sample No. 2228, and the other is of light brown colour occurring as patches among the darker type. The two types grade into each other through different shades of colour. They are generally isotropic, although in some parts the lighter material may display a faint double refraction. Refractive index determinations were carried out on both types of glassy material and the following results were obtained:

<u>Sample No. 2209</u>	Dark brown glass	n	1.567 (± .005)
	Light " "	n	1.574 (± .003)

In contrast to No. 2228, abundant vesicles are found in the groundmass of the present rock. The vesicles are connected with a system of cracks traversing the section, and both are filled with zeolitic material and analcime. The analcime occurs in most cases as well-formed crystals lining the cavities, in which the centre is occupied by zeolite.

In view of the above microscopic observations, the light brown material seems to have been derived by a process comparable to that responsible for palagonite formation described by Peacock from Iceland. The Icelandic palagonite differs, however, from the present glass, being of lower refractive index. The difference in refractivity as well as specific refractivity of basaltic glass has been shown by Tilley to be influenced by certain constituents, even in quite small amounts, e.g. water, magnetite and ilmenite (Tilley 1922, P.289). The palagonitisation process has been considered to be a late thermohydrochemical one to which hydrous basaltic glasses are susceptible. The permeating solutions remove ferric ions which causes the bleaching of the original glass. Lime and alkalies are also removed in this process and may be fixed as calcite and zeolites in cavities (Peacock 1926, P.315).

Between the flow represented by the sample No. 2209 and the horizontal plateau basalt, occurs a flow (specimen 2210) which displays a new feature not seen in the rocks here described. Megascopically the rock is nonporphyritic, greenish-grey in colour and of a dense aphanitic texture. In thin section, the rock is seen to be formed of dominant pyroxene and iron ore in a very fine-grained groundmass. In some parts of the section there occur irregular patches of varying texture. Fine-grained patches highly charged with iron ore are usually seen enclosed in a coarser groundmass with fluidal arrangement of pyroxene thin prisms, .03mm in length, and parallel streaks of iron ore. Very few lemon-yellow iddingsite pseudomorphs are found with excellent crystal outlines reminiscent of olivine crystal. These occur as the only microporphyritic individuals. Under higher power objective the base for these constituents is found to be of greenish glass with patches of chloritic material.

Vesicles are commonly encountered filled with zeolitic material and analcime with chloritic material forming the lining along the walls. The analcime occurs in many cases as well-formed crystals along the walls of the cavities; the central part is filled with zeolitic material.

In the vesicular areas, abundant pyroxene prisms are seen projecting from the adjacent groundmass, as well as separate clusters floating in the infilling material. Sometimes, the pyroxene develops into coarse prisms .15 mm. in length and showing idiomorphic outlines with twinning parallel to (100) in some cases.

In general, these observations suggest auto-brecciation which took place probably before the final consolidation of the magma.

Apart from the nonporphyritic nature, this rock is comparable to the glassy pyroxene rock No. 2209. The close association of the corresponding flows and the presence of the pyroxene in preference to plagioclase, as early phases of crystallisation, would appear to indicate that both flows belong to the same stage of magmatic evolution.

Chemical Analysis:

The rock No. 2228 was subjected to chemical analysis and the results are given in Table (9), together with the norm.

As is seen by comparison with Table 7 (p. 55) the analysis of the glassy rock agrees fairly well with that of the normally developed type. The difference in state of oxidation seems to be related to the degree of crystallinity. ~~in both types.~~ The molecular ratio $FeO : Fe_2O_3$ in both rocks is:

Specimen 2216	$FeO : Fe_2O_3$	4.2
Specimen 2228	" "	7.7

Washington found that in many lavas ranging from rhyolites to basalts, ferrous dominates over ferric oxide in the glassy rock while it is the reverse in crystalline rocks of similar composition (Tilley 1922). Tilley in his study of natural glasses supports this conclusion reached by Washington (Tilley 1922). The present differences are in harmony with the character of the rocks, one having a crystalline-(No. 2216), the other having a glassy-groundmass (No. 2228)

The differences in normative percentage of anorthite

Table 9. Analysis 3.

Glassy Pyroxene Phyric Andesine Basalt. No. 2228.

	Weight %			Norm.		
SiO_2	44.74	Or		8.12		
Al_2O_3	11.87	Ab		16.77		
Fe_2O_3	3.33	An		13.37		
FeO	11.59	Np		6.08	Sal.	44.34
MgO	7.89	Di.		25.41		
CaO	10.13	$Ca\ SiO_3$	12.93			
Na_2O	3.31	$Mg\ SiO_3$	6.98			
K_2O	1.38	$Fe\ SiO_3$	5.50			
H_2O	2.03	Ol.		16.46		
H_2O	0.26	$2\ MgO\ SiO_2$	8.81			
TiO_2	2.13	$2\ FeO\ SiO_2$	7.61			
P_2O_5	0.89	Mt.		4.43		
MnO	0.20	Il.		4.04		
	99.75	Ap.		2.12	Fem.	52.86
					$H_2O^{\pm}$	2.29
						99.49
S.G.	3.06					

III. 6. 3. 4 (Liburgose). Or : Ab : An - 21 : 45 : 34

Niggli Values.

Si	97		
al	15	ti	3.5
fm	52	mg	0.49
c	24	k	0.22
alk	9	p	0.78

Plag.	Ab 57	An 43	
Di.	Wo 51	En 27	Fs 22
Ol.	Fo 54	Fa 46	

in ~~both~~ the rocks is a reflection of higher aluminium content in No. 2228, as more aluminium is present to combine with lime which consequently affects the amount of lime entering the normative diopside.

The ratio FeO : MgO is generally considered as an important quantity to indicate the position of the rock on the liquid line of descent. This ratio is found to be almost indentical in both rocks being 10.72 : 7.80 in No. 2216, respective to 11.59 : 7.89 in No. 2228.

According to this chemical similarity of the glassy and the normally developed rocks, it is found possible to group them together in one magmatic group.

Difficulty is encountered in attempting to classify these rocks according to their mineralogical and chemical characteristics. According to Iddings' classification which is based on normative mineral percentages, these rocks may be classified as basalts. In this classific-

Table 10. Comparison.

Please see overleaf.

	B	C	1	2	3	4	5
SiO_2	44.16	44.74	45.08	48.48	45.10	48.31	46.50
Al_2O_3	8.34	11.87	14.15	8.47	12.86	13.66	10.86
Fe_2O_3	5.74	3.33	2.28	2.72	5.66	2.67	2.70
FeO	10.72	11.59	8.89	8.66	7.10	8.80	12.77
MgO	7.80	7.89	7.01	11.82	8.56	6.34	6.27
CaO	11.20	10.13	10.20	10.56	9.10	8.82	11.04
Na_2O	3.26	3.31	3.99	3.15	3.99	3.27	2.69
K_2O	1.75	1.38	1.79	0.54	1.02	2.24	1.16
H_2O	1.07	2.03	0.75	11.9	1.53	0.83	1.99
H_2O	0.40	0.26	0.15	0.24	1.10	1.11	-
TiO_2	4.47	2.13	2.93	3.77	3.50	2.20	3.02
P_2O_5	0.83	0.89	0.62	0.33	1.00	0.80	0.64
MnO	0.09	0.20	0.22	0.11	0.08	0.11	0.18
	99.83	99.75	100.15	100.04	100.60	100.16	99.92
S.G.	3.065	3.063	3.01	2.88	2.85	-	2.985
Norm.							
Or	10.34	8.12	10.56	3.34	6.12	15.47	-
Ab	14.88	16.77	23.71	20.96	26.72	28.21	
An	2.89	13.37	15.29	7.23	14.46	9.57	
Np.	6.87	6.08	5.62	3.12	3.41	4.29	
Di.	37.99	25.41	13.74	41.14	19.70	19.28	
Ol.	6.37	16.46	14.83	12.66	10.56	11.80	
Mt.	8.33	4.83	3.25	3.94	8.12	2.96	
Il.	8.48	4.04	5.62	7.14	6.69	4.25	
Ap.	1.23	2.12	1.24	0.67	2.35	2.22	

A and B: Pyroxene phyric andesite basalt. Nos. 2216 and 2228 respectively.

1. Olivine Trachy-andesite. Jan Mayen (Holmes 1916, P.203-204). Anal. Harwood.

2. Olivine oligoclase basalt, Mouna Loa, Hawaii (Washington 1923, P.115-116). Anal. Washington.

3. Limburgite, Central Victoria (Edward 1938, P.291). Anal. A.G. Hall.

4. Andesine basalt (= Oligoclase basalt) Central Victoria (Edward 1938, P.279). Anal. A.B. Edwards.

5. Plagioclase basalt Kape Franklin. Quoted from chemical analysis of Igneous and Metamorphic rocks. (Geol. Survey of Great Britain 1931).

6 - 7. Basalt quoted from Wolf, F. Von: Der Vulkanismus Bd. 2 Teil 2. 1, Stuttgart 1931, P.933.

8. Monchiquite, Japan. Quoted from Washington Tables of Chemical Analysis 1917. P.675.

ation the term basalt is defined as olivine bearing rocks with equal amounts of normative plagioclase and femic minerals (Iddings 1913). Furthermore, Iddings subdivided the acid plagioclase-olivine basalts, on the basis of the normative plagioclase, into oligoclase basalts and andesine basalts. These latter are, however, substituted in the C.I.P.W. classification with augite andesite for olivine-bearing and olivine-free, acid plagioclase-augite rocks (Johanson 1931). In view of the above consideration, the term pyroxene andesite can be possibly assigned to these rocks, if the normative plagioclase is taken into account, but due to the fact that high silica content is characteristic for the andesite proper, the term andesine basalt is thought to be more suitable for such rocks which show affinities with both basalts and andesites. As the main phenocrystic component is pyroxene the term pyroxene phyric andesine basalt is assigned to the lavas of the whole group.

In Table 10 for the sake of comparison, the two analysed rocks are repeated together with analyses of chemically comparable rocks described from other volcanic regions.

The present rocks show a close similarity to olivine trachy andesite (Col. 1) from Jan Mayen, described by Holmes (1916). They differ, however, with regard to the dominant phenocrysts, being olivine in the trachy andesitic rock. The same is also true with regard to the olivine oligoclase-basalt (Col. 2) from Hawaii, described by Washington (1923). The limburgite (Col. 3) from Central Victoria shows chemical similarity to the present rock but differs in having more modal olivine as phenocrysts. The andesine basalt (Col. 4) from Central Victoria shows a comparable chemical composition (Edwards 1938). The normative composition is in good agreement but modally the two rocks differ as andesine forms the main phenocrystic component in the Central Victoria rock. In (Cols. 5 - 7) are three basalts which show chemical similarity to the Greenland rocks A and B. The present analyses are also comparable with a monchiquite (Col. 8) from Japan.

(c) Andesine phyric Andesine Basalt.

Between the previously described group and the nonporphyritic group to be described subsequently, there occur three or more lava flows characterised by the presence of plagioclase phenocrysts, besides pyroxene and olivine.

The following specimens have been classed as belonging to this group:-

E.G. 2223 Nn. Nunataks, lava flow below the pyroxene andesine basalt 2221.

2224 Lava flow, below 2223.

2225 " " " 2224.

As these rocks are essentially similar, a general description will be given of the whole group.

Megascopically, the rocks are typically porphyritic. Plagioclase is the conspicuous porphyritic constituent, occurring as large thin plates, 1.5 cm. in average dimensions. In cross section they appear as parallel elongated plates, 2 mm. in thickness. This porphyritic feature varies in the different rocks, due to difference in frequency and dimensions of the plagioclase phenocrysts. Pyroxene phenocrysts in subordinate amounts occur as rounded crystals, 5 mm. in diameter. The groundmass is dark grey and fine grained. Vesicles are present but vary in abundance in the different rocks. They are generally filled with white zeolitic material (thomsonite and chabasite).

In thin section, the rocks are found to consist largely of plagioclase, and a lesser amount of olivine, pyroxene and iron ore phenocrysts. The groundmass is dominated by felspar accompanied by pyroxene, olivine, iron ores, apatite, analcime, zeolite and chloritic material (Fig. 5 and Pl. III, Fig. 1).

The following mineral composition for the rocks of this group was obtained by micrometric measurement methods, and the results are given in Table 11 (Vol. - %)

Table 11. Micrometric Analyses.

Specimen No.	Phenocrysts.				Groundmass.		
	Plag.	Pyrox.	Olivine	Iron Ore	Leucocratic Minerals.	Fe-Mag. Minerals.	Iron Ore
2223	6	3	5	4	41	31	16
2224	16	1	5	1	57	8	12
2225	19	2	5	2	56	10	6

The plagioclase phenocrysts occur as large tabular and lath shaped crystals, solitary or in glomeroporphyritic accumulations. Inclusions in the plagioclase of parts of the groundmass (pyroxene, zeolites and chloritic material) are commonly seen along cracks crossing the crystals. The albite and carlsbad twin laws are dominant and, to a less extent, the pericline law. Zoning is not conspicuously developed. The composition of the plagioclase was determined by immersion liquid methods, and the following results were obtained:-

Specimen	2223	44%	An.
	2224	44 - 45%	"
	2225	44 - 47%	"
		46%	An.

The composition corresponds to basic andesine.

Olivine occurs as rounded crystals of 1 mm. in maximum diameter, with occasional development of crystal faces. It is generally fresh except for alteration along the borders and cracks where brownish-green chloritic materials are present. Cleavage parallel to (010) is commonly met with. The following optical data were determined for the olivine (Fedorow stage):-

Specimen 2224	$2V_\alpha$	= 83°	(± 1)	Fa_{30}
2225	$2V_\alpha$	= 85°	(± 1)	Fa_{26}
Average	2V	= 84°		Fa_{28}

The pyroxene phenocrysts occur as rounded and prismatic crystals of brownish colour with a purplish tinge. The mineral is perfectly fresh, with occasional inclusions of iron ores and olivine or its pseudomorphs. Fedorow stage measurements on the pyroxene showed the following optical properties:-

Specimen 2225 $2V_\gamma$ = 51°
58°
2V = 54° c/γ 42
γ' = 1.714 (± 2)

The composition of the pyroxene according to 2V and γ is Wo_{41} En_{38} Fs_{21}

The groundmass seems to be of the same mineralogical composition in all specimens but texturally its range of variation is very great. Rock No. 2225 is of rather coarse groundmass, which is dominated by plagioclase occurring in thin laths of .3 mm. in maximum length. They are of random orientation, although in some parts they show subparallel arrangement. Twinning is commonly on the albite and carlsbad laws. Measurements of maximum symmetrical extinction in a large number of grains showed that their composition varies only very slightly round a mean value of $Ab_{69}An_{31}$ i.e. acid andesine. According to the immersion liquid method, the refractive index determinations showed that the anorthite content in the plagioclase is about 28% (Winchell). Interstitial to the laths, there occur allotriomorphic untwinned felspars, probably alkali felspar, but exact determinations could not be carried out due to the small grain size. Analcime occurs in the interstitial constituents, and may be seen as colourless isotropic patches enclosed between the glomeroporphyritic plagioclase.

The pyroxene is next in abundance to the felspar. It occurs as rounded grains and fine prisms, .15 mm. in maximum diameter. Cleavage is not perfectly developed. Extinction angle (c/γ) is about 44°. The olivine is in subordinate amounts, and occurs as small rounded grains of

.07 mm. diameter. It is highly altered and in many cases completely replaced by deep green chloritic material. The iron ore occurs as grains and octahedra. Its percentage varies with the texture of the groundmass so that in fine grained rocks the ore content is much higher than in coarser types.

Interstitial zeolites are abundant forming yellowish wedge-shaped areas among the groundmass constituents. Felspar laths and pyroxene grains may be enclosed in these parts where they show sharp crystal boundaries. Apatite is abundant as fine elongated needles .25 mm. in length enclosed in the groundmass felspar.

Sample No. 2223 is the finest variety with regard to the groundmass. It has an average grain size of .02 mm. and is highly charged with iron ore as dusts and grains. In many respects this groundmass is comparable to that of the described pyroxene phyric group.

Chemical Analysis:

The rock No. 2225 was subjected to chemical analysis and the results are shown in Table 12. The present analysis shows a similarity to the analyses Nos. 2 and 3 of the previous group. Otherwise, the only difference is the low magnesia and lime in the present analysis.

The system of nomenclature adopted for this group is based both on quantitative relations of the normative

Table 12. Analysis 4.

Andesine Phyric Andesine Basalt. Specimen 2225.

	Weight %
SiO_2	45.81
Al_2O_3	12.96
Fe_2O_3	4.36
FeO	10.31
MgO	5.75
CaO	7.52
Na_2O	3.36
K_2O	1.70
H_2O	1.91
H_2O	0.88
TiO_2	4.03
P_2O_5	1.11
MnO	0.20
	99.84
S. G.	2.920

		Norm.	
Or		10.01	
Ab		28.40	
An		15.01	Sal. 53.42
Di		12.25	
$Ca\ SiO_3$	6.28		
$Mg\ SiO_3$	3.65		
$Fe\ SiO_3$	2.32		
Hy		7.00	
$Mg\ SiO_3$	4.28		
$Fe\ SiO_3$	2.72		
Ol		7.56	
$2\ MgOSiO_2$	4.44		
$2\ FeOSio_2$	3.12		
Mt.		6.33	
Il.		7.65	
Ap.		2.62	Fem. 43.41
			$H_2O^{\pm}$ 2.79
			99.62

III. 5. 3. 4 Camptonose.

Niggli Values.

si	112	ti	7.4	Or : Ab : An - 19 : 53 : 28		
al	19	mg	0.42	Plag.	Ab 65	An 35
fm	51	k	0.25	Di.	Wo 51	Fs 19
c	20	p	1.09	Hy.	En 61	Fs 39
alk	10			Ol.	Fo 59	Fa 41

mineral molecules and modal composition of the rock. From the calculated norm, the salic and femic minerals are nearly equal, so that the rock may be classed as a basalt (Iddings, Washington 1923). As the modal felspars range from andesine 46% An. in the phenocrysts to oligoclase andesine 28 - 31% An. in the groundmass, and the average composition is shown by the norm to be andesine 35% An., the rock can strictly be called andesine basalt. Iddings and Washington have classified similar rocks as andesine basalts, as the name indicates an intermediate character between true basalts and andesites. For comparison, the analysis is repeated in Table 13, together with analyses for rocks from other volcanic regions. In Columns 1 and 2 are similar rocks described from the Hawaiian Islands by Washington (1923). The andesine basalt (No. 3) from Central Victoria is also of similar composition (Edward 1938). Comparison can also be made with the Salfemane basalts from Pantellaria

Table 13. Comparison.

	D	1	2	3	4	5
SiO_2	45.81	48.42	47.98	47.46	45.72	45.10
Al_2O_3	12.90	13.97	15.32	15.12	12.45	15.04
Fe_2O_3	4.36	4.17	2.49	2.96	1.57	8.85
FeO	10.31	9.57	8.86	9.39	10.01	4.62
MgO	5.75	4.61	6.16	5.70	5.29	6.68
CaO	7.52	8.86	10.28	7.27	9.58	8.71
Na_2O	3.36	3.30	3.56	3.51	3.46	3.78
K_2O	1.70	1.29	1.08	1.74	1.08	1.04
H_2O	1.91	0.84	0.62	0.57	0.40	1.76
H_2O	0.88	0.42	0.25	0.72	0.01	1.31
TiO_2	4.03	3.25	3.53	3.10	6.43	2.66
P_2O_5	1.11	0.91	0.22	0.78	1.54	0.56
MnO	0.20	0.17	0.12	0.25	0.16	0.45
	99.84	99.78	100.49	99.57	99.64	100.56
S. G.	-	(2.982)	(2.989)	(2.82)	-	-
Norm.						
Q	-	0.84	-	10.33	-	-
or.	10.01	7.78	8.90	29.77	6.12	-
ab.	28.40	27.77	31.96	23.04	28.82	-
an	15.01	19.77	21.68	-	15.57	-
np	-	-	1.99	-	-	-
Di	12.25	15.49	2.22	6.98	18.67	-

Table 13 (Continued)

	D	1	2	3	4	5
Hy.	7.00	12.88	-	3.57	5.91	-
Ol.	7.56	-	15.35	12.73	6.08	
Mt.	6.33	6.03	3.71	4.33	2.32	
Il.	7.65	6.33	6.39	2.35	12.16	
Ap	2.62	2.02	0.67	1.71	3.36	

D. Andesine Phyric andesite basalt, Specimen No. 2225.

1. Aphyric andesine basalt, Mouna Kea (Washington 1923 (P.493). Anal. Washington.

2. Felspar phyric basalt (andesine basalt) Kohala. (Washington 1923, P.483). Anal. Washington.

3. Andesine basalt. Central Victoria. (Edward 1938, P.278)

4. Camptonose (Salfemane basalt). Dyke in tuff. Pantellaria (Washington 1907, P.75).

5. Olivine basalt (Dunsapie type). Plug. Duncomb Hill, Dumbartonshire (MacGregor 1938, P.352). Anal. A. Scott.

No. 4 described by Washington (1907). The olivine basalts (Dunsapie type) No. 5 from the Carboniferous of Scotland is of comparable composition but in detail it differs in having modal labradorite in both phenocrysts and in groundmass.

2. NON-PORPHYRITIC GROUP.

As indicated by their name, the rocks belonging to this group are typically non-porphyritic and are generally of uniform character, dark grey in colour and aphanitic.

The lavas belonging to ~~represented by~~ this group of rocks are three ~~form a~~ consecutive ~~continuous~~ ~~series of~~ flows which are interrupted only by a thin pyroxene phyric flow (No. 2228). They are preceeded by few flows of the pyroxene phyric and andesine phyric types.

The nomenclature adopted for these rocks could not be achieved by mineralogical study due to their very fine-grained texture and instead the chemical composition was used.

The rocks to be described are classified as follows:

(a) Aphyric andesine basalt.

(b) Mugearitic basalt.

(a) Aphyric Andesine Basalt.

The following specimens have been classed as belonging to this group:-

2226 Nn. Nunataks, thickest lava flow about 50' below the andesine phyric andesine basalt 2225

2229 As 2226 but at lower level.

In thin section, the rocks are seen to be formed of dominant felspar, pyroxene, olivine or its pseudomorphs, iron ore, apatite, analcime and chlorite. Hornblende and biotite in subordinate amounts are also encountered.

The mineral composition was determined by micrometric measurement and the following results were obtained (Vol. - %) :-

	Leucocratic Minerals.	Ferromag. Minerals.	Iron Ore.
Specimen 2226	58	24	18

Felspar occurs mainly as irregular interlocking grains of low double refraction and shows no twinning. Sometimes the felspar may be seen to occur as fine laths 0.05 mm. in length, but with ill-defined twinning. Because of this fine grain no exact determinations could be carried out.

In Specimen No. 2229 the lath-shaped texture is more marked and it was found that the dominant felspar is plagioclase. Refractive index determination showed that its composition is about 18 - 26% An. (immersion liquid method). The untwinned low doubly refracting material probably includes orthoclase. Analcime also occurs among the felspathic constituents as isotropic material. It is, however, difficult to estimate the mutual proportions of these constituents because of the low double refraction of the felspathic groundmass.

Pyroxene forms fine grains .1 mm. in length and isometric grains of .04 mm. in diameter. It is of pale green colour with an occasional brownish tinge. Cleavage is poorly developed.

Olivine or its pseudomorphs occurs as microporphyritic individuals of rounded and elongated tabular forms .25 mm. in length. In the rock No. 2226 the olivine is completely pseudomorphed by green chloritic material of high double refraction (Fig. 5, and Pl. III, Fig. 2). In the rock No. 2229, the olivine is seen to exist as relics in similar pseudomorphs as in No. 2226 (Pl. IV, Fig. 1). In a few cases it is altered to brown iddingsite.

Iron ore is abundant as fine grains .1 mm. in diameter.

Apatite as colourless needles .06 mm. in length is commonly seen enclosed in the felspathic constituents.

Chemical Analysis:

The rock No. 2226 was subjected to a chemical analysis, the results of which are given in Table 14.

In Table 15 the analysis is repeated for the sake of comparison with rocks from other localities showing chemical similarity and the same magmatic symbol (III. 5. 2. 4).

Table 14. Analysis 5.

Aphyric Andesine Basalt. Specimen 2226.

	Weight %
SiO_2	47.37
Al_2O_3	14.51
Fe_2O_3	5.37
FeO	8.68
MgO	5.01
CaO	8.12
Na_2O	3.50
K_2O	1.56
H_2O	1.44
H_2O	0.50
TiO_2	3.04
P_2O_5	0.90
MnO	0.03
	100.03
S. G.	2.92

Norm.			
Or		9.23	
Ab		29.55	
An		18.79	Sal. 57.57
Di.		12.66	
Ca SiO_3	6.52		
Mg SiO_3	4.01		
Fe SiO_3	2.13		
Hy.		8.97	
Mg SiO_3	5.88		
Fe SiO_3	3.09		
Ol.		2.82	
2 $MgOSiO_3$	1.78		
2 $FeOSiO_3$	1.04		
Mt.		7.79	
Il.		5.76	
Ap.		2.12	Fem. 40.12
			$H_2O^{\pm}$ 1.94
			99.63

III. 5. 3. 4.
Camptonose.

Or : Ab : An - 15.5 : 51.7 : 32.8

Niggli Values.

Si	117	ti	5.7	Plag.	Ab_{61}	An_{39}	
al	21	mg	0.40	Di.	Wo_{51}	En_{32}	Fs_{17}
fm	47	k	0.23	Hy.	En_{66}	Fs_{34}	
c	21	p	0.89	Al.	Fo_{63}	Fa_{37}	
alk	11						

The rock is characterised by high content of titanium dioxide, and alkalies with soda dominating over potash. The norm shows hypersthene although modally absent, and it probably combines with diopside as pigeonitic component. The normative plagioclase has a composition of Ab_{61} An_{39}. According to the quantitative chemical classification the rock belongs to the Salfemane class (III) and subrang Comptonose (4).

As to the general relations between this analysis and those of the other lavas discussed, it is found that this analysis agrees very well with analysis No. 4 of the felspar phyric andesine basalt. The total amount of iron oxides is almost exactly the same, but there is a slight difference in the degree of oxidation. Otherwise the only difference is in the values of silica and alumina which differ slightly. This chemical similarity and close field association seems to bring out the fact that these rocks although very different in texture are still closely

Table 15. Comparison

	E	1	2	3	4	5	6	7	8
SiO_2	47.37	48.40	49.92	49.72	49.09	48.42	46.22	45.72	46.89
Al_2O_3	14.51	16.66	12.83	14.56	15.15	13.97	12.23	12.45	13.74
Fe_2O_3	5.37	8.54	6.96	3.60	2.95	4.17	4.91	1.57	3.88
FeO	8.68	2.45	6.21	8.55	10.22	9.57	7.71	12.01	10.56
MgO	5.01	4.85	3.78	6.89	4.94	4.61	6.74	5.29	4.72
CaO	8.12	7.44	7.35	9.66	8.47	8.86	0.86	9.58	8.01
Na_2O	3.50	3.42	3.72	2.25	4.03	3.30	3.39	3.46	3.18
K_2O	1.56	1.76	1.73	0.62	1.31	1.29	1.13	1.08	1.46
H_2O+	1.44	1.19	1.05	1.24	0.17	0.84	0.17	0.40	1.85
H_2O-	0.50	1.23	-	0.71	0.07	0.42	0.05	0.01	0.96
TiO_2	3.04	3.06	2.04	2.21	2.66	3.25	5.68	6.43	4.04
P_2O_5	0.90	0.49	9.45	0.22	0.80	0.91	1.46	1.54	0.45
MnO	0.03	-	0.52	0.11	0.17	0.17	n.o	0.16	0.16
	100.03	99.89		100.35	99.95	99.78	99.55	99.64	99.99
S.G.	2.919								
Norm.									
Q	-	-	-	-	-	-	-	-	0.84
Or.	9.23	-	-	3.34	7.78	6.67	6.12	-	7.78
Ab.	29.55	-	-	27.77	34.06	28.82	28.82	-	27.77
An.	18.79	-	-	23.55	19.46	14.73	15.57	-	19.46
Di.	12.66	-	-	18.24	14.22	19.54	18.17	-	15.49
Hy.	8.97	-	-	14.22	0.81	8.06	5.91	-	12.88

Table 15 (Continued)

	E	1	2	3	4	5	6	7	8
Ol.	2.82	-	-	2.36	12.41	0.28	6.08	-	-
Mt.	7.79	-	-	5.34	4.18	7.19	2.32	-	6.03
Il.	5.76	-	-	4.28	5.02	10.79	12.16	-	6.23
Ap.	2.12	-	-	0.67	2.02	3.36	3.36	-	2.02

E. Aphyric andesine basalt. Specimen No. 2226.

1. Basaltic mugearite. Lower member of composite lava flow, Renfrewshire (Kennedy 1931, P.171). Anal. B.E. Dison. (Contains 0.07 Fes$_2$).

2. Mugearite Canna Island, Scotland (Harker 1908, P.130).

3. Andesine basalt, Leeward Islands, Hawaii (Washington and Keyes 1926, P.339). Anal. Keyes.

4. Olivine oligoclase basalt (= mugearite) Kohala (Washington 1923, P.480). Anal. Washington.

5. Andesite, Hamakua volcanic series (Washington 1923, P.493). Anal. H.S. Washington.

6 - 7. Comptonose (Salfemane basalt). Pantellaria (Washington 1907, P.74-75).

8. Olivine basalt (Jedburgh type). Carboniferous Lava. Anal. B.E. Dixon. Quoted from: Analyses of Igneous and Metamorphic Rocks. Geol. Surv. G.B. 1931, P.69.

related and probably belong to the same stage of evolution of the magma. These marked mutual affinities become still more obvious when Niggli values are considered, which are very much the same for both rocks.

		si	al	fm	c	alk	k	mg
Specimen	2226	117	21	47	21	11	0.23	0.40
"	2225	113	19	51	20	10	0.25	0.42

Chemical composition was taken as the basis for nomenclature of these rocks as, owing to the very fine grain, the microscopic study could not reveal their true nature. The normative percentages of salic and femic constituents are nearly equal and lie within the range defined by Iddings for basalts, 62.5 - 37.5% (Iddings), but as the normative plagioclase is acid andesine the rock may be classed as andesine basalt. The close chemical similarity between this rock and the andesine phyric andesine basalt also supports such nomenclature.

In Table 15 the basaltic mugearite (Col. 1) from Renfrewshire described by Kennedy (1931) is comparable to the present rock, but differs in the state of oxidation of the iron oxides. Similarity is more clearly seen when Niggli values are compared.

	Si	al	fm	c	alk	k	mg
Specimen 2226	117	21	47	21	11	0.23	0.40
Basaltic	125	25.5	42	21	11.5	.25	.45

The rock also resembles in some ways a mugearite (Col. 2) described by Harker from Scotland (Harker 1908). The andesine-basalts (Col. 3), the olivine oligoclase andesite (Col. 4) and the andesite (Col. 8) from the Hawaiian Islands described by Washington 1923, 1926) have similar chemical compositions to the Greenland rock. Comparison can also be made between the present rock and the salfemane basalts, Comptonose (Cols. 5 and 6) from Pantellaria described by Washington (1907). In (Col. 7) an olivine basalt of Jedburgh type from Scotland shows a chemical similarity to the present rock; the main difference is the presence of modal labradorite in the Scottish rock.

(2) Mugearitic Basalt.

This group is represented by one specimen No. 2227, collected from a flow between the nonporphyritic flows Nos. 2226 and 2229 previously described.

Megascopically, it is similar to the previous rocks, being typically non-porphyritic, dense and aphanitic.

In thin section, the rock is seen to be formed of dominant plagioclase, pyroxene, olivine or its pseudomorphs, iron ore and apatite (Fig. 5 and Pl. IV, Fig. 2).

The mineral composition was determined on Dollar's integrating stage and the following results were obtained:-

	Vol. - %
Leucocratic minerals (Felspar, apatite)	64
Ferromagnesian minerals	22
Iron ore	14

(Specific gravity: 2.836)

Plagioclase occurs as laths .2 mm. in length in a parallel arrangement exhibiting trachyitic texture. Green chloritic material is in most cases seen streaming between the adjacent laths. Twinning is mainly on the albite and carlsbad laws. Zoning is commonly seen as wavy bands running parallel to the length of the laths. According to maximum symmetrical extinction and immersion liquid methods the plagioclase has a composition around a mean value of 19% An. Among the plagioclase laths there are also allotriomorphic grains of felspar with low double refraction, probably potash felspar.

Pyroxene occurs as fine prisms and isometric grains 0.2 mm. in diameter. It is of pale greenish colour with a brownish tinge in a few cases. Cleavage is poorly developed.

Olivine is not found fresh, but instead numerous pseudomorphs are found which as a rule show rounded forms reminiscent of olivine. The material forming these pseudomorphs is generally brown iddingsite and to a less extent green chloritic material.

Iron ore is abundant as grains and thin rods. Apatite as fine prisms is abundant among the felspars.

The rock is mineralogically and texturally similar to a mugearite from Skye described by Harker (1904) and the mineral composition in both rocks shows a fair agreement, as shown below:

	Skye Mugearite	Specimen No. 2227
Plagioclase	57	64
Orthoclase	12	
Apatite	3	
Olivine, augite, ore	26	36

The present rock also shows a mineralogical similarity to the previous nonporphyritic rocks, but differs in having a trachytic texture which is absent in the latter.

TILTED MOUNTAIN AREA.

The specimens collected from this area have some features in common with those collected from Nn. Nunataks, but they differ, however, in showing less variation.

The lavas may be divided into two groups, based on mineralogical and textural features:-

(a) Porphyritic Olivine Basalts.

(b) Aphyric Basalts.

In the field the porphyritic and aphyric flows are found to alternate, and the lowest and the uppermost flows are both nonporphyritic.

(A) PORPHYRITIC OLIVINE BASALTS.

The following specimens are classed as belonging to this group:-

No. 2242	A flow below the uppermost aphyric basalt flow.
2244	A flow at lower level.
2240	" " " " "
2238	" " above the lowest aphyric basalt flow.

Megascopically, the rocks are dark grey in colour and of slightly variable texture, but generally fine-grained. They contain greenish and black crystals of 2 - 3 mm. in magnitude. These are either completely formed of olivine or the latter may be accompanied by a few pyroxene phenocrysts. Vesicles are few, at most 2 mm. in diameter.

In thin section, the specimens No. 2238 and 2240 are seen to be formed of olivine phenocrysts in a groundmass which consists of dominant clinopyroxene, subordinate plagioclase felspar and iron ore. The mineral composition has been determined by the micrometric method on Dollar's integrating stage, and the following results were obtained (Vol. - %):-

	No. 2238.
Olivine Phenocrysts	26%
Pyroxene Groundmass	52
Plagioclase "	16
Iron Ore	6

The olivine phenocrysts occur as idiomorphic to subidiomorphic crystals. The grain size is serial and varies between 1.5 and .7 mm. It is generally colourless and shows distinct (010) cleavage. In most cases, it has a thick opaque border of deep brown bowlingite. The olivine usually contains a few small magnetite grains as inclusions. Strong resorption effects on the olivine are shown by the sinuous appearance of the crystals, which are seen also in several cases to be subdivided into separate individuals by fissures filled with parts of the groundmass. The axial angle of the olivine $2V_\alpha$ is 88°, which gives 18% Fa.

The groundmass consists of abundant pyroxene occurring in thick interlocking prisms of distinct purplish brown tinge, .2 mm. in length. The plagioclase occurs interstitially between the pyroxene, rarely showing crystal bounders or regular twinning. The pyroxene is frequently seen projecting into the plagioclase or completely enclosed by it, in which case the pyroxene develops idiomorphic forms. This relation seems to indicate a late stage of crystallisation of the plagioclase. Fedorow stage measurements of the maximum symmetrical extinction angle showed that the plagioclase has a composition between 25 - 35% An.

Magnetite occurs rather abundantly, in variable grain size between .4 - .03 mm. It is usually accompanied by a mineral of brownish purple colour. This mineral also occurs as separate small scales and thin threads. It is anisotropic, but its double refraction is masked by its strong adsorption colour. It is probably a titaniferous ore as can be perceived from the accompanying pyroxene, being of deep purplish colour, indicating a high titania content.

These rocks are comparable to the olivine-rich oligoclase basalts described from the Nn. Nunataks (Specimen No. 2215.) The latter rocks differ, however, in having pyroxene as phenocrysts and larger grain size of the olivine phenocrysts.

The Specimen No. 2244 is similar to the previous rock in many respects. It only differs with respect to the groundmass plagioclase, being more calcic and having a more decidedly lath-shaped development (about .4 x .08 mm.). According to maximum symmetrical extinction angle on several individuals, the plagioclase is 45 - 50% An. Interstitial felspar also occurs among zeolitic material. The relative proportion and composition of this felspar could not be determined.

The mineral composition according to micrometric measurements is as follows (Vol. - %):-

	No. 2244.
Olivine (Phenocrysts)	19%
Pyroxene (Groundmass)	53
Plagioclase (Groundmass)	18
Iron Ore	3
Zeolitic material and interstitial felspar.	7

As is seen above, the mineral composition is nearly identical with the previous specimens. This rock may be considered as a transition to the rock No. 2242, described below.

Specimen No. 2242 is of slightly coarser nature than the above described rocks. It contains black rounded crystals of pyroxene, 3 mm. in diameter.

In thin section, the rock is mineralogically the same as the other rocks of the group, except for the presence of small amounts of pyroxene and plagioclase as porphyritic constituents. The mineral composition was determined by micrometric measurements and the following results were obtained (Vol. - %) :-

	No. 2242.
Olivine (Phenocrysts)	18%
Pyroxene (")	8
Plagioclase (")	5
Groundmass (Pyroxene, felspar and zeolitic material).	66
Iron Ore.	3

Olivine occurs as subidiomorphic crystals, of a serial grain size (1.5 mm. - .4 mm.). As in the previous specimens, the olivine has a thick opaque border of bowlingite and the crystals show distinct resorption effects. The axial angle of the olivine $2V_{\alpha}$ is 78° (Fedorow stage) which gives a value of 35% Fa.

Clinopyroxene occurs as irregular individuals, solitary or in glomeroporphyritic groups. In the latter mode of development the crystals are of rather small magnitude, .5 mm. in diameter, against 4 mm. in solitary crystals. It has a distinct purplish tinge. Inclusions of small grains of olivine and iron ore are frequently met with. The following optical determinations were made:-

$$2V_{\gamma} = 50 \ (\pm 2) \qquad c/\gamma = 43 \ \text{(Fedorow stage)}.$$

These values indicate that the pyroxene is moderately rich in lime, Wo_{33} En_{46} Fs_{21}.

Plagioclase occurs in tabular and elongated crystals, solitary or in groups. There is no sharp distinction between the phenocrysts and groundmass felspar, the grain size being serial and ranging between 2 mm. and .4 mm. in length. Inclusions of zeolitic material and fine pyroxene grains are common. Twinning is mainly on the albite and carlsbad laws. Zoning is not conspicuously developed. Fedorow stage determinations (Maximum symmetrical extinction angle) on several grains showed that the plagioclase has a composition of 50 - 55% An.

The groundmass consists of clinopyroxene as rounded grains and prisms, .3 mm. in average diameter. The pyroxene occurs interstitially between the small plagioclase laths, and has a purplish tinge similar to the phenocrysts. Interstitially between the pyroxene and the felspar there are patches of zeolitic material and chlorite. The zeolite occurs in many cases as radiating fibres which appear between crossed nicols as spherules with fibrous green chlorite as a central core. Fibrous chlorite of the same character also appears in the groundmass filling vesicles.

(B) APHYRIC BASALT.

The rocks belonging to this group are typically nonporphyritic, and are mineralogically similar to the olivine-poor basalts described under Plateau Basalts (Cf. P. 25).

The following specimens are classed in this group:-

No. 2241 Uppermost flow.
" 2243 Lava flow at lower level.
" 2239 " " " " "
" 2237 Lowest flow.

Megascopically, the rocks are grey with rusty brown patches. Vesicles are rare, occurring as irregular cavities at most 4 mm. in diameter, filled with chabasite and sometimes green chloritic material.

In thin section the rocks are found to be formed of, in order of abundance, plagioclase, pyroxene, and iron ore.

The plagioclase occurs as thin laths, .2 mm. in length. The laths are of divergent orientation, but in some parts of the section they show subparallel arrangement. According to maximum symmetrical extinction angle, the plagioclase has an average composition of 55% An. (Fedorow stage). The clinopyroxene is of faint brownish tinge and occurs in irregular individuals, of the same magnitude as the plagioclase. It shows a subdoleritic relationship to the plagioclase. Iron ore is fairly abundant as irregular lumps enclosing grains of plagioclase and pyroxene. Some iddingsitic material, as rounded patches is found, probably pseudomorphous after original olivine. Chloritic material of the same character is also seen dispersed among the main constituents.

TABLE 16.

	2215
SiO_2	43.26
Al_2O_3	5.88
Fe_2O_3	3.66
FeO	11.66
MgO	17.86
CaO	8.96
Na_2O	1.73
K_2O	1.16
H_2O +	1.41
H_2O -	0.20
TiO_2	3.55
P_2O_5	0.64
MnO	0.22
	100.19
Sp. G.	(3.20)

Norm:

Or.		6.84
Ab.		12.00
An.		4.81
Np.		1.42
Di.		28.26
FaO SiO_2	14.78)	
MgO SiO_2	10.43)	
FaO SiO_2	3.05)	
Hy.		-
MgO SiO_2	-	
FeO SiO_2	-	
Ol.		31.35
2 MgO SiO_2	23.70	
2 FeO SiO_2	7.65	
Mt.		5.31
Il.		6.73
Ap.		1.51

Plagioclase	Ab71	An29	
Diopside	Wo_{52}	En_{37}	Fs_{11}
Hypersthene		--	
Olivine	Fo_{76}	Fa_{24}	

Mode (Vol.-%)

Phenocrysts:

Plagioclase	-
Pyroxene	3
Olivine	29
Iron Ore	2

Groundmass:

Leucocratic X Minerals.	21
Ferromagnesian ø Minerals.	36
Iron Ore.	9

X Includes felspar, apatite and analcime.

ø Includes pyroxene, and subordinate olivine or its pseudomorphs.

TABLE 16.

PLEASE SEE OVERLEAF.

CHEMICAL ANALYSES, NORM AND MODE OF PRINCEN AF WALES LAVAS.

2216	2228	2225	2226
44.16	44.74	45.81	47.37
8.34	11.87	12.90	14.51
5.74	3.33	4.36	5.37
10.72	11.59	10.31	8.68
7.80	7.89	5.75	5.01
11.20	10.13	7.52	8.12
3.26	3.31	3.36	3.50
1.75	1.38	1.70	1.56
1.07	2.03	1.91	1.44
0.40	0.26	0.88	0.50
4.47	2.13	4.03	3.04
0.83	0.89	1.11	0.90
0.09	0.20	0.20	0.03
99.82	99.75	99.84	100.03
(3.065)	(3.063)	(2.920)	(2.919)
10.34	8.12	10.01	9.23
14.88	16.77	28.40	29.55
2.89	13.37	15.01	18.79
6.87	6.08	-	-
37.99	25.41	12.25	12.66
19.72)	12.93)	6.28)	6.52)
13.04)	6.98)	3.65)	4.01)
5.23)	5.50)	2.32)	2.13)
-	-	7.00	8.97
-	-	4.28)	5.88)
-	-	2.72)	3.09)
6.37	16.46	7.56	2.82
4.41)	8.81)	4.44)	1.78)
1.96)	7.65)	3.12)	1.04)
8.33	4.83	6.33	7.79
8.48	4.04	7.65	5.76
1.23	2.12	2.62	2.12
Ab_{83} An_{17} Wo_{52} En_{34} Fs_{14} -- Fo_{69} Fa_{31}	Ab_{57} An_{43} Wo_{51} En_{27} Fs_{22} -- Fo_{54} Fa_{46}	Ab_{65} An_{35} Wo_{51} En_{30} Fs_{19} En_{61} Fs_{39} Fo_{59} Fa_{41}	Ab_{61} An_{39} Wo_{51} En_{32} Fs_{1} En_{66} Fs_{34} Fo_{63} Fa_{37}
-	-	19	-
23	15	2	-
5	5	5	-
4	2	2	-
29	-*	56	58
5	-	10	24
34	-	6	18

* Groundmass is mainly glass (77%), with microlites of pyroxene and iron ore.

IV - GENERAL CONSIDERATION ON THE DIFFERENTIATION OF THE ROCKS.

A - GRAPHICAL PRESENTATION OF CHEMICAL DATA.

In the following discussion on the chemical variation among the rocks analysed, it is assumed that members of this series of lavas are genetically related. A complete elucidation of the genetic relationship of the rocks cannot, however, be attained at present, as it would require not only a greater number of chemical analyses, but also an increased knowledge of the field relations and extent of the different types.

The five chemical analyses are given together in Table 16, with their corresponding normative and modal composition.

In order to get a clear view of the chemical variation in the rocks studied and to form a general conception of the nature of differentiation, a number of variation diagrams have been constructed (Figs. 8 - 10).

The first of these (Fig 8) is an ordinary variation diagram upon which weight percentages of the various oxides are plotted against percentage silica. The most striking feature of this diagram is the rapid decrease in magnesia with small increase in silica, while lime and iron oxides increase in amount. At the same time, alumina shows a rapid increase in the early stages in the differentiation,

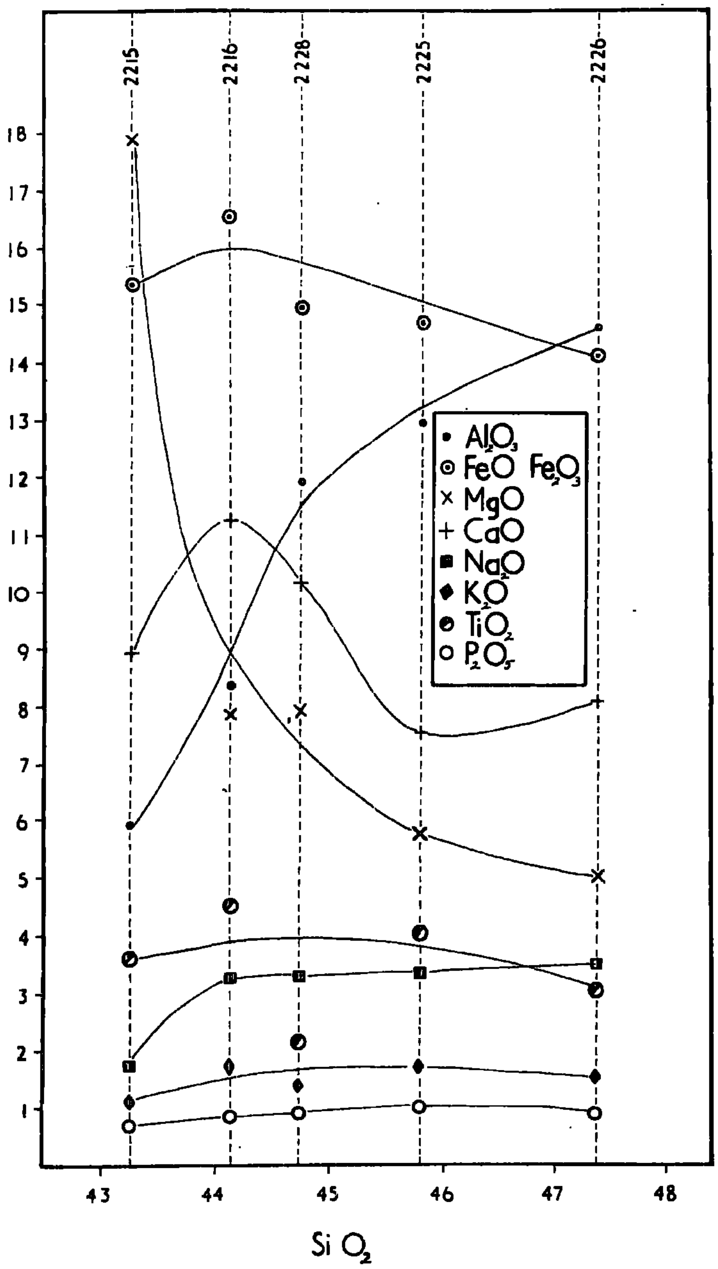


Fig. 8.
Variation diagram of the analysed rocks plotted against silica percentage.

the curve flattening out somewhat at higher silica percentages, as do the curves for the other oxides. The form and direction of the curves, then, indicate that the main changes which took place in the early stages of crystallisation were a rapid decrease in magnesia and increase in lime and iron oxides. This seems to suggest that the early separation of a magnesia-rich olivine was followed by a lime-rich pyroxene, which is in good agreement with the optical data for the early crystallised phases, i.e. phenocrysts. The rapid and continuous increase in the alumina is due to the fact that plagioclase felspars were not among the early crystallised minerals.

Variation diagrams based on the ratio

$$\frac{FeO + Fe_2O_3}{FeO + Fe_2O_3 + MgO} \times 100$$

i.e. expressing relative enrichment of iron, have been shown to be more satisfactory than those based on silica percentage, in following the sequence in certain differentiation series (Deer and Wager 1939, Walker and Poldervaart 1949). Graphical representation based on this ratio provides one of the best methods of representing the early and middle stages of crystallisation differentiation. In Fig. 9 the analyses have been represented graphically by plotting the oxides percentages against the ratio $\frac{FeO + Fe_2O_3}{FeO + Fe_2O_3 + MgO} \times 100$.

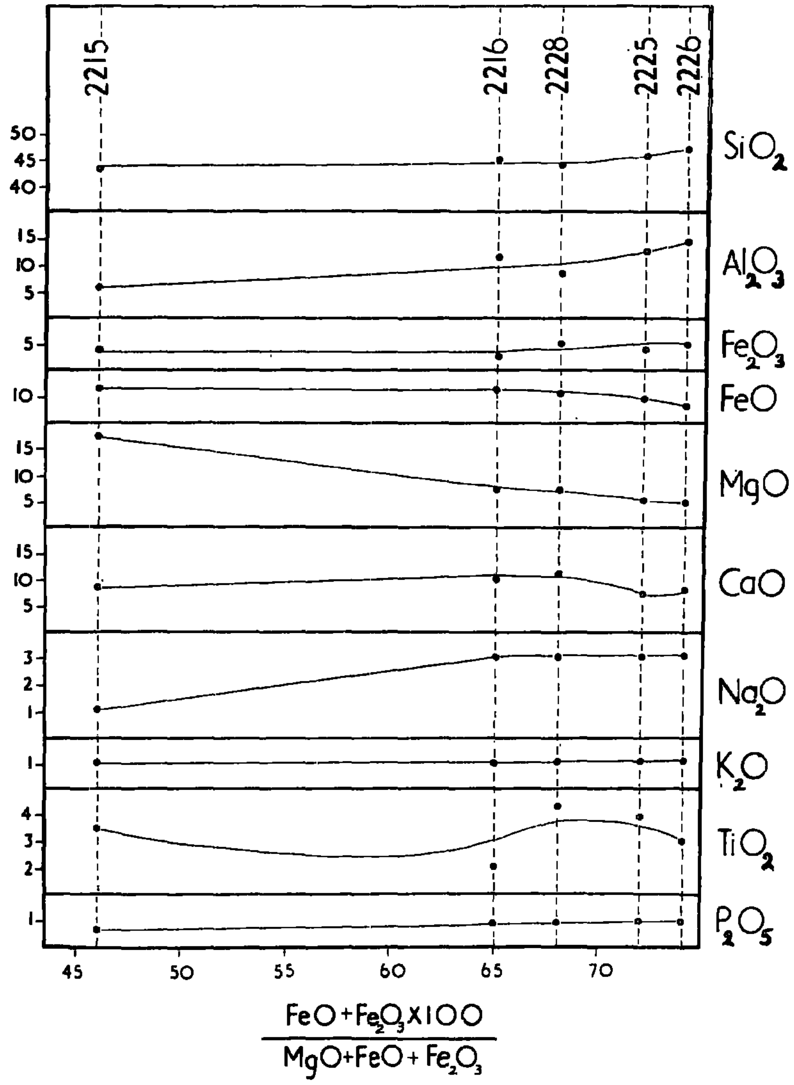


Fig. 9.

Variation diagram of the analysed rocks plotted against iron-magnesium ratios.

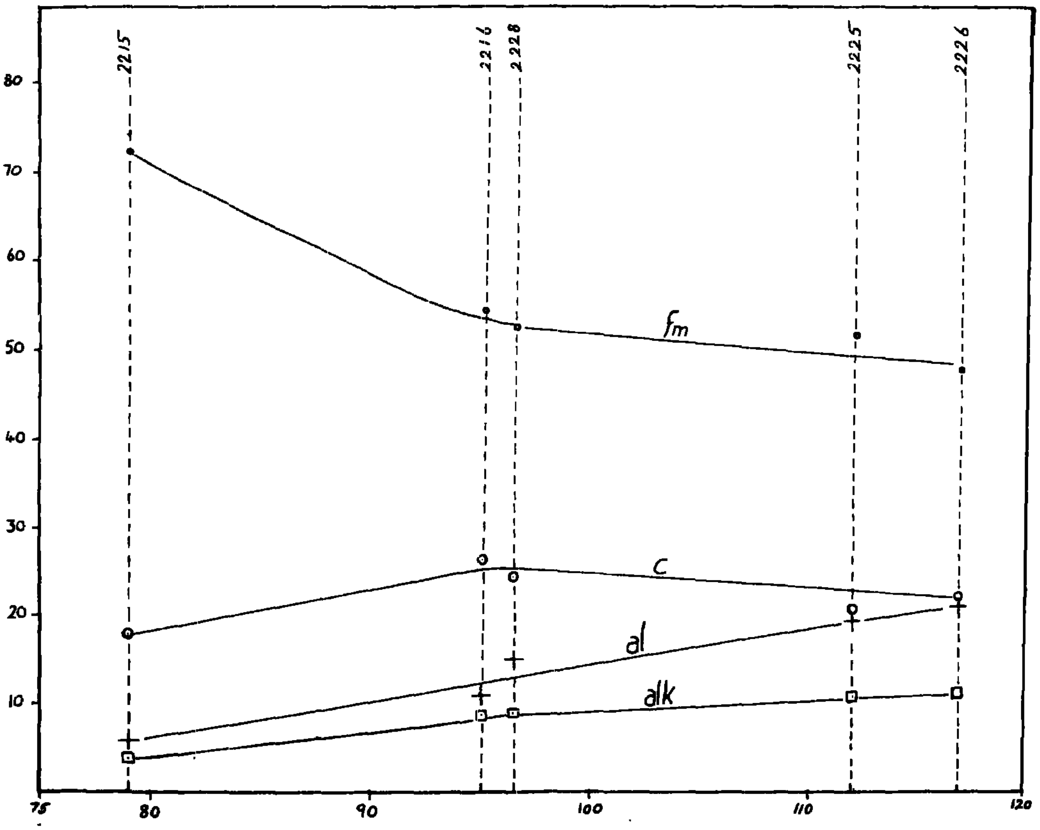


Fig. 10.

Variation diagram, based on Niggli values, of the analysed rocks.

The projected points for the different oxides occur on smooth curves, and the irregularities present in the previous diagram, Fig. 8, are mostly eliminated. The two diagrams show, however, a similarity in the essential features discussed above.

In order to elucidate further the variations, the analyses are also plotted on a variation diagram (Fig. 10) based upon Niggli values. The most characteristic feature is the antagonistic course of the c and fm curves towards the basic end of the diagram. With regard to the other curves, the diagram is very regular.

The petrographic data for this group of lavas show fair agreement with these chemical variations illustrated by the foregoing diagrams. The main petrographic features of the lavas may be briefly summarised as follows:-

(1) Magnesia-rich olivine (16 - 27% Fa) and lime-rich pyroxene ($Wo_{44}\ En_{36}\ Fs_{20}$) form the main phenocrysts in most of the porphyritic lavas without early plagioclase felspar.

(2) Normative and modal felspar in these rocks is oligoclase and is restricted to the groundmass. The nephelite molecule occurs in the norm, however.

(3) In those rocks where the plagioclase felspar appears as phenocrysts, together with phenocrysts of olivine and pyroxene, it is an andesine with 45 - 46% An,

while the groundmass felspar is acid andesine to oligoclase-andesine.

(4) The nonporphyritic rocks show normative and modal felspar of a composition about oligoclase-andesine. The normative pyroxene shows a composition approaching pigeonitic (lime-poor) character

$Wo_{35}\quad En_{50}\quad Fe_{25}$

(5) Olivine is a common ingredient throughout the whole group of lavas, both porphyritic and nonporphyritic types.

Judging from these petrographical and chemical characteristics, it seems that as a consequence of the early crystallisation of magnesia-rich olivine, followed by lime-rich pyroxene, the quotient CaO / Na_2O has been lowered compared with the ratio in the original melt. Alumina is thus left to combine with most of the alkalies and a little lime to form acid plagioclase.

So, on the whole, the form and the direction of the curves in the variation diagrams (Figs. 8 - 10) seem to be mainly controlled by the species of minerals separating as well as by their composition.

B - POSSIBLE FACTORS RESPONSIBLE FOR THE DIVERSITY OF THE ROCKS.

The diversity of the Prinsen af Wales lavas may be ascribed to the following factors:-

(1) The original composition of the parent magma
(2) crystal fractionation accompanied by gravitative settling of early phases, and
(3) physical environments.

The character of the parent magma of the Prinsen af Wales lavas is undoubtedly of the first importance in controlling the composition of the early crystallising minerals. The average composition of the original magma is accordingly to be sought among the more common types, namely Nos. 2216, 2228, 2225 and 2226. The average composition is given below (Table 17) and it shows to be intermediate between the averages for the Plateau basalt and the nonporphyritic central magma types as defined by the authors of the Mull memoir (Bailey 1924).

Table 17. Average Composition of the Prinsen af Wales Lavas (Calculated Water-free).

	Weight-%
SiO_2	46.79
Al_2O_3	12.15
$FeO + Fe_2O_3$	15.09
MgO	6.79
CaO	9.51
Na_2O	3.46
K_2O	1.63
TiO_2	3.52
P_2O_5	0.93
MnO	0.13

The average Prinsen af Wales Lavas is clearly basaltic as is shown by the high content of iron oxides, magnesia and lime. The high content of alkali, especially soda, indicates on the other hand an andesitic affinity.

The conception of two contrasted magma types, the olivine basalt and the tholeiitic type, as put forward by Kennedy, suggest that enrichment in alkalies during the later stages of differentiation is a characteristic of rocks of the olivine-basalt magma type. He emphasized that "the composition of the parent magma forms the ultimate control of differentiation, but the actual means whereby the particular end is attained is seen in the mineral phases which separate" (Kennedy 1933, P.250). Kennedy explains the difference in mineral characteristics of the two magma types by showing that the olivine basalt lies well within the stability field of forsterite in the system forsterite-diopside-silica and close to the forsterite-diopside curve. Crystallisation starts with the precipitation of forsterite followed by lime-rich pyroxene. Considerable amounts of lime are extracted in this early separation of pyroxene, and consequently the residual liquids are impoverished in this constituent. This early removal of lime by the pyroxene prevents it from combining with alumina to form anorthite, and consequently the alumina is forced to combine with the alkalies to form alkali-felspars, and eventually felspathoids. The tholeiitic magma, on the other hand, lies close to the boundary of the forsterite field or entirely within the pyroxene field. The early formed pyroxene is an enstatite-augite, or lime-poor variety. Consequently, most of the lime will be available for combination with alumina to form the anorthite molecule, which is shown to be an important constituent, even in relatively acid rock types.

Barth in his paper "The Crystallisation Process of Basalts" believed in one world-wide primary magma and showed that slight variation in the composition of this magma as well as different conditions of cooling might give rise to over-silicated, under-silicated, or neutral residua (Barth 1936, P.350-351).

In the strongly fractionated Skaergaard intrusion, which belongs to an olivine basalt magma type, Wager and Deer (1939) showed that there is a continuous trend of crystallisation for the pyroxene from diopside-rich towards clinohypersthene-rich types. This crystallisation trend passes through the two fields of the two parental magmas as defined by Kennedy (Deer and Wager 1939, P.256-257), the diopside-rich variety being characteristic of the olivine basalt field. Accordingly, they did not incline to Kennedy's hypothesis of two separate magmas and

TABLE 18.

	F	1	2	3
SiO_2	46.79	47.4	51.6	47.35 - 53.97
TiO_2	3.52	2.2	1.6	0.94 - 3.25
Al_2O_3	12.15	15.6	14.3	11.05 - 14.87
Fe_2O_3	4.47	3.7	3.5	2.73 - 5.87
FeO	10.62	9.2	9.2	6.32 - 13.08
MnO	0.13	0.3	0.3	0.09 - 0.53
MgO	6.79	8.5	5.3	2.58 - 6.84
CaO	9.51	10.2	10.2	6.36 - 12.89
Na_2O	3.46	2.1	2.8	2.36 - 3.48
K_2O	1.63	0.6	1.1	0.54 - 2.27
P_2O_5	0.93	0.2	0.3	0.21 - 0.55
	100.00	100.00	100.00	
No. of Anal.	4	7	11	9

F. Average of 4 analyses of the Prinsen af Wales Lavas.

1. Hebridean olivine basalt (Bailey and others 1924).

2. Nonporphyritic Central Magma (Bailey and others 1924).

3. Range in percentages of oxides in Tholeiitic Magma type (Daly 1944, P.1395).

believed that the calc-alkaline series of igneous rocks is the result of mixing of basic and acid material. The normal course of differentiation in basaltic magmas has been shown to be towards iron enrichment in the early and middle stages and enrichment of silica and alkalies towards the end. Walker and Poldervaart (1949, P.650-655) reached the same conclusion but they consider it likely that the calc-alkaline suite may be produced by fractionation of basalt magma. They did not exclude, however, the possibility of assimilation of sialic material, followed by crystallisation-differentiation of the hybrid magma (1949, P.661).

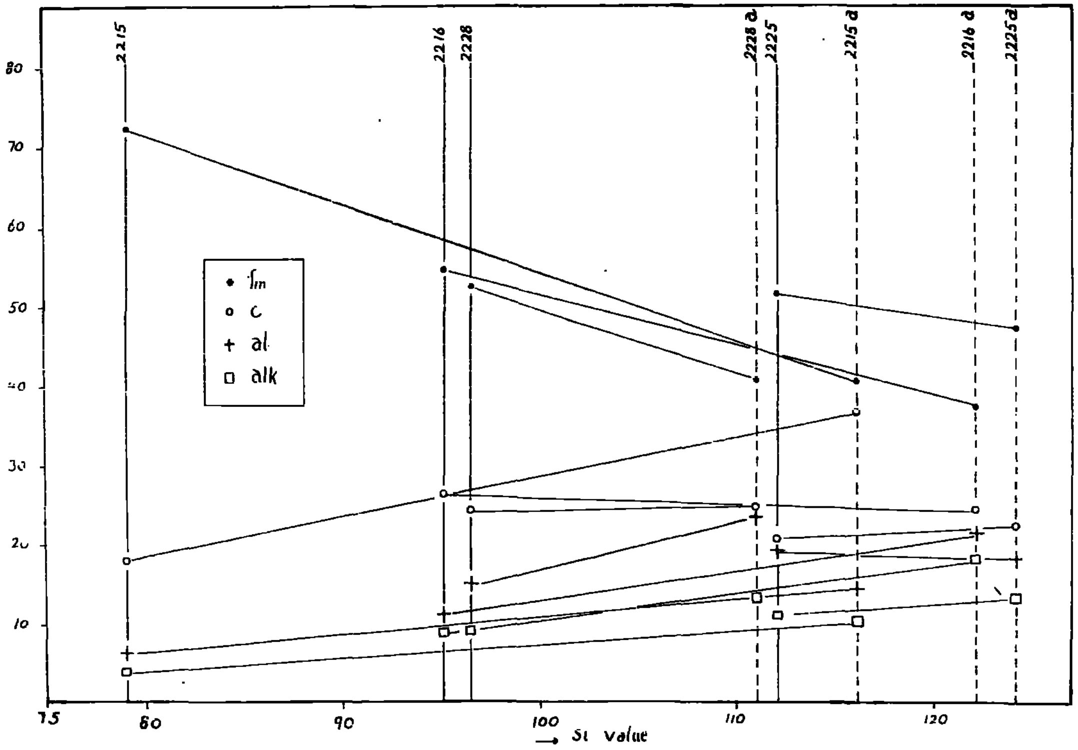
In a recent paper, Daly (1944, P.1363-1397) discussed critically the conception of the two magma types as pictured in Mull. He showed that the range in stated percentages of the oxides in nine analyses representing the Nonporphyritic Central or Tholeiitic magma type of Mull approaches towards the basic end, the Plateau Basalt magma type (Table 18). Moreover, it is shown that several well-known olivine basalt provinces lie within that range. Daly ascribes the chemical diversity throughout the world ultimately to crystal fractionation of a world-wide primitive olivine basalt magma accompanied to a less extent by syntexis. The latter process is believed to be more pronounced in the continental than in the oceanic sectors of the globe.

TABLE 19.

BULK COMPOSITION OF THE PORPHYRITIC ROCKS (2215, ETC.) AND THE CALCULATED COMPOSITION OF THE GROUNDMASS (2215a, ETC.)

	2215	2215a	2216	2216a	2228	2228a	2225	2225a
SiO_2	43.26	36.30	44.16	45.51	44.74	45.25	45.81	46.01
Al_2O_3	5.88	9.50	8.34	13.37	11.87	15.99	12.90	11.54
Fe_2O_3	3.66	2.46	5.74	2.14	3.33	1.53	4.36	2.42
FeO	11.66	10.62	10.72	8.30	11.59	10.54	10.31	11.09
MnO	0.22	0.36	0.09	0.14	0.20	0.27	0.20	0.29
MgO	17.86	3.43	7.80	3.46	7.89	3.94	5.75	4.07
CaO	8.96	13.29	11.20	8.15	10.13	9.00	7.52	7.74
Na_2O	1.73	2.80	3.26	5.24	3.31	4.46	3.36	3.41
K_2O	1.16	1.87	1.75	2.81	1.38	1.86	1.70	2.12
H_2O +	1.41	2.28	1.07	1.72	2.03	2.74	1.91	2.72
H_2O -	0.20	0.32	0.40	0.64	0.26	0.35	0.88	1.26
TiO_2	3.55	5.74	4.47	7.19	2.13	2.87	4.03	5.75
P_2O_5	0.64	1.03	0.83	1.33	0.89	1.20	1.11	1.58
	100.19	100.00	99.83	100.00	99.75	100.00	99.84	100.00
Niggli Values:								
si	79	116	95	122	96.5	111	111.9	124
al	6	14	11	21	15	23	18.6	18
fm	12	40	54	37	52	40	51.0	47
c	18	36	26	24	24	24	19.8	22
alk	4	10	9	18	9	13	10.6	13
mg	0.68	0.32	0.46	0.37	0.49	0.37	0.41	0.35
k	0.30	0.34	0.26	0.26	0.22	0.27	0.25	0.29
ti	4.9	10.8	7.27	14.5	3.51	5.3	7.4	11.6
p.	0.6	1.1	0.78	1.5	0.8	1.2	1.1	1.8

No. 2215: Olivine rich oligoclase basalt.
" 2216: Pyroxene phyric andesine basalt.
" 2228: " " " " (glassy development)
" 2225: Andesine phyric andesine basalt.



Relation between the chemical composition of the porphyritic rocks and their groundmass

Fig. 11.

2215, etc. Bulk composition of the analysed porphyritic rocks. (in terms of Niggli Values)

2215 a, etc. Calculated composition of the groundmass. " " " "

In view of the above considerations, petrographic and chemical, the parent magma of the Prinsen af Wales lavas seems to have been an olivine basalt of mild alkalinity.

Fig. 11 throws some light on the reasons for the petrological diversity found among the Prinsen af Wales Lavas and to what extent this diversity is due to crystallisation differentiation and to what extent it may be due to other causes. In Table 19, in addition to the bulk composition of the analysed porphyritic lavas, the calculated compositions of the groundmass (2215a, 2216a, etc.,) have also been included. For these calculations, micrometric analyses, determinations of specific gravity of the rocks, and the densities of the component minerals according to Winchell (1933) have been employed. In the plagioclase, a percentage of orthoclase substituting for part of the albite was included, according to estimates by Alling (1921, P.249).

If the different types of rock had been developed from a parent magma by normal crystallisation differentiation, the groundmass should show tendencies towards compositions approaching those of the later members of the differentiation series. A glance at Fig. 11 shows that such a relationship does not exist. In most cases the groundmass shows higher si, al, and alk, the other groups c and fm being lower than for the bulk composition of the rock. Rock No. 2215 shows a deviation from the normal course taken by the other porphyritic rocks of low si, by having a higher value for c than has the bulk composition of the rock. By the marked predominance of olivine among the phenocrysts, the groundmass is enriched in pyroxene (probably lime-rich) and alkali felspars. This rock has been most probably enriched in olivine by gravitative accumulation.

From the above features, it appears that crystal settling may be considered responsible to a great extent for the diverse characters of these rocks.

The phenocrysts of the porphyritic flows could certainly not have attained their present dimensions by crystallisation after extrusion, but must have been formed during an intercrustal period of partial crystallisation prior to extrusion. Most probably there has been a gravitative accumulation of the early crystallised phases, the pyroxene and olivine sinking and the felspars tending to float. Micrometric measurements of the felspar phyric flows show that there is a gradual transition to the upper pyroxene phyric lavas, through the decrease in the percentage of the felspar phenocrysts and a corresponding increase in the percentage of the porphyritic pyroxene. This variation can be explained by the differential movement of the crystallising phases under the effect of gravity and hence the mineralogical and chemical composition of a particular flow will be controlled by the position of the part drained from the magma column.

As the matter is usually complicated by the gravitative settling of early crystallised minerals, it is difficult to made any calculations to demonstrate the actual changes that took place in the evolution of these types. At any rate, it seems safe to conclude that the parent magma, olivine basalt, was of such composition as to lie well within the pyroxene field in the system Diopside-Anorthite-Albite (Bowen 1928). The early crystallising phases were magnesia-rich olivine and pyroxene of diopsidic type. By progress of crystallisation and removal of early crystals, the composition of the rest magma approaches the boundary curve. There, felspar started to crystallise together with pyroxene. The composition of the crystallising felspar depends undoubtedly upon the composition of the rest magma at that stage. The relatively early crystallisation of lime-rich pyroxene would impoverish the residual liquid in lime and eventually the composition of the magma seems to lie somewhere on the boundary curve where plagioclase of composition about 50% An was produced, corresponding to the plagioclase phenocrysts in the felspar-phyric rocks. Differential movement of the separating phases probably continued to take place; the felspar would tend to rise while the pyroxene would sink. This process probably explains the enrichment of the earlier felspar phyric lavas in plagioclase phenocrysts compared with the later flows of the same group. Tapping of the magma at different levels in the magma chamber will bring to the surface lavas of different composition.

The nonporphyritic flows seem to represent a part of the magma crystallising at that stage. This suggestion is based on chemical and normative similarity of the felspar phyric and the nonporphyritic flows (cf. Analyses Nos. 4 and 5).

The progress of crystallisation along the boundary curve with concomitant separation of the phases produced, would lead to enrichment of the crystallising plagioclase in the albite molecule. This conclusion is in fair agreement with the modal and normative composition of the groundmass plagioclase in the pyroxene phyric rocks, being an oligoclase-andesine.

Although the above system (Di-An-Ab) would throw some light on the course of differentiation followed by the magma in the evolution of most of the types, it will fail to explain the origin of the olivine-rich basalts, such as Nos. 2215 and 2238. In these types, olivine is the dominant phenocryst, while pyroxene forms the greater part of the groundmass associated with a small amount of felspar. The abundance of the olivine phenocrysts seems, as has been mentioned above, to be the result of crystal settling under the influence of gravity. On the other hand, the groundmass has undoubtedly crystallised after extrusion and accordingly it represents a true melt of its own composition.

It has been shown in Fig. 11 that the calculated composition of the groundmass in the olivine-rich rock (No. 2215) differs from that of the other types in having a high content of lime; this probably indicates that the pyroxene in the groundmass is a calcic variety.

It is difficult, however, to explain the origin of such a melt which would yield on crystallisation mainly pyroxene. It is possible to explain this if we assume that the sinking of early crystals of pyroxene takes place soon after crystallisation; the crystals would thus reach a level in the magmatic chamber where the temperature is sufficiently high for its resorption.

It is of interest to mention that the calculated composition of the groundmass (Table 19 - No. 2215a) approaches that of the average for the other analysed rocks, except for its lower magnesia content and slightly higher content of lime. This may also suggest that the groundmass probably represents a liquid of a composition near to that of the parent magma, though modified to some extent by resorption of sunken early crystals of pyroxene.

The part played by volatiles in the magma is unknown, and it is difficult to say to what extent the alkaline character of this basic series of lavas is affected by them. The derivation of the alkaline ultrabasic rocks such as limburgitic basalts, by volatile transfer has been suggested by Macdonald (1944, P.1360). At shallow depths a release of gases takes place accompanied by a further upward movement of gases which probably contain compounds of rock forming oxides, among them soda and potash. Precipitation of these materials may take place in the upper parts of the magma, aiding in the production of alkali-rich ultra-basic rocks.

In a previous section, the petrography of the horizontal Plateau Basalts in Prinsen af Wales region were described, and it was found that they show slight variation. Like the rest of the Plateau Basalts in East Greenland they are felspar-phyric and aphyric basalts. Plagioclase is usually the dominant phenocrystic constituent, while pyroxene hardly occurs as phenocrysts but it usually belongs to a late period of crystallisation. On the other hand, the variation among the Prinsen af Wales lavas shows a marked and more advanced stage of differentiation during the intratelluric crystallisation. Moreover, the crystallisation of pyroxene in the intratelluric stage seems to have been an important factor in determining the course of differentiation. These upper inclined lavas most probably belong to the same volcanic cycle which produced the horizontal basalt series. It is likely that a part of the main magma has been checked for a considerable time at a level in the crust which was relatively higher than the main magma chamber. There, different conditions of temperature and pressure were enough to disturb the physico-chemical equilibria that presumably existed between the molecular constituents of the magma. Such mechanism is believed to give rise to marked differentiation products (Dale 1944; MacGregor 1948, P.144-148; Macdonald 1949, P.1586-1587).

The absence of hypersthene as an early crystallisation mineral in these lavas also seems to lend support to this hypothesis (Larsen 1940, P.926; Macdonald 1944, P.136; 1949, P.90). High pressure is believed to favour the formation of hypersthene at depth instead of olivine. This has been explained by the fact that hypersthene has a considerably greater density than the average density of an equivalent mixture of olivine and amorphous silica.

A parasitic magma chamber of this kind would also probably explain the limited extent and the smaller thickness of these lavas, compared with the thick pile of the Plateau Basalts.

The inclined nature of these lavas seems to bear some relationship to the physical environments under which the parent magma existed. It is, however, difficult to decide the nature of these environments, but nevertheless tentative suggestions may be given.

This inclined nature has been interpreted to be due to a high degree of viscosity of these lavas on extrusion. In this connection the gas content may be mentioned as one of the important factors in determining the degree of fluidity of lavas. The non-vesicular character of the rocks might be regarded as indicating that a large amount of volatiles has been lost before the lavas reached the surface. A shallow depth of the magmatic chamber as suggested above, and consequently a low pressure, may possibly offer an explanation for the escape of the volatiles.

Another factor that may possibly affect the fluidity of these lavas is the early crystallisation of pyroxene which is believed to have been an important factor in causing the diversity of these rocks. Washington (1923, P.421) in his study on the formation of the two types of the Hawaiian lavas, the Pahoehoe and the Aa, has shown that they have the same content of ferrous oxides, although the Pahoehoe has a higher degree of viscosity than the other form. Besides the low gas content in the Pahoehoe form, he ascribes its viscosity to the early formation of augite phenocrysts. On the other hand, the rapidly flowing highly crystalline Aa form as observed in Hawaii as well as in Etna and Vesuvius is characterised by the abundance of labradorite phenocrysts but not of augite. Similar early development of felspar phenocrysts is also seen in the Plateau Basalts in several regions. Because of the early crystallisation of pyroxene the portion of the lava that remains liquid becomes increasingly poor in femic constituents and thus fluidity decreases rapidly. In the Aa and Plateau Basalts, on the other hand, by the early crystallisation of felspar, femic constituents increase in the liquid, and therefore greater fluidity is continually maintained for a long period.

C - COMPARISON WITH OTHER VOLCANIC REGIONS.

In the section on the petrography of the Prinsen af Wales lavas, the individual chemical analyses which are considered to be representative for the corresponding groups were compared with rock types from other volcanic regions. It is found worth while to compare these

TABLE 20.

PLEASE SEE OVERLEAF.

	A	B	C	D	E
SiO_2	43.26	44.16	44.74	45.81	47.37
Al_2O_3	5.88	8.34	11.87	12.90	14.51
Fe_2O_3	3.66	5.74	3.33	4.36	5.37
FeO	11.66	10.72	11.59	10.31	8.68
MgO	17.86	7.80	7.89	5.75	5.01
CaO	8.96	11.20	10.13	7.52	8.12
Na_2O	1.73	3.26	3.31	3.36	3.50
K_2O	1.16	1.75	1.38	1.70	1.56
H_2O +	1.41	1.07	2.03	1.91	1.44
H_2O -	0.20	0.40	0.26	0.88	0.50
TiO_2	3.55	4.47	2.13	4.03	3.04
P_2O_5	0.64	0.83	0.89	1.11	0.90
MnO	0.22	0.09	0.20	0.20	0.03
	100.19	99.83	99.75	99.84	100.03
Sp. g.	3.20	3.065	3.063	3.920	2.919
Norms.					
Q	-	-	-	-	-
or.	6.84	9.34	8.12	10.01	9.23
Ab.	12.00	14.88	16.77	28.40	29.55
An.	4.81	2.89	13.37	15.01	18.79
Np.	1.42	6.87	6.08	-	-
Di.	28.26	37.99	25.41	12.25	12.66
Hy.	-	-	-	7.00	8.97
Ol.	31.35	6.37	16.46	7.56	2.82
Mt.	5.31	8.33	4.83	6.33	7.79
Il.	6.73	8.48	4.04	7.65	5.76
Ap.	1.51	1.23	2.12	2.62	2.12

A. Olivine rich oligoclase basalt, E.G. 2215 (New analysis).

B. Pyroxene phyric andesine basalt (normal development, E.G. 2216 (New analysis).

C. Pyroxene phyric andesine basalt (glassy development), E.G. 2228 (New analysis).

D. Andesine phyric andesine basalt, E.G. 2225 (New analysis).

E. Andesine basalt, E.G. 2226 (New analysis).

1. Olivine basalt, E.G. 1057, Kap Dalton, E. Greenland, Hill west of Anchorage and 100 ft. below lowest sediment; anal. H.F. Harwood. (Wager 1934, P.32-33).

TABLE 21.

1	2	3	4	5	6	7	F
48.89	47.26	47.81	48.64	48.20	46.84	46.28	45.52
13.60	14.17	13.64	12.62	11.97	17.11	11.95	11.91
4.72	4.68	4.50	4.34	4.52	4.95	4.81	4.70
9.65	8.32	8.84	7.34	11.65	5.01	8.28	10.33
4.54	6.65	6.51	7.33	4.94	5.72	7.52	6.61
10.09	10.64	11.29	11.85	10.21	10.21	11.69	9.24
2.74	2.30	2.54	1.85	2.39	1.61	2.28	3.36
0.30	0.81	0.35	0.31	0.79	0.69	0.92	1.60
1.38	1.45	0.76	1.05	0.62	2.53	1.47	1.61
1.14	0.90	1.26	2.25	-	1.63	-	0.51
2.64	2.69	2.51	2.20	3.01	3.98	3.26	3.42
0.39	0.23	0.24	0.18	0.92	0.19	0.45	0.90
0.24	0.19	0.44	0.12	0.40	0.16	0.19	0.13
100.10	100.26	100.47	100.08	99.62	100.61	99.93	99.84
2.90	2.97	2.95	-	2.997	2.82	-	-
4.50	0.70	0.80	4.90	3.48	7.38		-
1.78	4.80	2.20	1.70	5.00	3.89		9.50
23.27	19.40	21.50	15.70	20.44	13.62		26.50
23.66	25.90	24.50	25.30	19.46	37.33		12.70
-	-	-	-	-	-		1.000
21.70	21.70	25.50	26.30	20.86	10.15		22.20
10.5	13.4	13.30	12.00	15.57	9.60		-
-	-	-	-	-	-		11.20
6.7	5.90	6.50	6.30	6.50	4.64		6.80
5.1	5.20	4.70	4.30	5.78	7.60		6.50
0.5	0.50	0.70	0.30	2.02	0.30		1.80

2. Olivine basalt, E.G. 1093, North side of Barclay Bugt, East Greenland, Anal. Harwood (op cit. 1934).

3. Olivine basalt, E.G. 1112, Kap Daussy, East Greenland; Anal. Harwood (op. cit. 1934).

4. Basalt Lava (86) Summit of Jackson Island, Gael. Hamkes Bay, East Greenland; Anal. Herdsman (Wager 1935, P.17)

5. Dolerite, No. 141, the coast near Kirchenpauer Buct, Clavering Is; Anal. N. Sahlborn (op. cit. 1935).

6. Basalt, Scoresby Sound, East Greenland; Anal. Harwood (Holmes 1916, P.189).

7. Average of E. Greenland basalts, 7 analyses after Buckland and Malmqvist. (Quoted from Krokstrom 1944, P.38).

F. Average of 4 analyses of Prinsen af Wales lavas (Nos. 2216, 2228, 2225, 2226).

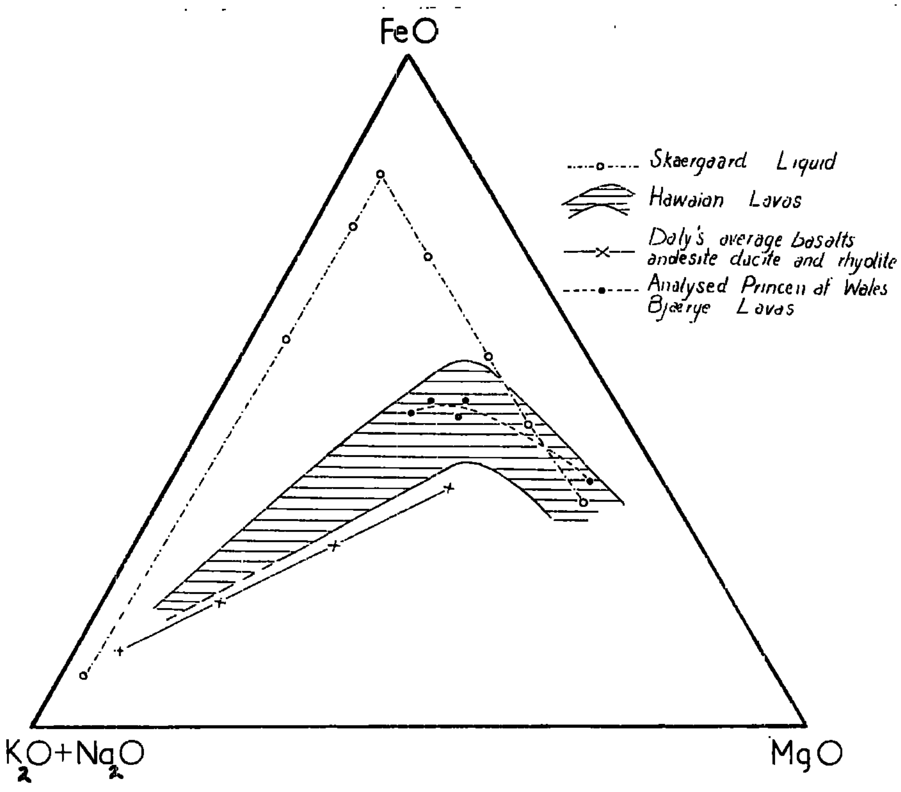


Fig. 13.

The analyses of the Prinsen af. Wales Lavas compared with the Trend of differentiation of the Hawaiian Lavas.

analyses represented by a calculated average with well-known volcanic provinces.

The average chemical composition of the Prinsen af Wales lavas was shown to be an olivine basalt with an alkaline affinity. In general character the average composition shows some features in common with the Plateau Basalts in East Greenland (Table 20, Cols. 1 - 6). The high iron oxides, titanium dioxide, lime and magnesia in both cases suggest inherited characters from a common parent magma. The similarity can also be perceived by comparing the average composition of the Prinsen af Wales lavas with that of seven analyses of basalts from East Greenland given by Backlund and Malmqvist (1932, P.47). The high titanium dioxide is common to almost all Greenlandic basaltic rocks (Backlund and Malmqvist, op. cit; Holmes 1918, Krokström 1944). It is believed that this high content of titanium in the Greenlandic basalts is a feature connected with the magmatic evolution in the region as a whole. The geographical distribution of the titanium dioxide in the Brito-Arctic region has been discussed by Holmes (1918, P.217) and he believes that a belt passing through the Hare Island, the Faroes, Iceland and Scoresby Sound represents a region underlying which the magmatic sources are particularly titaniferous. On both sides of this belt the content of titanium dioxide fades out.

Moreover, he correlated the geographical distribution of titanium dioxide with the variation in time between the older and younger rocks in the North Atlantic Tertiary Province, and pointed out that the later phases of igneous activity were the more alkaline. The recent discoveries of highly alkaline basalts, which started the Tertiary igneous activity in East Greenland, cast some doubt on the general conception given by Holmes that the progression in time is in direction of increasing alkalinity. In the basal conglomerate at Kap Dalton pebbles were collected which are believed to be derived from highly alkaline igneous field North of Scoresby Sound of late Cretaceous or early Tertiary (Wager 1935, P.29). In comparing the Prinsen af Wales Lavas with these pebbles, nothing is found similar to these highly alkaline suite of pebbles. The nearest comparison is found between a dyke of pyroxene monchiquite cutting through one of the flows (No. 2221) and a pyroxene monchiquite pebble (Wager, op. cit., P.22).

In Table 21 the average chemical composition of the Prinsen af Wales lavas is compared with the average of a number of magmatic provinces.

The Prinsen af Wales lavas show petrographic similarity to the lavas of Etna (Washington and others, 1926, P.406-408). These are dominantly andesitic and

TABLE 22.

AVERAGES OF THE PRINSEN AF WALES LAVAS, ETC.

	F	1	2	3	4
SiO_2	46.79	51.91	50.8	50.04	49.25
TiO_2	3.52	1.61	1.5	3.12	2.71
Al_2O_3	12.15	18.16	15.3	13.47	14.05
Fe_2O_3	4.47	3.09	4.5	2.65	3.43
FeO	10.62	5.37	6.9	9.79	9.94
MnO	0.13	0.13	0.2	0.12	0.21
MgO	6.79	3.90	7.5	7.79	6.77
CaO	9.51	8.36	8.6	10.49	10.20
Na_2O	3.46	4.85	3.0	2.43	2.48
K_2O	1.63	2.00	1.3	0.55	0.62
P_2O_5	0.93	0.62	0.4	0.29	0.35
	100.00	100.00	100.00	100.00	100.00
No. of Anal:	4	-	27	23	30

F. Average of 4 analyses of the Prinsen af Wales Lavas.

1. Average of the lavas of Etna (Washington and others, 1926, P.406).

2. Average of Central Victoria Lavas (Walker and Poldervaart 1949, P.649).

3. Average of Hawaii olivine basalts (Daly 1944, P.1392).

4. A grand average after Washington for Plateau Basalts from Asia, Africa, North America and various parts of the North Atlantic Field (Daly, 1944, P.1391).

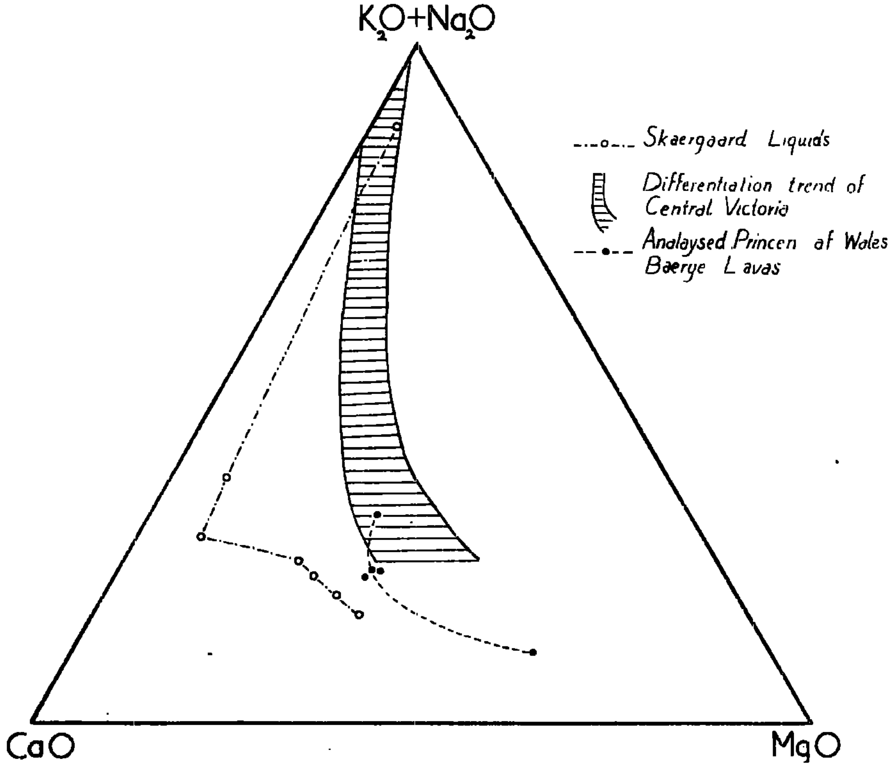


Fig. 12.

The analyses of the Prinsen af Wales Lavas compared with the trend of differentiation of the Central Victoria Lavas.

basaltic. Pyroxene and less olivine are the most abundant mafic minerals. The average composition of the Etna lavas (Col. 1), shows, however, a higher content of silica, alumina and alkalies.

Comparison can also be made between the average of the Prinsen af Wales Lavas and the Central Victoria Lavas (Col. 2). The character of the Central Victoria parent magma is considered to be an olivine basalt with a mild alkalinity (Edward, 1938). Limburgites (= olivine oligoclase basalts) and andesine basalts are represented among the various rock types, with which chemical comparison was already made on earlier pages. The trend of differentiation of Central Victoria lavas is also compared with the trend of the analysed rocks of Prinsen af Wales Lavas. For this comparison the constituents, MgO, CaO and $Na_2O + K_2O$ are plotted as variables on a triangular diagram, Fig. 12 (After Wager and Deer 1939, P.316). The trend of differentiation of the Prinsen af Wales Lavas shows a similarity to that of the Central Victoria Lavas at early stages. As to the crystal sequences in Central Victoria, it has also been shown that magnesia-rich olivine was the early mineral to crystallise from the magma, followed by lime-rich pyroxene. The course of differentiation followed by the Prinsen af Wales parent magma did not, however, extend to the late stages of alkali enrichment as shown by Central Victoria parent magma.

The average composition of the Prinsen af Wales lavas can also be compared with the average of the Hawaiian lavas (Col. 3). The latter is, however, less alkalic and of slightly higher silica content. The differentiation trends of the Hawaiian Lavas and Prinsen af Wales lavas are compared in the triangular diagram, Fig. 13, with MgO - FeO and $Na_2O + K_2O$ as variables (after Walker and Poldervaardt 1949, P.667). In the same diagram the differentiation trends of the Skaergaard Intrusion and Daly's average calc-alkaline suite are also entered. The Prinsen af Wales lavas show a similar tendency in their trend to that of the Hawaiian lavas and they follow in the early stages the trend of the Skaergaard Intrusion. The Hawaiian lavas then follow for the rest of the differentiation sequence the trend of Daly's average calc-alkaline suite.

In Col. 4 is given a grand average for the Plateau Basalts from various volcanic regions, including the North Atlantic field (Daly 1944, P.1391). In comparison with the average of the Prinsen af Wales lavas, the average of the Plateau Basalts is slightly higher in silica and alumina and lower in alkalies, while the other constituents are similar.

CHARACTERISTIC FEATURES OF THE PRINSEN AF WALES BJAERGE LAVAS.

Groundmass.	Remarks.
Essential: Oligoclase to oligoclase-andesine, pyroxene and iron ore. **Accessory:** Apatite, analcime. **Texture:** Fine-grained. Felspar/Ferromagnesian ratio is 1 : 2	The groundmass is dominated by pyroxene. Felspar is interstitial.
Essential: Plagioclase (oligoclase-andesine) pyroxene and iron ore. **Accessory:** Apatite, glass. Orthoclase and nepheline are shown by the norm but not detected. **Texture:** Fine-grained. Felspar/Ferromagnesian ratio is 5 : 1.	The groundmass may be completely formed of glass with microlites of pyroxene and iron ore. In some rocks the glass is partially palagonitised.
Essential: Acid andesine, pyroxene and iron ore. **Accessory:** Apatite, analcime, zeolite. **Texture:** Subdoleritic. Fine-grained. Felspar/Ferromagnesian ratio is 5 : 1.	The felspar phenocrysts are andesine (46%). The proportion of the phenocrysts varies among the group. The upper flows are less in felspar phenocrysts and their groundmass is of finer texture than the lower ones and highly charged with iron ore.
Essential: Oligoclase-andesine, pyroxene, Olivine and iron ore. **Accessory:** Apatite, analcime. **Texture:** Fine-grained. Felspar/Ferromagnesian ratio is 3 : 1.	The olivine is mostly pseudomorphed by chlorite. The felspar is in interlocking grains, untwinned and of low double refraction.
Essential: Oligoclase, pyroxene, olivine and iron ore. **Accessory:** Apatite. **Texture:** Trachytic. Fine-grained. Felspar/Ferromagnesian ratio is 3 : 1.	The rock is similar to typical mugearite except for its higher content of ferro-magnesian minerals.
Essential: Pyroxene, plagioclase and iron ore. **Accessory:** Zeolite. **Texture:** Fine-grained. Felspar/Ferromagnesian ratio is 1 : 3.	These lavas alternate with that of the next group. In some rocks, the groundmass is dominated by pyroxene while the felspar (25-35% An) is interstitial. In others, the felspar (50-55% An) increases in amount and develops into lath shaped crystals. In the latter rocks subordinate pyroxene also appears as phenocrysts.
Essential: Plagioclase (55% An), pyroxene, iron ore. **Texture:** Subdoleritic. Fine-grained Felspar/Ferromagnesian ratio is 1 : 1.	These rocks are similar to non-porphyritic basalts of the widespread Plateau Basalts.

TABLE 22.

	Phenocrysts.		
	Felspar	Pyroxene	Olivine
1. N. NUNATAKS AREA. **A. PORPHYRITIC GROUP.** 1. Olivine rich oligoclase-basalt.	-	p (1)	P (2)
2. Pyroxene phyric andesine-basalt.	-	P	p
3. Andesine phyric andesine basalt.	P	p	p
B. NONPORPHYRITIC GROUP. 1. Andesine basalt.	-	-	-
2. Mugearitic Basalt.	-	-	-
2. TILTED MOUNTAIN AREA. A. Porphyritic Olivine Basalts.	-	p	P
B. Basalts.	-	-	-

(1) p = Present in subordinate amounts.

(2) P = present in abundance.

TABLE 22.

Please see overleaf.

SUMMARY AND CONCLUSION.

In the Prinsen af Wales Bjaerge region there occurs a group of lavas which are distinct from the underlying Plateau Basalts in being inclined and in showing a variation in dip of as much as 30° within short distances. Similar lavas, but with less variation in petrographical features, also occur to the east in the Tilted Mountain area.

The Prinsen af Wales lavas have been divided into two major groups, porphyritic and nonporphyritic. In the porphyritic types olivine, pyroxene and plagioclase appear as phenocrysts in different combinations and variable amounts. On the basis of petrographic and chemical characteristics, the lavas are classified into five groups:

(table 22) (1) Olivine-rich oligoclase basalts.

(2) Pyroxene phyric andesine basalt.

(3) Andesine phyric andesine basalts.

(4) Andesine basalts, and

(5) Mugearitic basalts.

The absence of hornblende and biotite in these lavas is characteristic and probably indicates that the volatile constituents have been an insignificant factor in bringing about the diversity of these lavas.

The sequence of extrusion of the lavas seems to have been in the order shown in Fig. 4, the latest lavas being probably the olivine-rich basalts. In the Tilted Mountain area, however, the olivine-rich basalts are found to alternate with the aphyric basalts, and their relation to the sequence shown by the lavas in the Prinsen af Wales Bjaerge region is not definite.

Chemically the Prinsen af Wales lavas are basaltic in composition, with an andesitic affinity. The diversity of the rocks seems to have been due to the following factors:

(1) Original composition of the magma,
(2) Crystal settling, and
(3) Physical environment.

The parent magma seems to have been rich in lime, magnesia and iron oxides, and low in alumina and silica. The crystallisation of lime-rich pyroxene in the early stages, and its gravitative settling, have been important factors in determining the course of differentiation followed by the magma. By this process, the alkalies are enriched relative to the lime in the rest magma, and consequently when the plagioclase begins to crystallise at a later stage it is an andesine. The olivine-rich basalts with pyroxenic groundmass are believed to be the result of settling of early crystals of olivine and pyroxene. At deep levels resorption of the pyroxene would thus modify the original composition of the magma, so that it would yield on crystallisation mostly pyroxene.

In contrast to the Plateau Basalts, the greater diversity of the Prinsen af Wales lavas may be partly ascribed to a marked change in the physical environment. Probably, a part of the main magma has been checked for a long time at a higher level in the crust, i.e. at lower temperature and pressure. This will result in a more marked differentiation than that shown by Plateau Basalts, which most likely reached the surface without significant pause, and consequently with little opportunity for differentiation.

Such a subsidiary magmatic chamber would also explain the limited extent and smaller thickness of these lavas. Moreover, the shallow depth and consequent low pressure favoured the excape of volatiles, which is believed to be the cause of the high viscosity, and hence the inclined nature of these lavas.

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EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Olivine-rich oligoclase basalt (2215). The rock consists of idiomorphic olivine phenocrysts, pyroxene and iron ore, in a groundmass mainly of pyroxene prisms with interstitial felspar (P.32). Magnification X34.

Fig. 2. Pyroxene phyric andesine basalt (2216). Pyroxene subordinate olivine and iron ore phenocrysts are in a groundmass composed of abundant iron ore, pyroxene and felspar (P.42). Magnification X48.

PLATE II.

Fig. 1. Pyroxene phyric andesine basalt (2228). Porphyritic constituents are as in previous rock; the groundmass is completely formed of glass with fine prisms and microlites of pyroxene (iron ore is also present) (P.51). Magnification X34.

Fig. 2. Pyroxene phyric andesine basalt (2230). The field shows clear interstitial felspar enclosing idiomorphic pyroxene crystals and apatite needles (P.57). Magnification X36.

PLATE III.

Fig. 1. Andesine phyric andesine basalt (2225). Plagioclase, pyroxene, olivine and iron ore are present as phenocrysts, in a groundmass formed of plagioclase pyroxene, in a subdoleritic relationship and iron ore (P.71). Magnification X34.

Fig. 2. Andesine basalt (2226). The field shows prisms of pyroxene, elongated pseudomorphs of chlorite after olivine and grains of iron ore, in a felspathic base (P.82). Magnification X.73

PLATE IV.

Fig. 1. Andesine basalt (2229). The minerals are the same as in the previous rock. The field shows relics of olivine in elongated chlorite pseudomorphs (P.82). Magnification X.38

Fig. 2. Mugearitic basalt (2227). The minerals present are the same as in the previous rock except for the presence of trachyitic texture (P.87). Magnification X.38

PLATE I.

Fig. 1

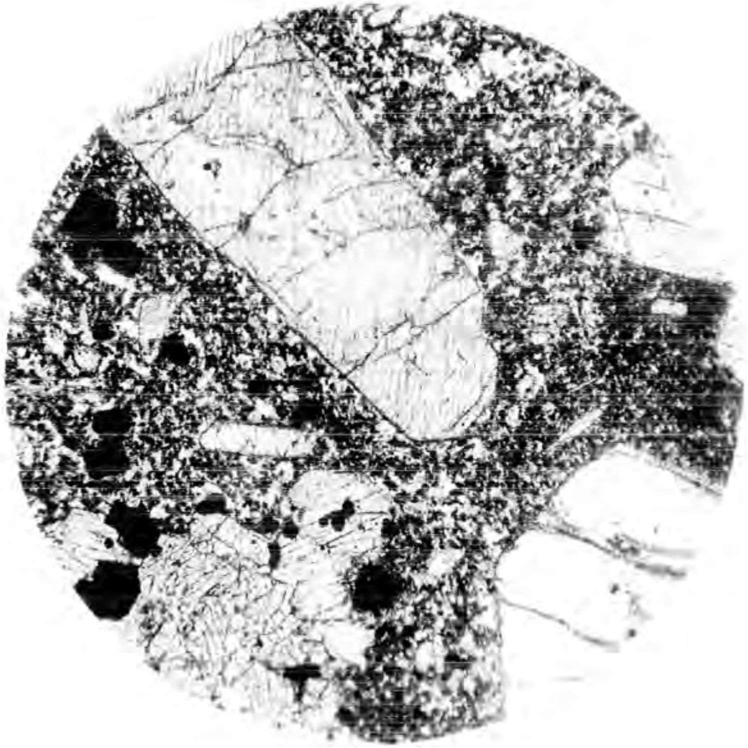


Fig. 2.

PLATE II.

Fig. 1.

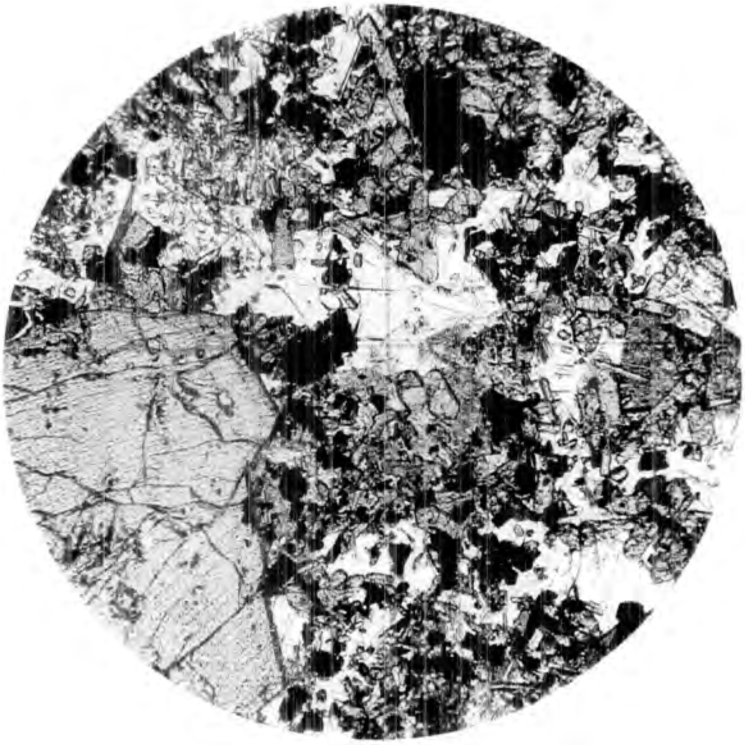


Fig. 2.

PLATE III.

Fig. 1.

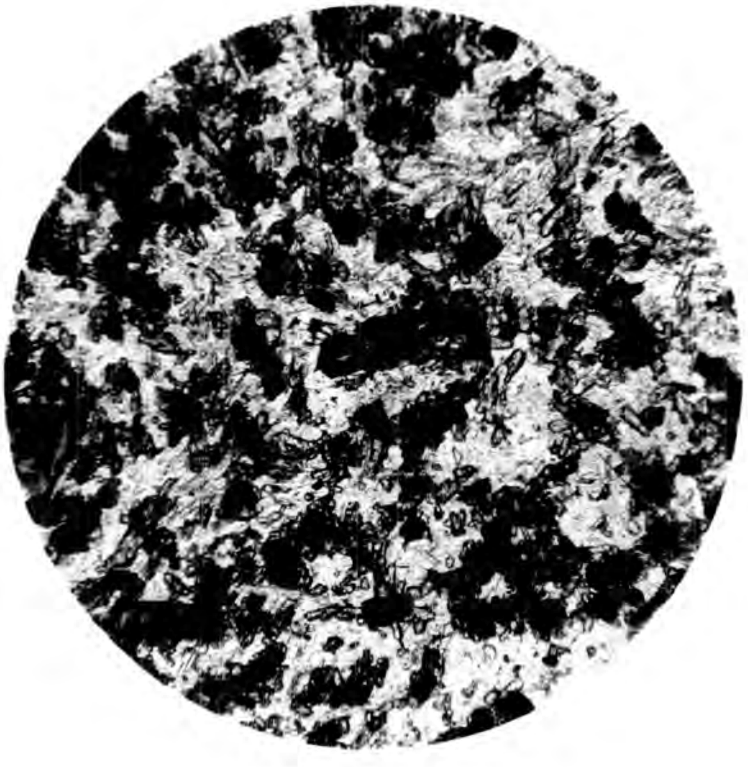


Fig. 2.

PLATE IV.

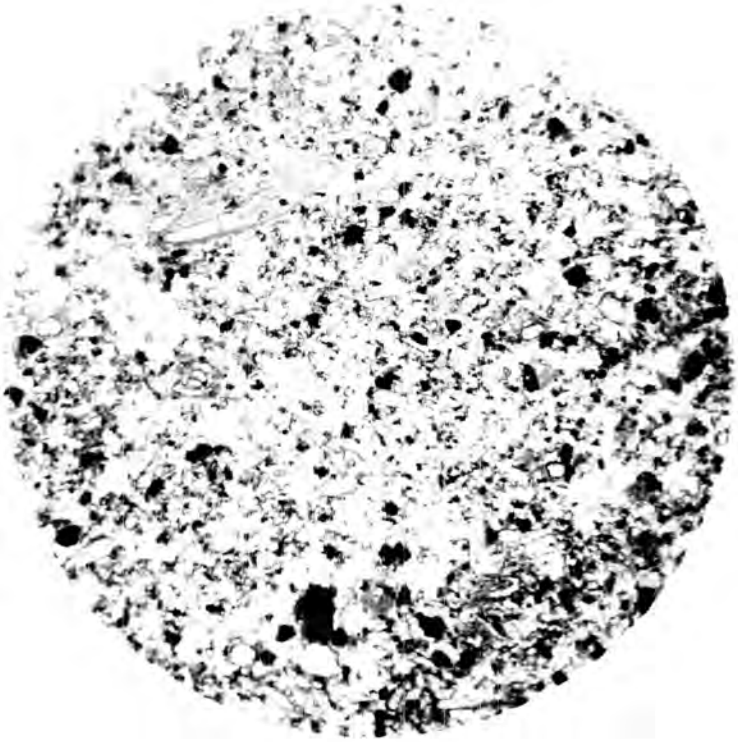


Fig. 1.

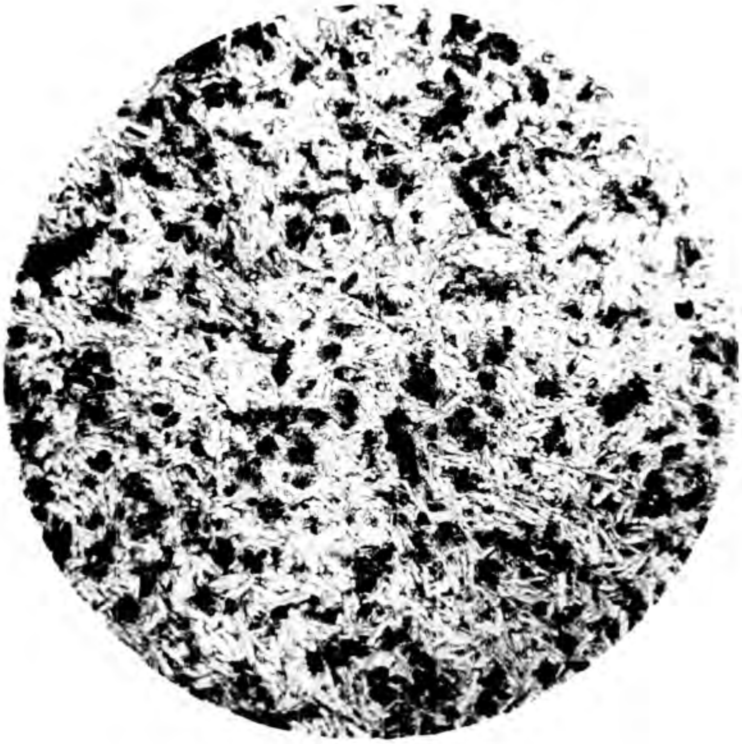


Fig. 2.

PART II

CONTENTS.

I - INTRODUCTION.

The Western extension of the Western Redhills complex of Central Skye is formed of different types of granitic intrusions, among which are the riebeckite and the pyroxene granophyres which form the redhill Meall Dearg.

The Meall Dearg granophyres were early described by Geikie (1894, P.218-220), who referred to these as mainly riebeckite granophyre. He discussed the age relations between the acid intrusions and the gabbros and proved that the latter is older than the granitic intrusions.

Harker in Skye Memoir (1904, P.126-168) confirmed Geikie's views with regard to the gabbro-granite age relations. He gave a detailed account of the granitic intrusions forming the Redhills complex and showed that it is formed of several varieties, but he did not, however, discuss their relative age relations. Petrographically, these granitic intrusions have been divided into hornblende-biotite granites and augite granophyres; some hornblende granophyres have been considered to form a link between the two. The riebeckite granophyre has been also recognised, but as a less common type, restricted to the Meall Dearg area.

The present study is concerned with the petrology of the Meall Dearg granophyres, the riebeckite and the pyroxene granophyres, for which the relative age relation is established. A detailed study of the pyroxene in the pyroxene granophyre has been carried out, and chemical composition and optical properties have been determined for these. As a reference to this work a sketch map is given as Fig. 1.

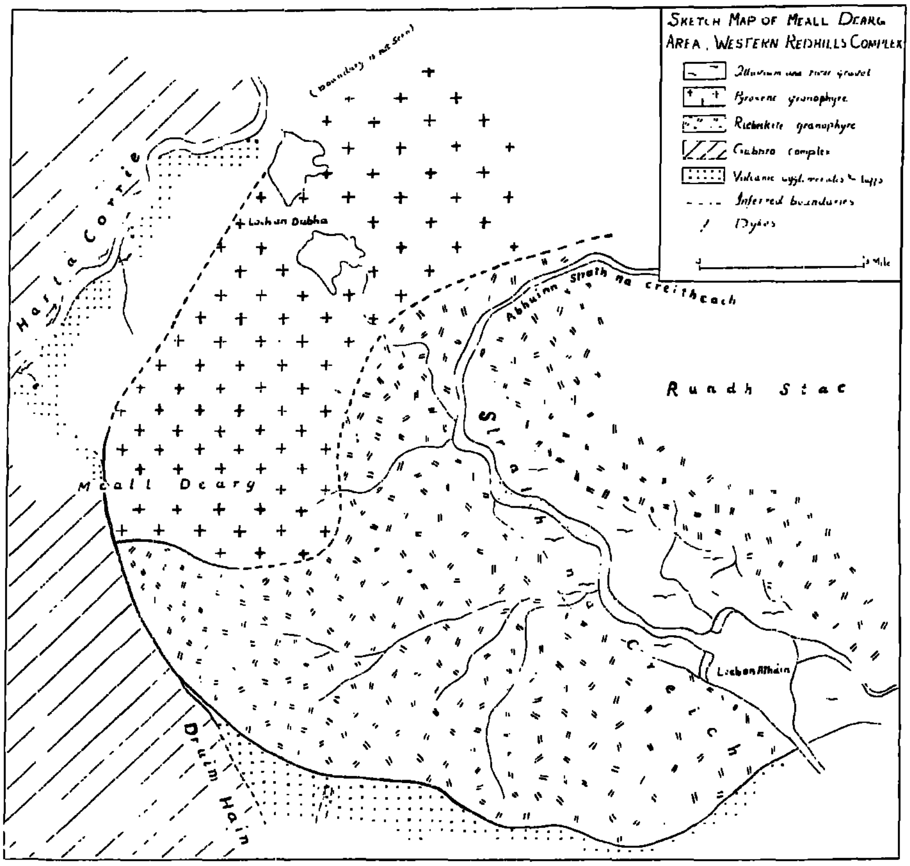

SKETCH MAP OF MEALL DEARG
AREA, WESTERN REDHILLS COMPLEX
Alluvium and river gravel
Pyroxene granophyre
Riebeckite granophyre
Gabbro complex
Volcanic agglomerates & tuffs
Inferred boundaries
Dykes
½ Mile
(boundary is not seen)
Harta Corrie
Loch an Dubha
Abhuinn Srath na creitheach
Rundh Stac
Meall Dearg
Srath na Creich
Lochan Athain
Druim Hain

Fig. 1.

II - FIELD DESCRIPTION.

A. GEOLOGICAL SETTING.

The sketch map, Fig. 1, illustrates the distribution of the different rock types in the area. The older formations into which the granophyres are intruded are:

(1) Agglomerates and tuffs, and

(2) Gabbro complex.

(1) Agglomerates and tuffs: These occur as a large tract to the south of the Meall Dearg granophyres, and to a less extent to the north of Meall Dearg. That the granophyres are younger than the agglomerates is proved by the chilling modifications of the granophyres against the agglomerate in the south. The contact between the granophyres and the northern outcrop of the agglomerates is, however, not exposed due to covering with vegetation. In this locality the agglomerates are in direct contact with the gabbros, as is seen in the Glen Sligichan.

(2) Gabbro-complex: This is the extension of the Cullin gabbros. Its contacts with the granophyres are excellently exposed, and the boundary between them runs in a south-easterly direction until it reaches the agglomerates in the south. The granophyres show fine-grained margins against

the gabbros, thus indicating younger age of the granophyres. The gabbroic rocks against which the granophyres are chilled are of dark colour and fine-grained texture. In thin section they are found to be of granulitic nature and formed of augite and plagioclase (calcic andesine to intermediate labradorite). The pyroxene is partially altered to amphibole and chlorite. This rock is found to be closely similar to a granulite described by Harker (1904, P.115-116) from Drium an Eihden. The nature of these rocks is, however, uncertain, and Harker believes that there are probably two distinct but similar granulitic rocks; one is a granulitic gabbro and the other is a metamorphosed basic lava entangled by the gabbro complex. As it is difficult to decide the nature of these rocks, it may be safe to say that the present granulitic rocks have been existing as such before the intrusion of the granitic magma.

In general, the gabbro-complex has been described by Harker (1904) and he showed that it is formed of several intrusions of different types. These intrusions are of heterogenous character, which shows itself sometimes in the form of alternating leucocratic and melanocratic bands, as seen in the area about Drium an Eihden.

B. MEALL DEARG GRANOPHYRES.

The two granophyres in the area under consideration are riebikite and pyroxene granophyres. They are generally of a uniform character and their distinctive features are retained throughout their outcrop.

(1) Riebeckite granophyre: This occupies the southern part of the area and its outcrop rises nearly up to the top of Meall Dearg where it comes in direct contact with the pyroxene granophyre. Its extension to the east has been followed to the foot of Ruadh Stac, where it forms part of the latter. In the northern part of Ruadh Stac the riebeckite granophyre is followed to the east by hornblende granophyre, but their mutual relations have not, however, been determined (Personal communication with Mr. J.M. Carr).

In the field, the rock is typically medium grained and of whitish colour. The ferromagnesian mineral, riebeckite, is scattered in the rock as fine grains and elongated prisms. Specimens with patches of pyrite and fluorite of 2-3 inches diameter were collected from a stream running from the side of Meall Dearg eastward to join the main stream, Abhuinn Strath no Creitheach.

In the southern part of the outcrop and to the west of Loch an Athain, the rocks display miarolitic features and show abundant cavities, 4 mm. in diameter, into which felspar and riebeckite crystals project. A specimen was provided by Prof. L.R. Wager of the drusy granophyre from this locality, and the cavities are lined by micaceous golden-yellow mineral, which was identified as stilpnomelane. This miarolitic feature was found to decline as the outcrop rises to the top of Meall Dearg. Against the gabbros and agglomerates the riebeckite granophyre shows chilled margins, a feature which is not seen in the rocks against the pyroxene granophyre.

(2) Pyroxene granophyre: This occupies the northern part of the Meall Dearg area, where it forms an elongated outcrop trending in a north-east direction. Its appearance in the field varies from green to light green in colour and weathers into a brownish-coloured rock. The rock is generally massive, medium-grained, in which rounded clots, ~~of~~ 3 mm. in diameter, occur, representing segrated dark minerals. In a few cases larger clots of 2 - 3 inches in diameter are met with, which in thin sections are seen to be of finer texture than the enclosing rock, and contain abundant pyroxene, iron ore and felspars, while quartz is in subordinate amounts. The contact between the pyroxene granophyre and the gabbro complex is well exposed on the ~~northern~~ N.W. side of Meall Dearg facing Harta Currie. There the contact is seen to be nearly vertical, with only a few degrees dip outwards. The rocks at the contact are of greenish colour and of felsitic nature.

The exposures between the two granophyres are only seen in two dimensions and no vertical contacts are available. The relative age relation of the two granophyres could only then be decided by the following textural variations displayed by the rocks along certain parts of the contacts.

(1) The exposed contact between the two granophyres on the top of Meall Dearg shows that the pyroxene granophyre develops a fine-grained margin against the riebeckite granophyre. The chilled zone does not, however, exceed a foot, and is different from that observed against the gabbros, being of coarser texture. This may suggest that a shorter interval must have elapsed between the two granophyre intrusions than that between the granophyres and the gabbros.

(2) In a stream running from the side of Meall Dearg eastwards and crossing the two granophyres contact, specimens of riebeckite granophyres were collected showing patches of greenish colour and of finer texture than the normally developed rock. Microscopic examination revealed that these rocks show crushing effects, most likely resulting from the intrusion of the pyroxene granophyre.

III - PETROLOGY OF THE GRANOPHYRES.

A. RIEBECKITE GRANOPHYRE:

When fresh the rock is of white colour, with recognisable greenish-black crystals of riebeckite. In thin section it is found to be formed of quartz, microperthite, plagioclase, riebeckite and iron ore. Other minerals are quantitatively subordinate and consist of apatite, zircon, allanite, epidote and fluorite. Chlorite and calcite are present as secondary minerals.

The quartz occurs partly as independent large grains and partly intergrown micrographically with the perthite. In several cases protuberances and detached parts of the surrounding felspar are seen enclosed in the quartz.

The microperthite is the dominant felspar and consists of altered potash felspar, orthoclase, penetrated by fine elongated strings of clear albite. The strings may be seen to develop into coarser individuals which may sometimes coalesce into patches (Pl. I, Fig. 1). Twinning on the carlsbad law is sometimes met with. The adjacent microperthite crystals are commonly of irregular outlines, and in a few cases they show rectangular outlines, surrounded by micrographic intergrowths of quartz and felspar. The latter is in optical continuity with that of the kernel. The apparent idiomorphism of the kernel felspar was found to be due to the abrupt termination of the quartz rods in the micrographic texture. This seems to indicate the early existence of an idiomorphic potash felspar which extended outwards at later stages with simultaneous crystallisation of the quartz.

The plagioclase is in subordinate amounts. It is an oligoclase and occurs in small allotriomorphic crystals showing irregular albite twinning. The lamellae appear as few interrupted individuals in a clear felspar. Moreover, they may coalesce into patches in a similar manner to the broad type of perthite. Few crystals of rather coarser size, 0.7 mm. in average diameter, are present, showing rectangular outlines and regular albite twinning. The composition according to maximum symmetrical extinction angle is about 18% An.

The riebeckite occurs as small prismatic crystals and ragged shreds, .4 mm. in length. In few cases it is subidiomorphic, showing the (010) and (100) faces. It is of deep blue colour and strong pleockroism: $Z = Y$ = deep blue, and X = greenish-brown. The extinction angle is very small, at most 3°. The principal refractive indices were determined by the immersion liquid method, and the following results were obtained:

$$\gamma = 1.704$$
$$\beta = 1.693$$
$$\alpha = 1.692$$

<u>Stilpnomelane</u>: In the specimen ~~from~~ of the drusy riebikite granophyre, west of Loch an Athain, the cavities are found to be lined with soft micaceous mineral of yellowish-brown colour. The mineral is pleockroic, $\gamma = \beta$ = dark brown; α = golden-yellow to pale brown. Fragments of the mineral were picked out of the cavities and the following optical properties were determined:

$$\gamma = \beta = 1.742$$

$$\alpha = 1.633$$

$$\gamma - \alpha = 0.109 \text{ (calculated).}$$

$$2V \text{ (negative)} = \text{about } 0.$$

The mineral is found comparable in hand specimen and optical properties to the stilpnomelane from drusy cavities in a granophyre described from the Skaergaard intrusion (Wager and Deer, 1939, P.188-190). The values for the refractive indices indicate that the stilpnomelane is an iron-rich variety (Hutton 1938, P.187, Fig. 5). As to its origin, the stilpnomelane seems to be the result of late aqueous solutions operating at late stages of consolidation. Pneumatolytic origin has been suggested by Hutton for some occurrences of stilpnomelane (1938, P. 194).

In some places near the contact with the pyroxene granophyre, the riebeckite granophyre shows signs of crushing (Specimens 10, 11). There the rocks are of whitish grey colour with greenish patches. Microscopically, the rock is found to consist of the same mineralogical constituents as the normal granophyre except for the signs of bracciation which the minerals had suffered. This effect results in wavy extinction of the various constituents and the mineral grains may be fractured or broken down into angular fragments of variable sizes.(Pl.I,Fig.2) The ferromagnesian minerals are completely pseudomorphed by brownish chloritic material and iron ore.

The rock against the gabbro (Specimen 3) is of whitish grey colour and aphanitic. In thin section it is seen to be formed of a few altered felspar phenocrysts in a fine-grained groundmass formed of quartz and felspar. The porphyritic felspar shows no twinning and is partly perthitic. The crystals are generally irregular in outline and show signs of deformation, being of wavy extinction and broken into detached fragments. Patches and streaks of spongy chloritic material associated with iron ore are present in the groundmass.

B. PYROXENE GRANOPHYRE.

In hand specimen the rock is medium-grained and of greenish colour. Microscopically, the rock is found to consist of quartz, orthoclase, plagioclase, pyroxene olivine or its pseudomorphs and iron ore. The other minerals present in quantitatively subordinate amounts include apatite, zircon, epidot, allanite and fluorite. Chlorite is present as a secondary mineral (Pl. II, Fig. 1). The mode was determined on Dollar's integrating stage, and is given in Table I.

The quartz occurs partly as large allotriomorphic crystals and partly in micrographic intergrowth with the perthitic felspar.

The orthoclase is always turbid by alteration products. It is generally perthitic of the fine string type, and occurs dominantly in irregular crystals, and to a less extent in rectangular crystals, sometimes surrounded by micrographic intergrowth. The perthite may also be completely intergrown with the quartz. Twinning on the carlsbad law is common.

The plagioclase is somewhat more abundant than in the riebeckite granophyre. It occurs in large subhedral individuals, 1.4 mm. in average diameter, with fine polysynthetic twinning. Zoning in most cases is strongly developed and the outer zone is usually perthitic. This outer perthitic zone may extend outward in a micropegmatitic intergrowth with quartz. According to maximum symmetrical extinction angle the plagioclase is an oligoclase (12-20% An.)

The pyroxene occurs in most cases as fresh crystals of greenish colour with faint brownish tinge. It is slightly pleockroic, $\gamma = \beta$ = brownish green, α = green. The commonest habit of development of the pyroxene is elongated prisms, 1.5 mm. in maximum length. These prisms are usually embayed by the surrounding felspar, and, furthermore, may be divided by the intervening felspar into detached parts in optical continuity. In some cases, the pyroxene may occur as an optically continuous group of small rounded crystals embedded in the perthite in ~~such~~ a relation similar to graphic intergrowths. The relationship of the pyroxene to its associating minerals seems to indicate that its crystallisation started a short time before the crystallisation of the plagioclase and the potash felspar. The pyroxene when altered is seen to be replaced by green chloritic material and to a less extent by greenish amphibole. Inclusions of abundant apatite prisms are seen in the pyroxene in few cases.

A detailed study of the pyroxene was made and the results are given on later pages. The pyroxene is found to be a ferrohedenbergite of a composition Wo_{39} En_5 Fs_{56}.

Olivine occurs in most cases as relics in pseudomorphs of brownish green chloritic material associated with abundant iron ore. The pseudomorphs are seen in many cases to be enveloped in large patches of deep green chlorite of rather high double refraction. No reaction relation has been observed between the olivine and the pyroxene. The olivine in the fresh remnants is of amber yellow colour and unnoticeable pleockroism. One rather coarse remnant was met with which allowed an optic axial determination; the axial angle 2V is found to be 54° (Federow stage) indicating a fayalite content of 87%. According to the classification and nomenclature of the olivine group (Deer and Wager, 1939, P.21-25) the olivine is a ferrohortonolite.

The sample 27 is from the marginal part of the pyroxene granophyre, occurring on the top of Meall Dearg, where it somes in direct contact with the riebeckite granophyre. This marginal zone is, however, of small width, and the grain size increases gradually inwards. In thin section the rock is seen to be formed of grains of pyroxene, felspar, quartz and iron ore. The felspar and quartz occur as interlocking crystals without micrographic intergrowth (P. II, Fig. 2). The pyroxene forms abundant fine rounded grains, .06 mm. in diameter, and is associated with abundant iron ore. Few patches of chloritic material and iron ore are present, probably after olivine. Coarse patches of riebeckite granophyre are seen among the fine-grained constituents, but with indistinct boundaries. The latter is only marked by streaks of the granular pyroxene and magnetite which run parallel to the edges of the coarse patches. A few riebeckite shreds are observed among the pyroxene of the enclosing rock. Such occurence of riebeckite together with the pyroxene has not, however, been observed in the normal rock away from the contact.

The contact type of rock against the gabbros (Specimens 15, 17) is of finer texture than the described marginal rock occurring against the riebikite granophyre. Microscopically the main mass of the rock (Specimen 15) is seen to be formed of felspar and quartz as fine angular and rounded grains. A few porphyritic crystals of felspar in isolated crystals or in micrographic intergrowth are commonly present. They are, however, mostly fractured and broken into angular fragments in ~~such~~ a manner suggesting crushing effects. The ferromagnesian minerals are completely pseudomorphed by green chlorite. Calcite and chloritic material are present in patches or streaks among the groundmass constituents. Specimen 17 is similar to the previous rock (No. 15), but is of relatively coarser texture. Microscopically it is seen to be formed of coarse patches of felspar and micropegmatite in a fine-grained matrix of quartz and felspar. The felspar and micropegmatite in the patches are mechanically deformed, being broken into angular fragments which are left in place and generally show wavy extinction. Angular grains of quartz are present in variable sizes and display andulose extinction. The pyroxene is completely pseudomorphed by green chlorite. Such crushing feature observed at the margin was also noticed to occur in the fine-grained margins of the riebeckite granophyre in direct contact with the gabbros. These features have not, however, been met with in the rocks away from the contact. Its occurrence in the marginal rocks suggests that the deformation of the rock is most probably the result of lateral stresses on the margins as a consequence of final consolidation and adjustment of the granitic masses.

Dyke rocks: On the eastern side of Meall Dearg the pyroxene granophyre is cut by few thin felsite dykes. One porphyritic felsite dyke further to the south of the other dykes is met with, cutting through the two granophyres across their boundaries. It is six feet wide and trends in a N.W. direction. The rock is of brownish colour and is composed of phenocrysts of quartz, microperthite and a subordinate amount of sodic plagioclase. The groundmass consists of quartz, felspar and abundant fine acicular crystals of riebeckite.

Chemical Analysis: The chemical analysis of the pyroxene granophyre gave the results shown in Table 1.

TABLE 1.

ANALYSIS OF THE PYROXENE GRANOPHYRE.

	Wt.-%
SiO_2	69.24
Al_2O_3	12.25
Fe_2O_3	2.20
FeO	4.14
MgO	0.20
CaO	1.92
Na_2O	4.20
K_2O	4.27
H_2O+	0.35
H_2O-	0.23
TiO_2	0.50
P_2O_5	0.23
MnO	0.14
	99.87
Sp. G.	(2.67)

Norm.		
Q.		23.40
Or.		25.19
Ab.		35.49
An.		1.38
Di.		5.37
$CaSiO_3$	2.55	
$MgSiO_3$	0.25	
$FeSiO_3$	2.57	
Hy.		2.90
$MgSiO_3$	0.25	
$FeSiO_3$	2.65	
Mt.		3.20
Il.		0.94
Ap.		0.54

Or : Ab : An = 41 : 57 : 2

Plag: Ab_{96} An_{4}

Di: Wo_{47} En_{5} Fs_{48}

Hy: En_{9} Fs_{91}

Ratios:

$$\frac{K_2O \times 100}{K_2O + Na_2O} = 50$$

$$\frac{FeO + Fe_2O_3 \times 100}{FeO + Fe_2O_3 + MgO} = 97$$

$$\frac{Fe_2O_3 \times 100}{FeO + Fe_2O_3} = 35$$

Mode. (Vol.-%)	
Quartz and micropegmatite	45
Orthoclase and perthite	28
Plagioclase	12
Pyroxene	5
Olivine or its pseudomorphs	2
Iron Ore and chlorite	8

The distinctive feature of the analysis is the equal content of soda and potash.

It has been remarked by Harker (1904, P.153) that the British Tertiary granites and granophyres fall into two subgroups, based on silica percentage:

(1) SiO_2 = 75 - 77%: These are mostly granites with little biotite as ferromagnesian mineral.

(2) SiO_2 = 70 - 72%: these are mostly typical granophyres, and the ferromagnesian minerals are hornblende and augite.

According to this classification, the rock lies in the granophyric group.

In Table 2, the pyroxene granophyre analysis (A) is compared with analyses for augite granophyres from the British Tertiary Province (Anal. 1 - 5). The augite granophyre ring dykes from Mull (Anal. 1 and 2) are comparable to the Meall Dearg granophyre, but they show slight variation with regard to the alkali content and the state of oxidation of the iron oxides. The same is also true for the augite granophyre, acid Craignurite cone sheets from Mull (Anal. 3), augite granophyre from Ardnamurchen (Anal. 4) and Carrock Fell (Anal. 5). From Skye the pyroxene granophyre is comparable, both chemically and modally, to a pyroxene granite (Anal. 6) from

TABLE 2.

Please see overleaf.

TABLE 2.

	A	1	2	3
SiO_2	69.24	73.32	73.12	71.30
Al_2O_3	12.25	12.25	12.44	11.24
Fe_2O_3	2.20	2.77	2.09	1.80
FeO	4.14	2.77	1.65	2.84
MgO	0.20	0.11	0.14	0.61
CaO	1.92	1.65	0.88	1.56
Na_2O	4.20	3.92	3.90	3.44
K_2O	4.27	2.34	4.67	3.66
H_2O+	0.35	0.35	0.24	1.04
H_2O-	0.23	0.35	0.25	0.39
TiO_2	0.50	0.51	0.39	0.58
MnO	0.14	0.12	0.17	0.31
P_2O_5	0.23	0.10	0.09	0.22
	99.87	99.99	100.03	99.99
Sp. G.	-	-	-	-

A. Pyroxene granophyre. Meall Dearg, Skye (new analysis).

1. Augite granophyre, Krock Ring Dyke, Beinn Bhearg, Mull (Bailey, Thomas, etc. 1924, P.20.) Anal. E.G. Radley.
2. Augite granophyre, Beinn a Ghraig Ring Dyke, Mull, (Bailey and Thomas etc. 1924, P.20). Anal. Radley.
3. Augite granophyre, acid Craignurite Cone sheet, Craignure Bay, Mull (Bailey, Thomas, etc. 1924, P.20) Anal. E.G. Radley.
4. Augite granophyre, Intrusion. S.30°E of Grigadale, Ardnamurchan. Anal. B.E.Dixon. (Richey, Thomas, etc., 1930, P.84.)

COMPARISON.

4	5	6	7	8	9
68.42	71.60	71.68	70.34	71.98	71.51
13.54	13.60	12.55	13.18	13.13	12.82
2.53	2.40	2.29	2.65	1.33	2.09
2.02	-	2.40	2.24	1.64	1.40
0.22	0.21	0.24	0.40	0.56	0.17
2.13	2.30	0.92	1.24	1.15	1.09
5.12	5.55	4.28	3.61	2.98	4.24
4.08	3.53	4.37	4.90	4.93	4.52
0.15	0.70	0.64	0.76	1.38	1.23
0.25		0.25	0.46	0.39	
0.81	-	0.38	0.46	0.37	0.10
0.38	-	0.03	0.10	0.19	tr.
0.10	-	0.05	0.19	0.14	-
99.75	99.89	100.08	100.53	100.17	99.17
-	-	-	(2.66)	(2.63)	

5. Augite granophyre, Carrock Fell, Cumberland (Harker, 1895). Anal. C. Barrow.
6. Pyroxene granite (G^1), Water Worn Cully S.E. face of Beinn Dearg Mhor at C.1400 feet, Skye, (Unpublished analysis). Anal. E.A. Vincent.
7. Hornblende granophyre, Druim Eadar da Choire, Skye (Harker 1904, P.153). Anal. W. Pollard. (Rock also contains CL_2 = 0.01).
8. Hornblende granophyre, Beinn a Chairn, Broadford, Skye (Harker 1904, P.153). Anal. W. Pollard. (Rock also contains CL_2 = 0.01).
9. Granophyre, S. of Saterstugen Breven, Sweden (Krokstrom 1932). Anal. K. Winge.

S.E. face of Beinn Dearg Mhor. (The analysis was kindly provided by Mr. E.A. Vincent). This granite is classified as G^2 and is shown to be younger than the hornblende granite (G^1) outcropping along its Western margin and to the north of Marsco (International Geol. Congress, XVII Session, 1948, P.12). Comparison can also be made between the pyroxene granophyre analyses and two hornblende granophyres (Anal. 7 and 8) described by Harker in the Skye Memoir. A granophyre from Sweden (Anal. 6) shows a close similarity to the Skye granophyre.

Before closing this discussion on the chemical analysis, it may be appropriate to point out the following features:

(1) Although the pyroxene granophyre shows a chemical similarity to the hornblende granophyre, pyroxene rather than hornblende was formed.

(2) The absence of alkali-iron pyroxene, although the rock is fairly rich in alkalis.

The formation of hornblende has been discussed by Iddings, and showed that the presence of hydrogen in the hornblende indicates the important role played by water in the magma (1920, P.138-141). Fenner (1926, P.696-700), Buddington (1931, P.259), Larsen and Irving (1936, P.889-898) believe with Iddings that the formation of hornblende is attributed to the high concentration of volatiles in the magma while the rock of corresponding composition whose crystallisation has taken place in less concentration of volatiles will be characterised by pyroxene. Kennedy (1936 P.207) on the other hand, did not incline to ascribe any controlling role to the water concentration in the magmas. He concludes that the basic oxides MgO - FeO - CaO in the original melt constitute the important factor in the separation of either hornblende or pyroxene. This is based on the fact that the hornblende has a composition lying in the pyroxene diagram within the field where a homogenous pyroxene cannot form.

The comparison between the pyroxene granophyre and the hornblende granophyres is further elucidated by comparing the following ratios:

SKYE PYROXENE GRANOPHYRE.

	Anal. A.	Anal. 7.	Anal. 8.
$\frac{K_2O \times 100}{K_2O + Na_2O}$	50	58	62
$\frac{FeO + Fe_2O_3 \times 100}{FeO + Fe_2O_3 + MgO}$	97	93	84
$\frac{Fe_2O_3 \times 100}{FeO + Fe_2O_3}$	35	54	45
CaO	31	32	34
% MgO	3	10	17
FeO	66	58	49

The discrepancies in the above ratios, although not striking, may suggest that variation in composition within certain limits is likely to be partly responsible for the formation of hornblende.

As to the second feature, i.e. the absence of alkali-iron pyroxene, it seems that the composition of the magma and the physical environments have been the controlling factors. As is shown later (Table 3) the pyroxene in the Skye granophyre is poor in soda and ferric oxide, the main constituents of the alkali-pyroxene. Calculation of the pyroxene analysis in terms of the normative minerals, acmite-hedenbergite and diopside, shows that the pyroxene contains 4% of the acmite molecule. Iddings (1920, P.136-137) favours as an explanation for the formation of the alkali pyroxene the presence of ferric iron and the deficiency of alumina to combine with all the soda to form albite. C.E. Tilley has shown that by the deficiency of alumina at the marginal facies of hornblende-biotite granite by transfer of alumina into the adjacent dolomite results in the development of aegirine-hedenbergite in place of the hornblende and biotite.

As to the importance of ferric iron in the formation of alkali pyroxenes, Sabine (1950, P.118) in his comparative study on the acmitic pyroxenes has shown that proportions of these constituents in the pyroxene are nearly equal.

The state of oxidation of iron in the magma is largely controlled by the reversible reaction, $2Feo + H_2O =$ $Fe_2O_3 + H_2$~~O~~, and it seems, as has been mentioned before, that the volatile constituents have not been an important quantity in the process of evolution of the pyroxene granophyre.

IV. THE CLINOPYROXENE FROM THE MEALL DEARG GRANOPHYRE.

Pyroxene granophyres are of common occurrence in the British Tertiary Petrography. No chemical analyses have been made for the pyroxenes in these granophyres, however. Separation and analysis of the pyroxene from the Skye granophyre has thus been undertaken in order to display its characters for any future comparison.

METHOD OF SEPARATION.

The concentrate for the chemical analyses was separated from the rock by the following procedure: The rock was crushed and sieved through silk bolting cloth of 120 mesh; the finest rock flower was washed away, and the powder was dried at 100° C. Separation into light and heavy fractions was then made, using bromoform of specific gravity 2.89. A large amount of rock powder was used in this stage in order to get a reasonable amount of concentrate. The heavy fraction was rubbed gently in an agate mortar to break down any composite grains, and was then centrifuged, using a Clerici's solution and distilled water mixture, of specific gravity 3.2. This served to float the chlorite and any composite grains as well as any escaped grains from the light fraction. Centrifuging was repeated with constant test for the products under the microscope. The iron ore was separated for its greater part by an electromagnet, followed by repeated centrifuging using Clerici's solution of specific gravity about 4. The concentrate was then washed thoroughly with hot water.

Microscopic slide of the pyroxene concentrate was prepared and a grain counting showed that the foreign material is only about 0.4%.

DETERMINATION OF THE PROPERTIES OF THE PYROXENE.

The specific gravity of the pyroxene was determined on the pure concentrate, using specific gravity bottle and toluene instead of water. The determination was repeated twice and the average was used.

The principal indices of refraction were determined ~~carried~~ on the concentrate by the immersion liquids and using sodium light. The accuracy of the determinations is ± .002 - .0015. For the determination of the refractive indices γ and α, grains were selected showing the highest double refraction. Measurements were made on several grains and the maximum and minimum values were used for γ and α respectively. The refractive index β was determined on pinacoidal parting tablets (Hess 1949, P.627-628). These were detected by showing the lowest double refraction, as an optic axis emerges from them. In convergent light these grains thus show an uncentred optic axis figure.

TABLE 3.

ANALYSIS AND OPTICAL DATA OF THE PYROXENE.

	Wt.-%
SiO_2	46.56
Al_2O_3	1.42
TiO_2	0.60
Fe_2O_3	2.01
FeO	28.05
MnO	1.24
MgO	1.82
CaO	17.96
Na_2O	0.45
K_2O	0.14
H_2O +	0.17
H_2O −	0.04
	100.46

Sp. G. (3.58)

2V (positive) = 56 (± 2)

c/γ = 47

Ref. indices γ = 1.756

Ref. indices β = 1.731

Ref. indices α = 1.724

– (Calc.) = .032

Wt.-%		
	Wo	38.9
	En	4.7
	Fs	56.4

Molecular composition:

Acmite	4%
Diopside	5%
Hedenbergite	79%
(Other constituents	12%)

TABLE 4.

CALCULATION OF FORMULA OF THE PYROXENE.

	Mol. Ratios.	No. Metal atoms on basis of 6(0,04)		
SiO_2	0.7721	1.904		1.99
Al_2O_3	0.1390	0.069		
TiO_2	0.0075	0.019		
Fe_2O_3	0.0126	0.062	1.179	2.013
FeO	0.3904	0.963		
MnO	0.0175	0.043		
MgO	0.0451	0.111		
CaO	0.3202	0.790	0.834	
Na_2O	0.0073	0.036		
K_2O	0.0015	0.008		

$(Na, Ca\ K)_{0.8}\ (Fe^{+3}, Fe^{+2}, Mn, Mg)_{1.2}\ (Si, Al, Ti)_{2.0}\ O_{6.0}$

If the microscope stage is rotated so that the isogyre lies east-west, then the β direction is north-south.

The optic axial angle was measured in the thin section on the universal stage. The probable accuracy is ± 2°. The extinction angle was also measured in the same time with the optic axial angle on the universal stage, using Conrad Burri method (Haff., 1941).

OPTICAL AND CHEMICAL DATA FOR THE PYROXENE.

The chemical analysis of the pyroxene is given in Tables 3 and 4, together with its optical properties. As is seen from the analysis, the pyroxene is low in sesiquioxides. Manganese dioxide is higher than titania, ferrous oxide is high, while magnesia is low and lime is moderate. According to the classification and nomenclature of the clinopyroxenes adopted by Walker and Poldervaart (1941, P.632), the pyroxene is a ferrohedenbergite.

The composition of the pyroxene was also deduced from the optical properties using the determinative diagrams constructed by Tomita (1939), Deer and Wager (1938) and Hess (1949). The values are given in Table 5.

As is seen in Table 4, the analysis shows a fair agreement with the compositions deduced from the optical data.

TABLE 5. COMPOSITION OF THE PYROXENE ACCORDING TO DIFFERENT DETERMINATIVE DIAGRAMS.

Tomita:	$2V - c/\gamma$	=	Wo_{36}	En_9	Fs_{55}	(Wt.-%)
Deer and Wager:	$2V - \gamma$	=	Wo_{38}	En_8	Fs_{54}	"
	$2V - \alpha$	=	Wo_{39}	En_{13}	Fs_{48}	"
Hess:	$2V - \gamma$	=	Ca_{36}	Mg_{10}	Fe_{56}	(Atomic per cent.)
	$2V - \beta$	=	Ca_{37}	Mg_{10}	Fe_{53}	" "
	$2V - \alpha$	=	Ca_{36}	Mg_7	Fe_{57}	" "

The general formula of the clinopyroxene as given by Machatschki (1931) is $(X, Y)_2 (Si, al)_2 (O_1 OH)_6$ in which x = Ca, Na (K), (Mu), (Mg) and Y = Mg, Fe, Al, Ti, Mu. Warren and Viscoe (1931) also showed that this formula is applicable to many augite analyses. In calculating the formula of the present pyroxene it is found that (Si, AL) group is less than 2, and thus Ti is supposed to replace part of the silicon. This replacement of silicon by titanium in the pyroxene structure has been shown in several cases to be necessary if the pyroxene structure is to be maintained (Deer and Wager, 1938, P.17-18).

Berman (1937, P.354) suggested as the general formula for the pyroxene $(W)_{1-P} (X, Y)_{1+P} Z_2O_6$ in which:

$W = Ca^{+2}, Na^{+1},$

$X = Mg^{+2}, Fe^{+2}, Mu^{+2}, Ni^{+2}.$

$Y = AL^{+3}, Fe^{+3}, Ca^{+3}, Ti^{+4}.$

$Z = Si^{+4}, AL^{+3}.$

TABLE 6.

	Atomic Proportion				2 Al.	Al.	Al.	Z
		Fe'''	Al.	Cr.	Ti	Fe'''	Al	Y
		Na	Na	Na				W
Si	772							Z
Al	28				16	7	(2½	797½
Fe^{+3}	25	18				7	(2½	
Fe^{+2}	390							
Mn	18							W X Y
Mg	45							826½
Ca	320							
Na	15	18						
K	3							
Ti	8				8			
O								
	824							

Ca	Mg	Fe	(atomic percentages).
39.4	5.5	55.1	

% Al. in Z = 0.3%

P stands for zero or close to it for diopside-hedenbergite or acmite-jadeite series, and would be 1 or close to it for orthorhombic pyroxenes and pigeonites. This grouping of elements is based on similarity of ionic radii. As the oxygen is constant in the unit cell of the pyroxenes, an introduction of Al into a diopside means that this Al must be shared equally by Mg like atoms and by the Si, otherwise the valency demands would not be satisfied. This relation is expressed by the Tschermak molecule, $CaAl(AlSi)O_6$ (Berman 1937, P.388). The calculation of the chemical analyses of the clinopyroxene in the ordinary way, viz. adjusting the number of atoms in the Z group to be 2 by adding a part or all of the Al, is accordingly unsatisfactory as it does not take into consideration the balancing of the electrostatic charges. In a recent paper on the clinopyroxenes, Hess pointed to these facts, and he proposed a more satisfactory method of calculation which is simply based on the distribution of the various ions in the structure and balancing of the electrostatic charges (Hess 1949, P.624-626). In Table 6 the present pyroxene is calculated by this method. The percentage of Al replacing the silicon (Z) is 0.3. This low percentage probably explains the close agreement of the chemical composition and the composition deduced from the optical properties.

COMPARATIVE CHEMICAL ANALYSES.

4	5	6	7
46.54	48.34	48.28	47.58
5.77	0.30	1.45	1.16
1.22	0.08	0.28	0.37
1.88	1.50	3.96	2.60
24.65	22.94	27.02	24.21
0.74	3.70	0.76	0.59
0.79	1.06	0.32	3.34
17.70	21.30	16.18	18.80
0.62	0.14	1.51	0.47
0.15	0.03	0.14	0.21
0.39	0.46	0.15	0.34
0.18	-	0.15	
100.53	99.85	100.20	99.67
(3.48)			
1.726	1.723	1.736	1.730
1.732	1.730	1.745	1.736
1.753	1.751	1.765	1.755
49°	61-67°	70.25°	60°
44°	46-49°	56.5°(?)	47°
43.7	47.7	49.5	42.5
2.4	3.2	1	9.1
53.9	49.1	59.5	48.4

4 - Ferrohedenbergite, from hedenbergite andesinite, Skaergaard Intrusion. (op. Cit. 1939, P.77-78). Anal. W.A. Deer.

5. Hedenbergite, Herault, California (Quoted from Hess 1949, P.653-4) Anal. E.S. Shepherd.

6. Ferroaugite, from quartz syenite, N.E. Ausable Forks N.Y. (Quoted from Hess 1949, P.120). Anal. L.C. Peck.

7. Hedenbergite, from Percy Quadrangle Syenite, New Hampshire (Chapman and Williams 1935, P.512). Anal. F.A. Conyer.

TABLE 7.

	A	1	2	3
SiO_2	46.56	42.62	46.60	45.16
Al_2O_3	1.42	5.24	3.07	Nil
TiO_2	0.60	1.69	0.59	0.71
Fe_2O_3	2.01	3.74	1.42	Nil.
FeO	28.05	31.54	29.65	31.48
MnO	1.24	0.78	0.44	0.44
MgO	1.82	0.47	0.66	1.38
CaO	17.96	12.27	16.01	19.30
Na_2O	0.45	1.02	0.73	0.73
K_2O	0.14	0.23	0.20	0.19
H_2O +	0.17	0.48	0.43	0.42
H_2O -	0.04	0.22	0.20	0.19
	100.46	100.30	100.00	100.00
Sp. G.	(3.581)	(3.65)		
α	1.724	1.743	1.745	1.745
β	1.731	1.751	-	-
γ	1.756	1.772	1.771	1.770
2V	56°	58°	52°	55°
γ: c	47°	47°	41°	-
Wo	38.9	30.0	36.8	39.5
En	4.7	1.5	1.9	3.5
Fs	56.4	68.5	61.3	57.1

A - Ferrohedenbergite, Meall Dearg, Skye (New analysis).

1 - Ferrohedenbergite from Fayalite Ferrogabbro, Skaergaard Intrusion (Wager and Deer, 1938, P.77-78). Anal. W.A. Deer.

2 }
3 } - Ferrohedenbergite from Fayalite ferrogabbro, Skaergaard Intrusion (Unpublished analysis by Mr. Muir). The two pyroxenes occur in the same rock.

TABLE 7.

PLEASE SEE OVERLEAF.

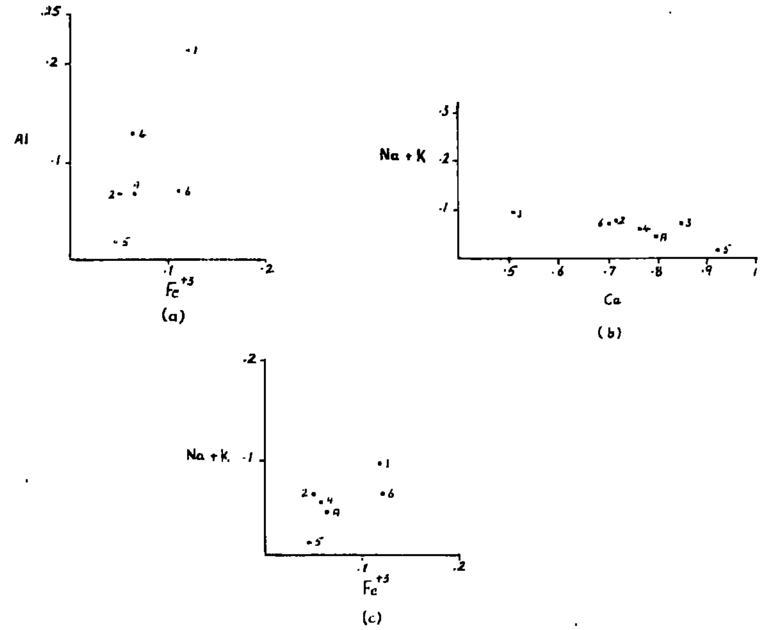
TABLE 8.

ATOMIC PROPORTIONS OF THE PYROXENES IN TABLE 7.

	A	1	2	3	4	5	6	7
Si	1.904	1.785	1.928	1.916	1.867	1.964	1.960	-
Al	0.069	0.215	0.072	-	0.133	0.014	0.070	-
(Al)	-	0.043	0.077	-	0.145	-	1.960	-
Ti	0.019	0.053	0.019	0.022	0.037	0.003	0.070	-
Fe^{+3}	0.062	0.118	0.045	-	0.057	0.046	0.040	-
Fe^{+2}	0.963	1.105	1.030	1.114	0.827	0.783	0.030	-
Mg	0.111	0.028	0.015	0.015	0.025	0.064	0.019	-
Mn^{+2}	0.043	0.029	0.042	0.089	0.048	0.128	0.026	-
Ca	0.790	0.550	0.709	0.852	0.761	0.929	0.707	-
Na	0.036	0.083	0.055	0.056	0.048	0.006	0.060	-
K	0.008	0.012	0.010	0.010	0.008	0.007	0.004	-

COMPARISON WITH OTHER IRON-RICH PYROXENES.

In contrast to the diopsidic pyroxenes, very few chemical analyses for the ferrohedenbergites are known. In Table 7 are given a number of chemically comparable iron-rich pyroxenes. (The writer is indebted to Mr. Muir for providing a manuscript of an unpublished paper on the clinopyroxenes of the Skaergaard Intrusion, and from which the Analyses Cols. 2 and 3 are quoted). The analyses, calculated on the basis of six oxygens to the unit cell, are given in Table 8, and the aluminium in the 4 - Coordination number which remains after allotting the amount necessary to make Si = 2 is shown as (Al).



(a)

(b)

(c)

Fig. 2.

To illustrate the mutual relationships of the various elements in these pyroxenes, a method of graphical representation (Fig. 2 a - c) is adopted after Sabine(1950, P.119) which he used in illustrating such relationships in the acmitic pyroxenes. These relations are shown to be:

(1) Fig.1A: The increase in amount of aluminium replacing the silicon is accompanied by an increase in the content of Fe .

(2) Fig. 1B: Sodium and potassium together vary inversely with calcium.

(3) Fig. 1C: Sodium and potassium together show a tendency to vary directly with Fe .

The above relationships indicate that the introduction of the monovalent ion sodium in place of the divalent ion calcium or the increase in the amount of aluminium replacing silicon, require a balancing of the electrostatic charges by the introduction of Fe^{+3} in place of a divalent ion (Fe^{+2}, Mg).

The pyroxenes Nos. 1 - 4 from the Skaergaard intrusion are of special interest as they represent late stage members of the clinopyroxene series derived by crystallisation differentiation of a basaltic magma. The Skaergaard intrusion has, in fact, provided the most valuable data for the course of crystallisation of clinopyroxenes. Wager and Deer (1939, P.240-248) have shown that the clinopyroxenes form an unbroken series of solid solutions, from diopside at the early stages to iron-rich members, ferroaugites, towards the end. Further study on the clinopyroxenes of the Skaergaard intrusion has been recently carried out (Muir, unpublished paper), and two distinct trend lines for the pyroxenes in the late stages of crystallisation could be established. That for the normal ferroaugites crystallised directly from the magma below the B-Wallastonite inversion temperature; the other trend is that of the pyroxenes derived from the B-Wallastonite-hedenbergite inversion. In the latter trend, the end stages pyroxene has a composition Wo_{30} Fs_{70} and corresponds to the position deduced for the lowest temperature relation in the hedenbergite-clinoferrosillite series in the artificial system $CaO - FeO - SiO_2$ (Bowen and others, 1933).

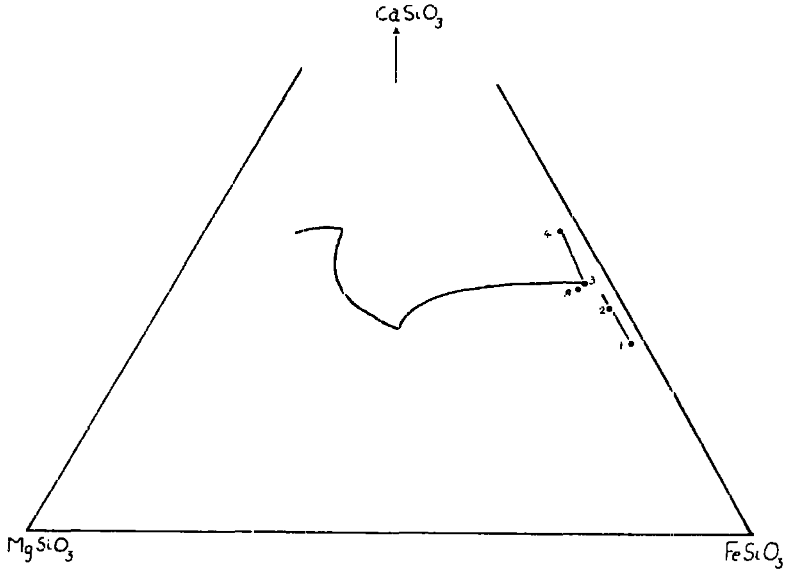


Fig. 3.

Fig. 3 shows the position of the Skye pyroxene (A) and the pyroxenes from the Skaergaard intrusion (Nos. 1 - 4). It is interesting to find that the Skye pyroxene lies on the trend of the normal pyroxenes which crystallised below the B-Wallastonite inversion temperature, and close to the Skaergaard pyroxene No. 3. The pyroxene No. 3 has been shown to occur in the same rock with the pyroxene No. 2, which is, as pyroxene No. 1, interpreted to be derived by inversion of B-Wallastonite. From the mutual relation of the two pyroxenes, the pyroxene No. 3 is considered to have been formed only a little later than the pyroxene No. 2 (Wager and Deer 1939, P.110-111).

According to the thermal relationships of the four component system diopside-hedenbergite-clinoenstatite-clinoferrosilite, Wager and Deer showed that with the fractional crystallisation of the magma, the pyroxene will bear a higher temperature relationship to the liquid than the pyroxene that would be in equilibrium with the magma if the conditions ceased to be those of fractional crystallisation (1939, P.247-248).

To illustrate such relationship, the percentages of the basic oxides CaO - MgO - FeO in the pyroxenes and their parent rocks, recalculated to 100% are plotted on the triangular diagram, Fig. 4, cognate points being joined by tie line. The Skye pyroxene, like the Skaergaard

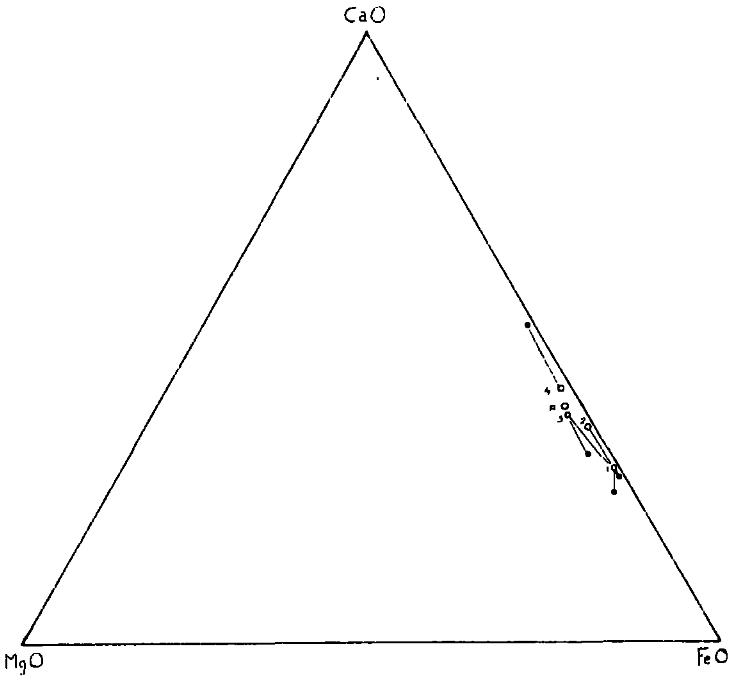


Fig. 4

pyroxenes Nos. 1 - 3, shows to be of relatively greater ratio of the high melting component than its parent rock. The pyroxene No. 4 shows, however, the reverse relation, which most probably is due to the enrichment of its parent rock in plagioclase felspar.

The above relationship shows that although the pyroxene is present in small amount compared with the other phases in equilibrium, it was capable of early crystallisation. Moreover, its constituents appear to be insoluble in acid magmas and the mineral can exist in equilibrium with free silica. The same is also true with regard to the accompanying iron-rich olivine. It has been shows by Bowen and

Schairer (1935) that quartz can exist in equilibrium with olivine between Fa_{68} and fayalite.

The position of the Skye pyroxene on the trend of clinopyroxene crystallisation (Fig. 3) is, however, inconsistent with the position of its parent rock on the trend of the differentiation followed by the Skaergaard magma.

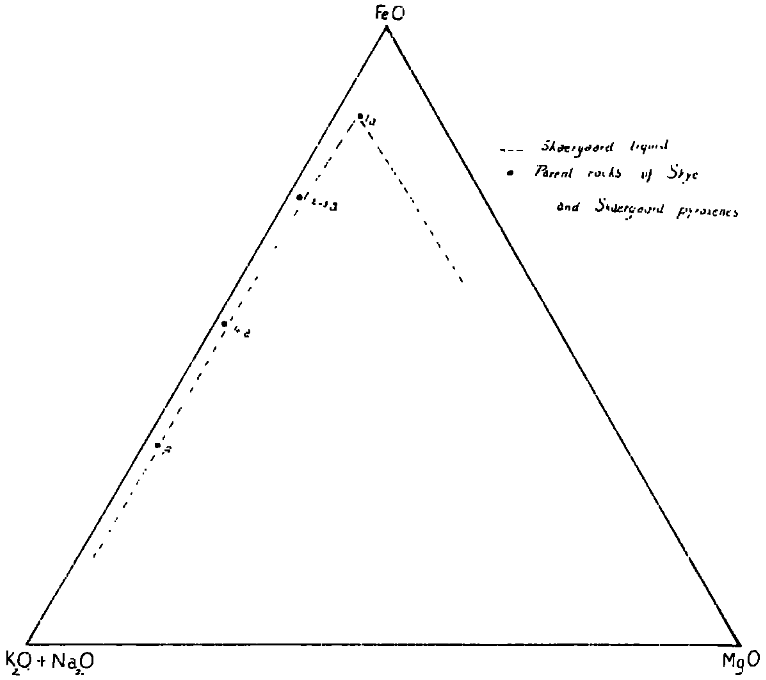


Fig. 5.

If the parent rocks of the Skye and the Skaergaard pyroxenes are plotted on a triangular diagram with MgO - FeO - K_2O + Na_2O as variables (Fig. 5) as is seen that the Skye granophyre (A) falls on the line of the Skaergaard series and is the nearest to the K_2O + Na_2O corner. Thus although it shows a position on the trend corresponding to the latest stages of crystallisation, its pyroxene compares with that from rocks of earlier stages, No. 3a. Its nearest neighbour is a hedenbergite granophyre, but is earlier in the sequence, and the composition of its pyroxene lies very close to the hedenbergite corner.

In view of this comparison, it appears that the Skye magma has not followed the same trend of iron enrichment shown by the Skaergaard magma. Such course of iron enrichment in a crystallising basaltic magma means that fractionation would affect the ferromagnesian minerals more than the felspars. There are, however, insufficient data that can provide direct information about the differentiation trend followed by the Skye magma.

It may be mentioned that the Skye pyroxene granophyre analysis fits well on the variation diagram for the Mull Magma Series at 69% Silica (Bailey 1924). The gabbro-granophyre association in Mull has been shown to be characterised by the persistence of pyroxene crystallisation into the granophyre stage. Bowen (1928, P.111-113), discussing this feature in contrast to hornblendic series of rocks, concludes that by the strong fractionation in the plagioclase series, the liquid will reach a composition that only permits the formation of pyroxene.

SUMMARY AND GENERAL REMARKS.

Two of the various granitic intrusions which form the Western Redhills complex in Central Skye are the riebeckite and the pyroxene granophyres, occurring in the Meall Dearg area. Their relative ages have been indicated by chilling of the pyroxene granophyre against the riebeckite granophyre and the signs of crushing shown by the latter.

There is insufficient data to allow discussion of the origin of the Meall Dearg granophyres and their relation with regard to the evolution of the other granitic intrusions in general. In fact, the Meall Dearg granophyres represent only a part of a large granitic complex and consequently any remarks on the origin of these granophyres will be purely speculative until more is known of the complex as a whole. Nevertheless, it may be worth while making the following suggestions in connection with this problem. The various intrusions may be considered on one hand to have originated independently from each other by fractional crystallisation of fresh supplies of basaltic magma brought up into the magmatic chamber. Alternatively, the different intrusions may be genetically related and may then be regarded to have been derived from a common parent magma.

This latter suggestion seems to be more probable than the first alternative, as can be inferred from the intimate geological association of the various intrusions.

Accordingly, the granitic magma which supplied the various intrusions must have existed in an immense bulk. It is difficult, however, to conceive how such granitic magma can be generated by crystallisation-differentiation of a basaltic magma. In fact, it has been shown that the granitic masses in Skye are quantitatively equalling the associated basic rocks (Richey, 1948, P.55). The estimation of the relative areal extent of the basic and acid plutonic rocks in Skye has been shown to be of the following magnitude:

	Square Miles.
Gabbro and dolerite	28½
Granophyres and granites	30½
Ultra-basic	¾

The amount of the granitic end product generated in the process of fractional crystallisation has been shown to be so small, less than 12 per cent. by volume of the original basaltic magma, so that the extraordinary magnitude of granitic bodies ~~cannot be ascribed~~ are unlikely to be due to this process (Grout, 1926, P.548-551; Fenner, 1926, P.760-765; Daly, 1933, P.289-293). Holmes (1931 and 1936) has discussed the common association of acid and basic rocks in the Tertiary Central Complexes in N.W. Scotland, and he believes that the granitic phase can be generated by remelting of the country rocks.

He suggests that a cupola-shaped magma reservoir rising into the earth's crust would ~~emanate~~ give rise to ring dykes and cone sheets. By means of convection currents the upper parts of this cupola will maintain high temperatures, enough to permit remelting of their roof, and the ultimate result provides the required condition of co-existence of acid and basic magma in the cupola-shaped reservoir (op. cit. P.249).

Comprehensive data is now available for the normal course of differentiation of large basaltic magmas as the Skaergaard intrusion (Wager and Deer 1939), being towards iron enrichment in the early and middle stages and enrichment in silica and alkalies towards the end. The calc-alkaline series, on the other hand, has been shown to follow a different course, and is believed to be in the main derived from mixing acid and basic material. This is based on the fact that in the normal course of differentiation the intermediate rocks of the calc-alkaline series are not represented. As the amount of the iron-rich rocks of the middle stages in the earth's crust is small, they believe, with Daly, Holmes and others, that the bulk of the post-Cambrian granites are the result of remelting of the Sial. Walker and Poldervaardt (1949, P.650-665) consider it likely that assimilation of the sialic material may be followed by crystallisation differentiation of the hybrid magma.

If these various intrusions are considered to be derived from the same stock magma, the riebeckite granophyre seems to have been fed from an upper part of the magmatic reservoir. This suggestion is based on the miarolitic feature displayed by the rocks and the presence of hydrated low temperature minerals as stilpnomelane and riebeckite. By the upward migration of the volatile constituents, the upper part of the magma is enriched in these constituents. The rate of solidification of the magmas on intrusion seems to have been faster than the release of the volatile constituents and the compressed gas inside the granitic mass at the final stages of complete solidification gave rise to these druses. Water seems to have been an essential constituent in this late stage gaseous phase, as indicated by the occurrence of the ferric iron-rich stilpnomelane in some of these cavities. The equilibrium between the ferrous and ferric iron in igneous rocks is controlled by the reversible reaction: $2\ FeO + H_2O = Fe_2O + H_2$. As has been mentioned above, at the late stage of solidification the escape of gasses seems to have been checked and consequently the vapour pressure would tend to promote the formation of more ferric iron. These constituents, ferric iron and water, were most probably fixed in the stilpnomelane.

The pyroxene granophyre, on the other hand, is completely free from drusy cavities or any hydrated minerals. This probably indicates that the pyroxene granophyre has been drained from a deeper part of the magma poor in volatile constituents. To this relatively dry nature of the pyroxene granophyre magma has been ascribed the formation of the pyroxene in preference to hornblende.

In the present limited study it was not possible to obtain information that could throw definite light on the method of implacement of these granophyres.

Harker postulated a laccolithic habit for the plutonic intrusions of the Western Redhills complex. He considered that the vertical junction between the gabbro and the granitic complexes marks the position of the feeding channels for the magma forming the laccolith (1904, P.126).

Richey in his paper on "Tertiary Ring Structures in Britain" (1928, P.69-78) showed that ring dykes and caulderon subsidence as demonstrated in Mull and Ardnamurchan can also be applied to the igneous intrusions of Skye. He suggests that three centres of igneous activity were acting successively in the following order: Cullins, Redhills proper (Western Redhills), and Beinn na

Caillich (Eastern Redhills) centres. The vertical boundary between the gabbro complex and the Western Redhills is believed to be an indication of a ring dyke structure.

It is of interest to mention that a distinctive feature of these granophyres is the utter absence of xenolithic inclusions of the country rocks. This probably suggests that the implacement of these intrusions was achieved by sinking of a large crust block, i.e. caulderon subsidence. Moreover, the absence of apophyses of one granophyre penetrating the other is probably a feature connected with caulderon subsidence (Chapman, 1937, P.184-185).

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EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Riebeckite granophyre. The field shows perthite in which the plebs coalesce into broad patches. (P 8) Nicols crossed. Magnification X.30

Fig. 2. Crushed riebeckite granophyre (11) against the pyroxene granophyre. Nicols crossed (P. 11). Magnification X.41

PLATE II.

Fig. 1. Pyroxene granophyre. The dark minerals are pyroxene (middle of the field) and altered olivine. The light are felspar and micropegmatite (P. 12). Magnification.x 41

Fig. 2. Fine-grained margin of the pyroxene granophyre against the riebikite granophyre, top of Meall Dearg. The minerals present are rounded grains of pyroxene (dark grey), iron ore, altered olivine (almost opaque with iron ore) and felspar (turbid). (P.14). Magnification.X41

PLATE I.

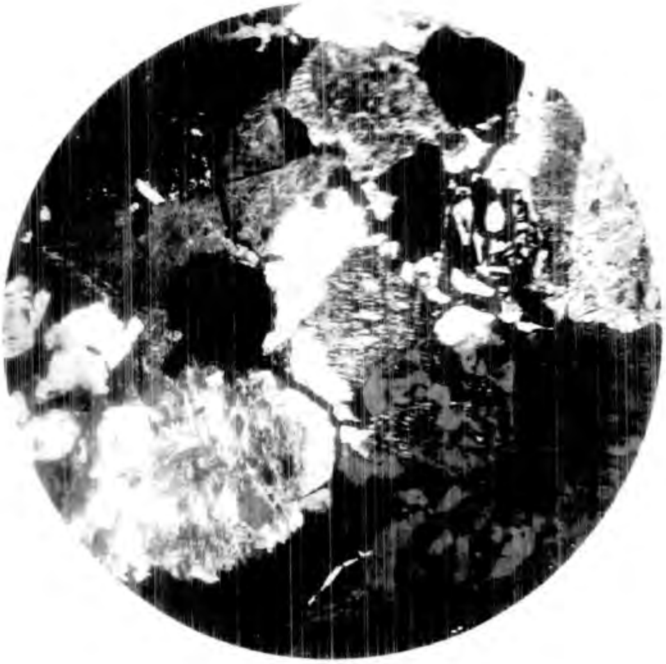
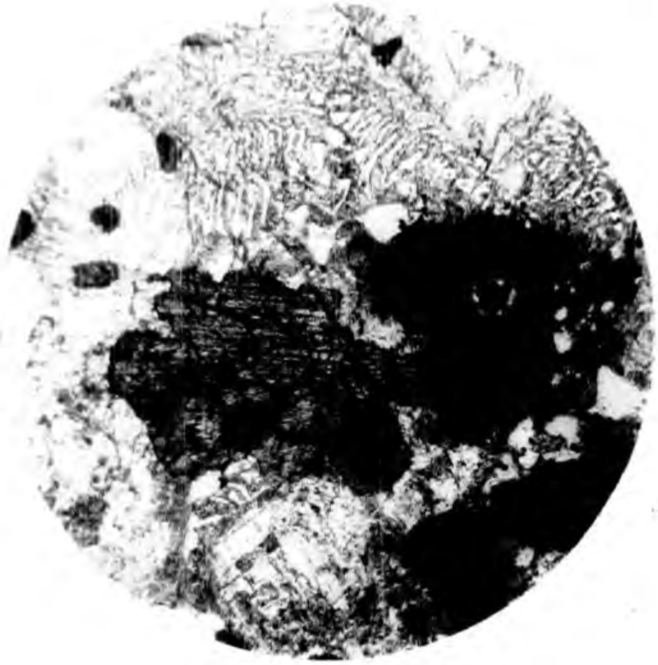


Fig.1

Fig.2.

PLATE II.



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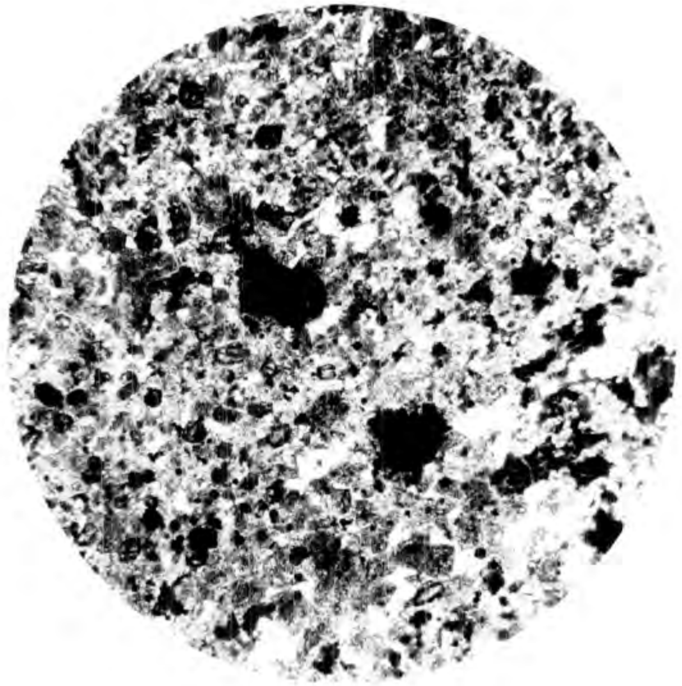

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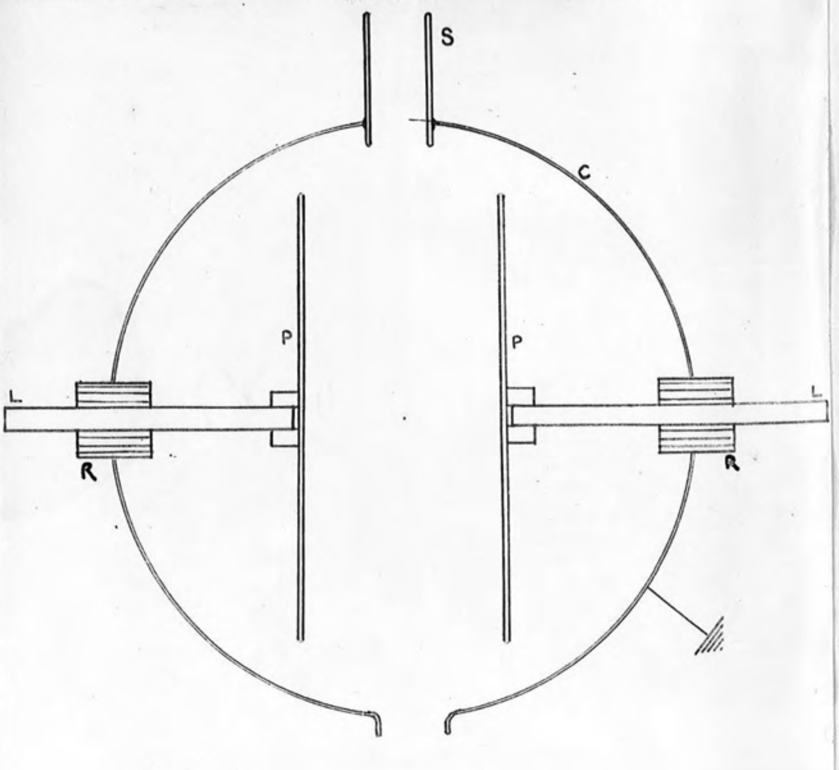

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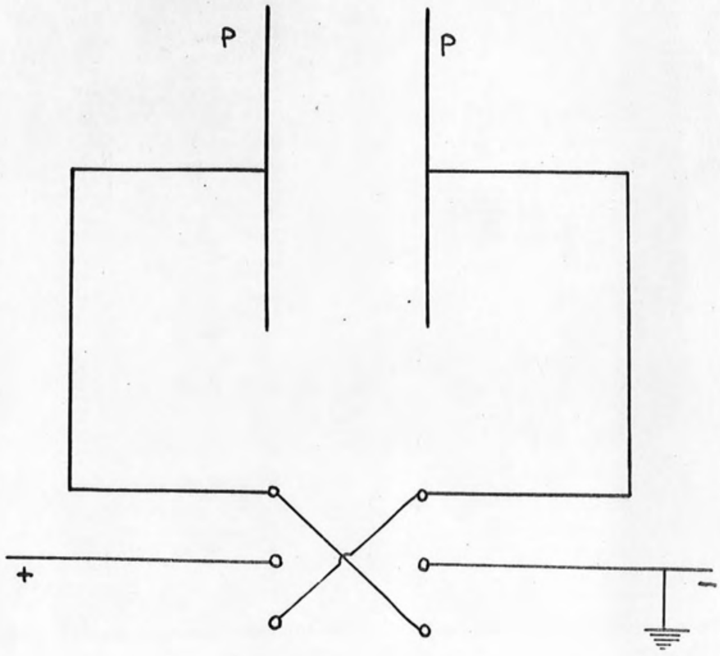

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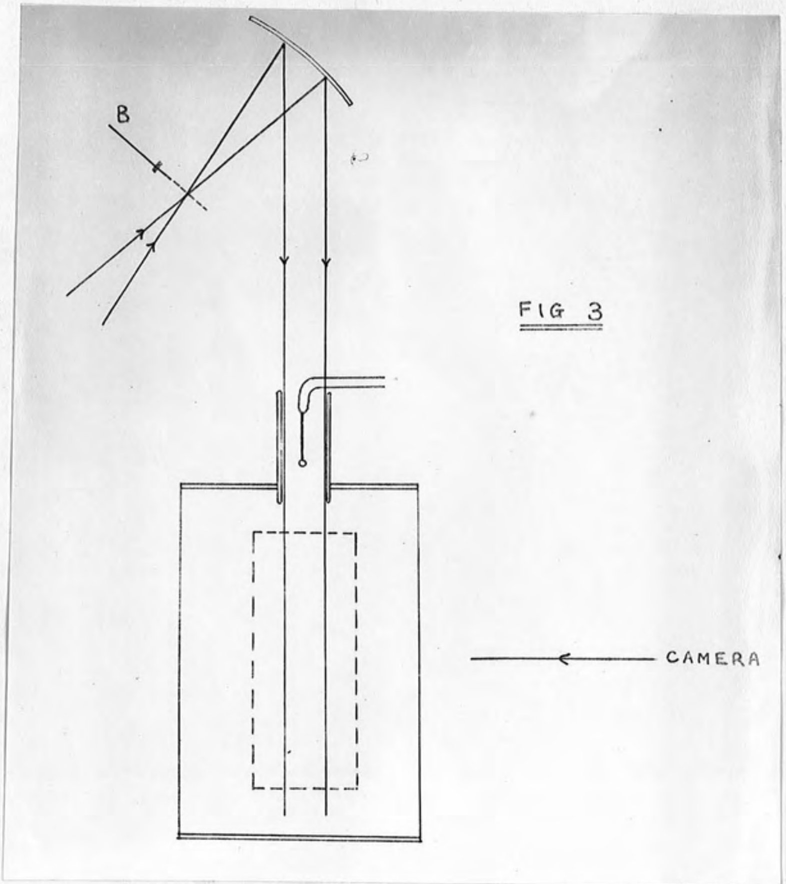
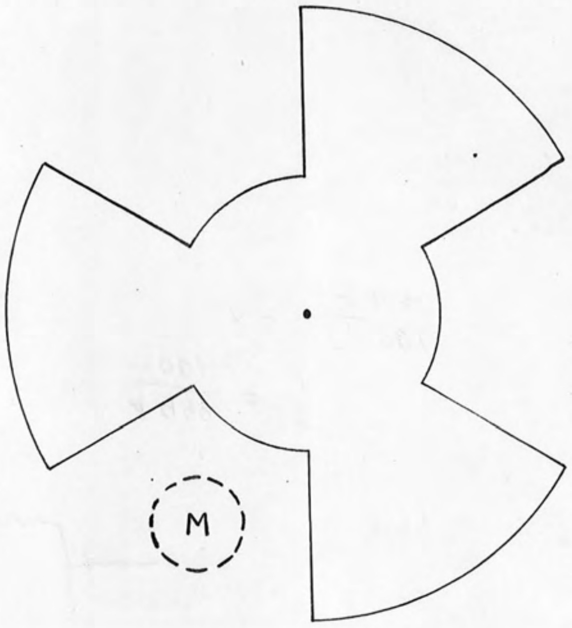


B
FIG 3
CAMERA



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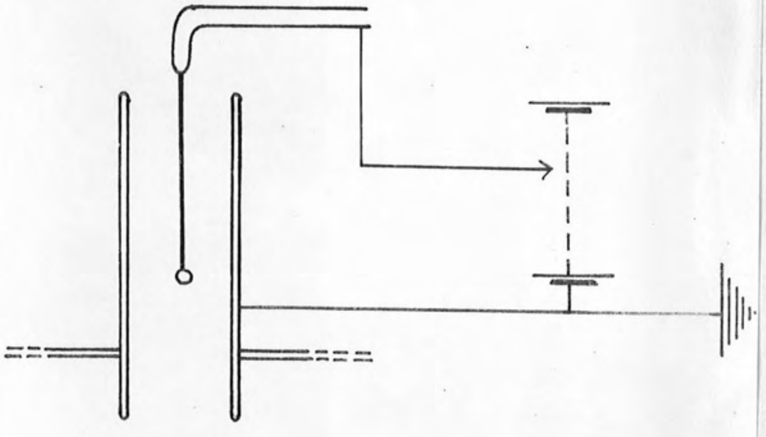

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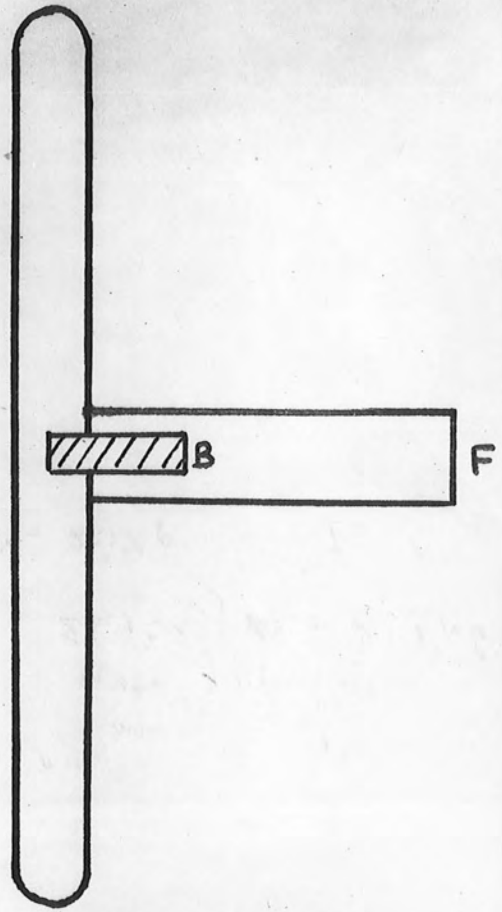

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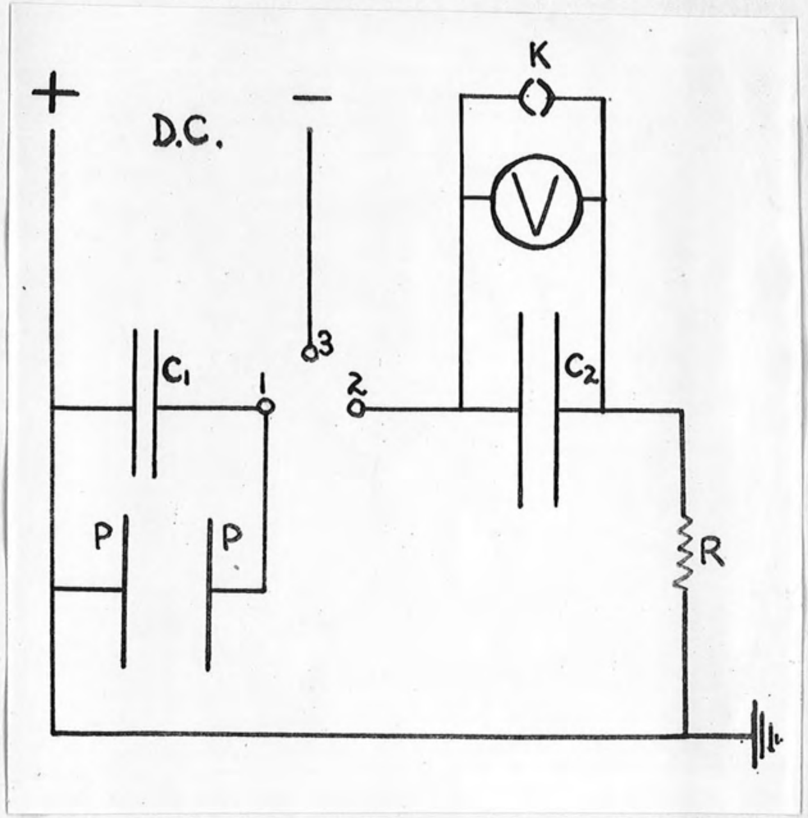

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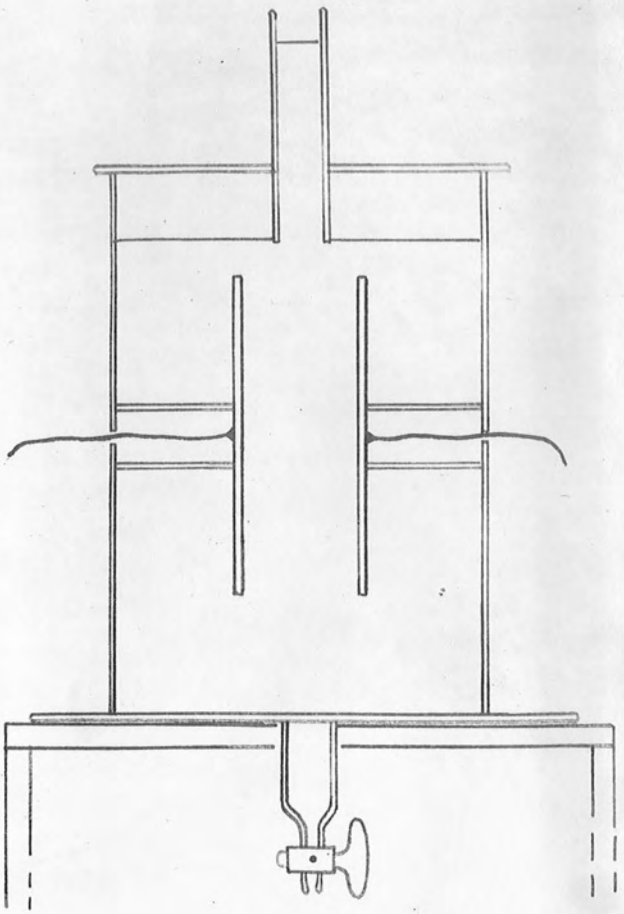

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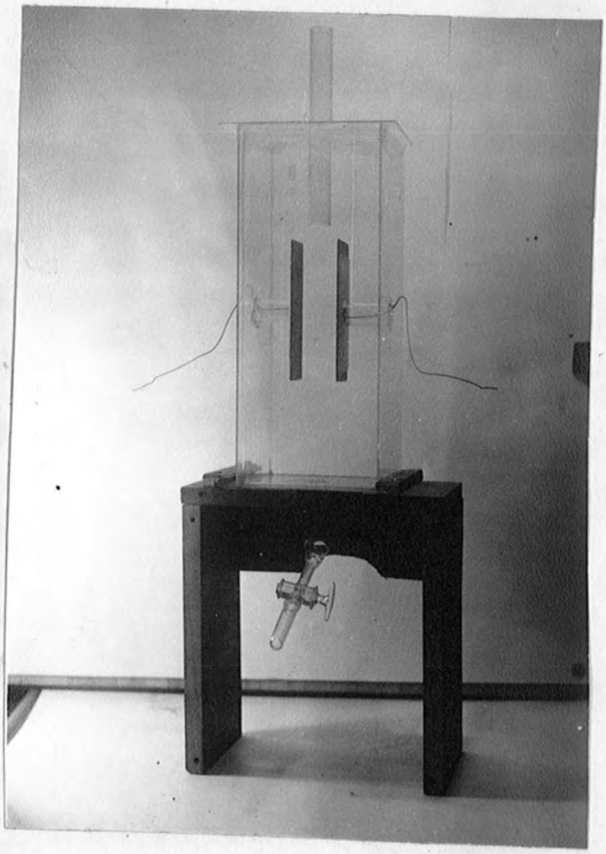

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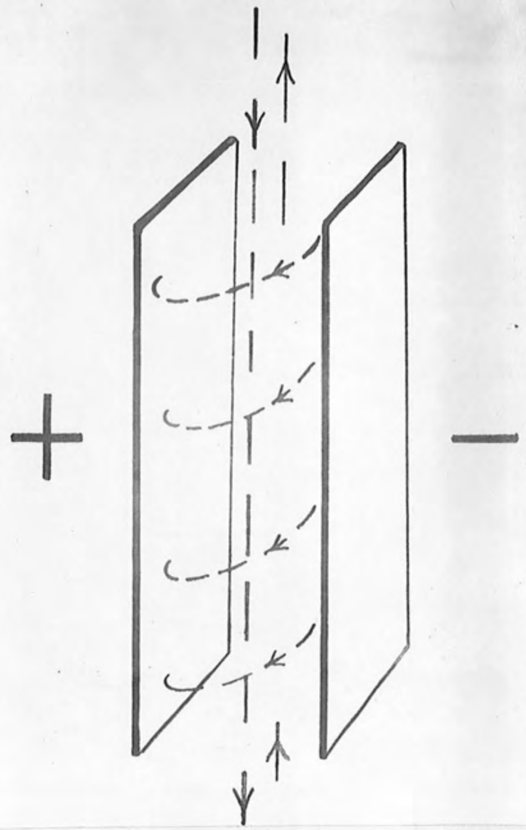
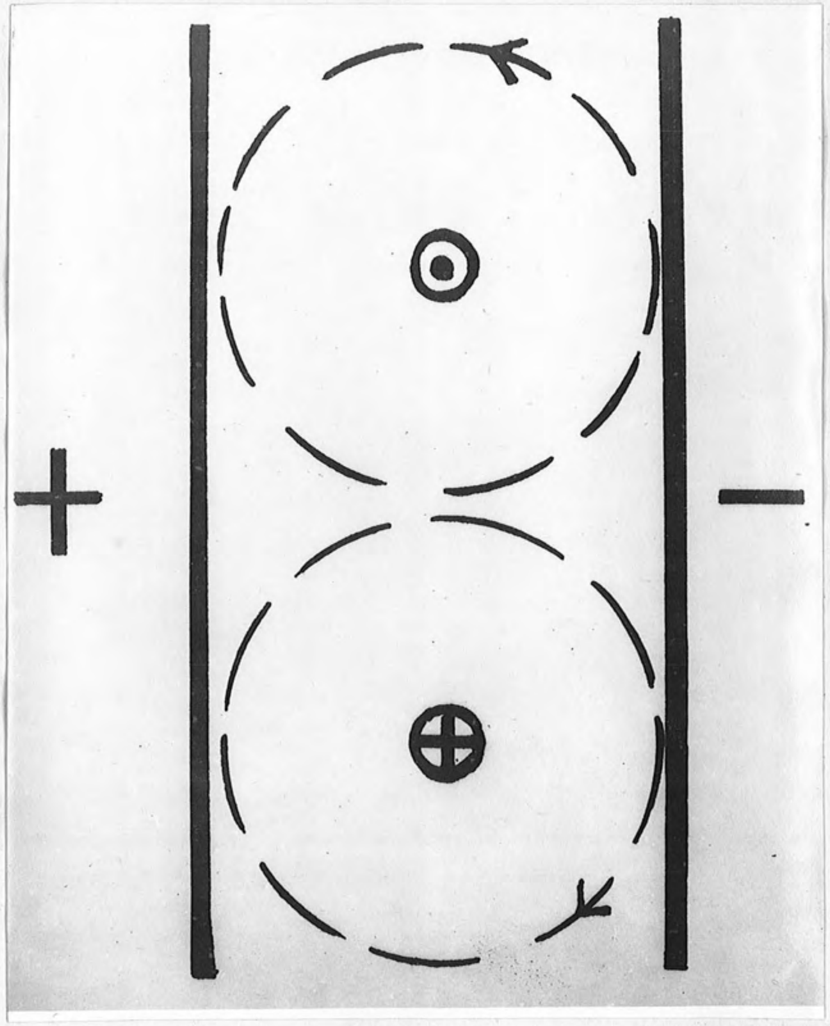


FIG. 10.



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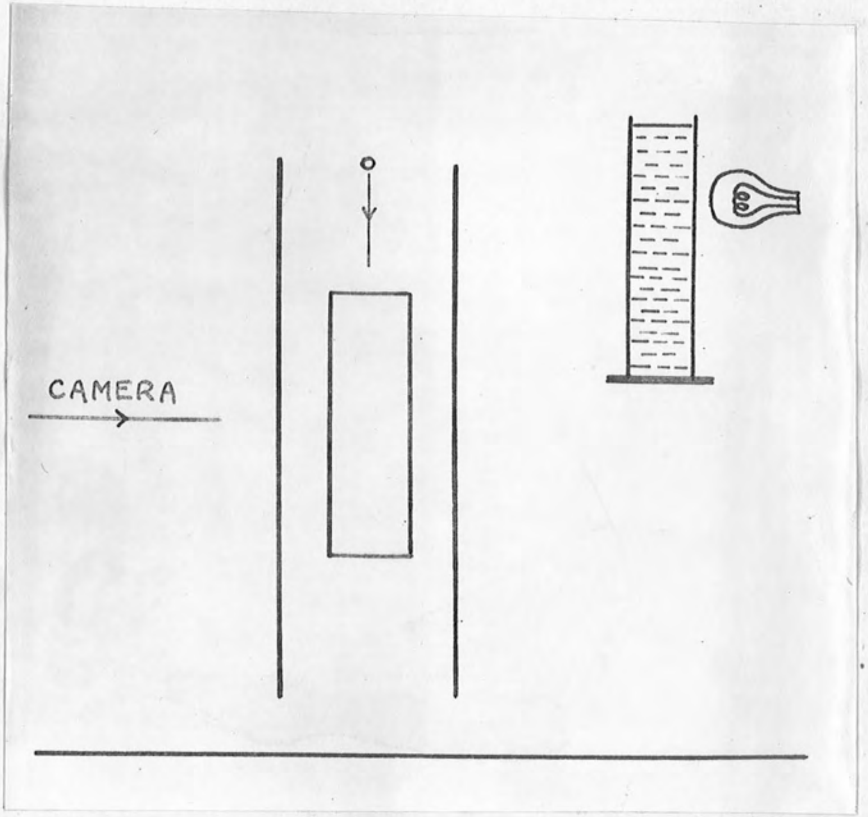

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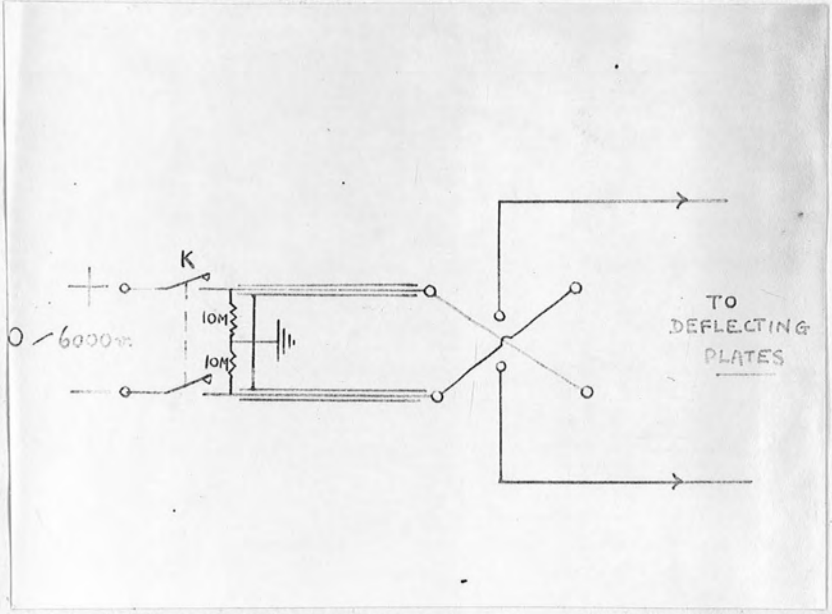

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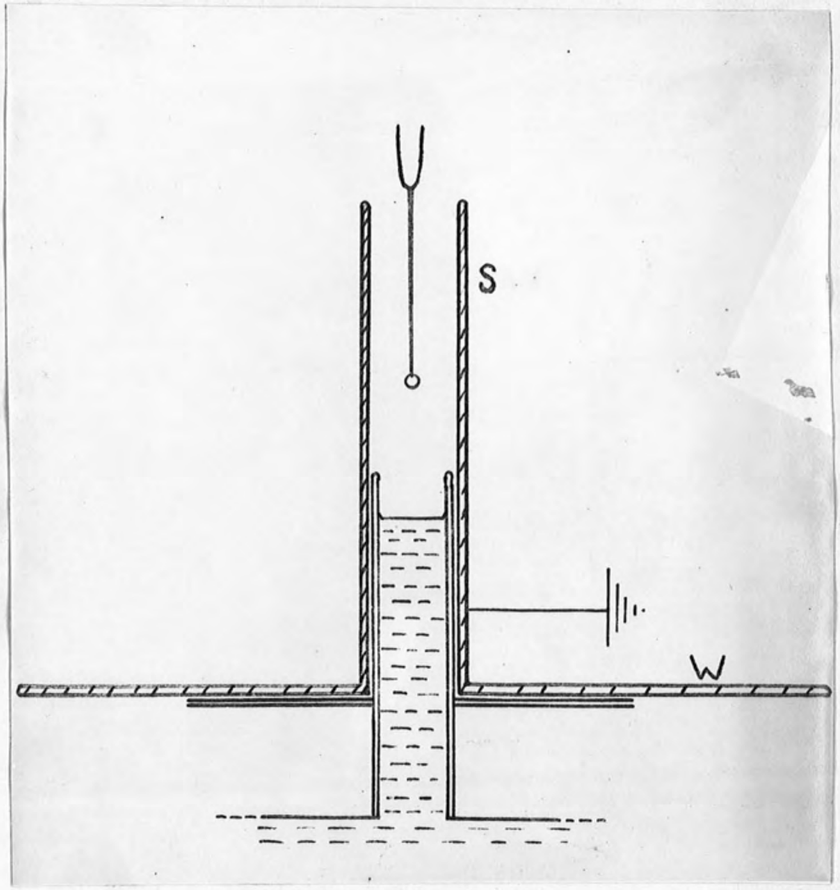

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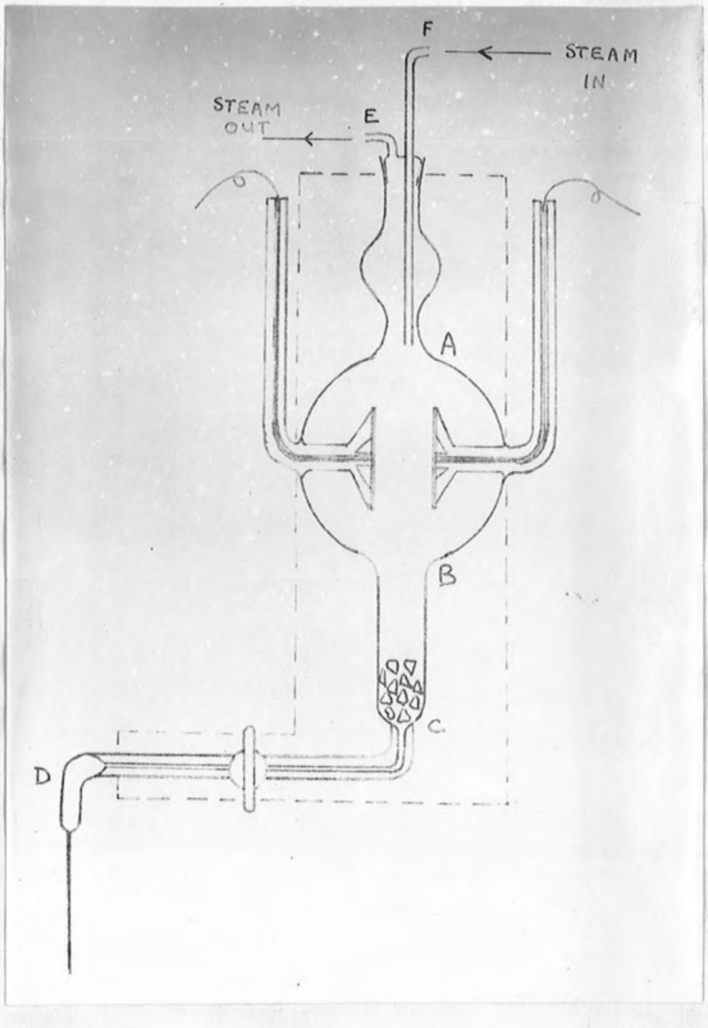

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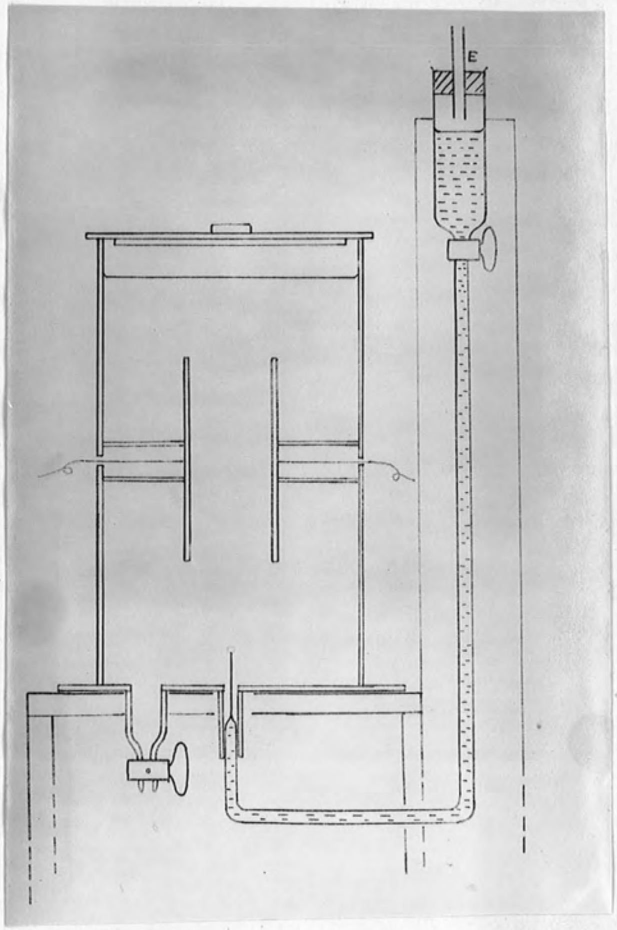

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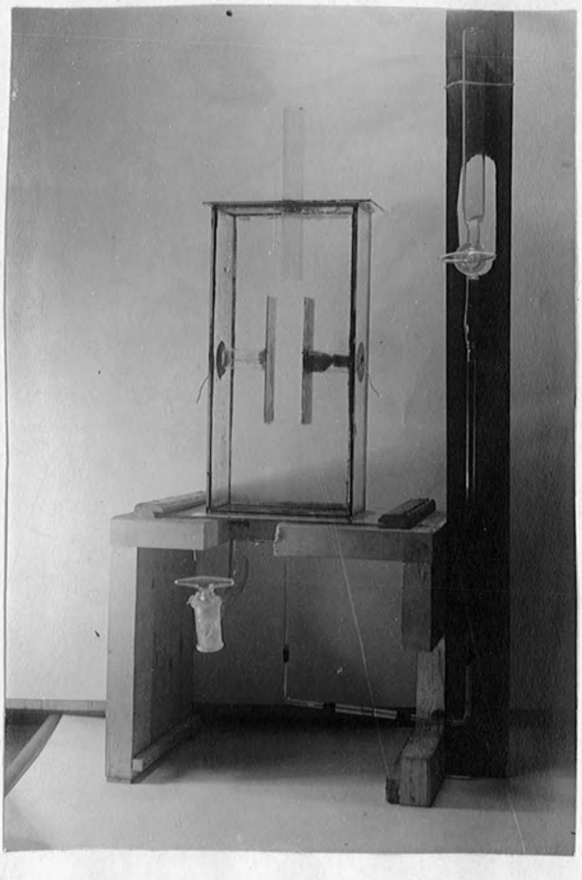

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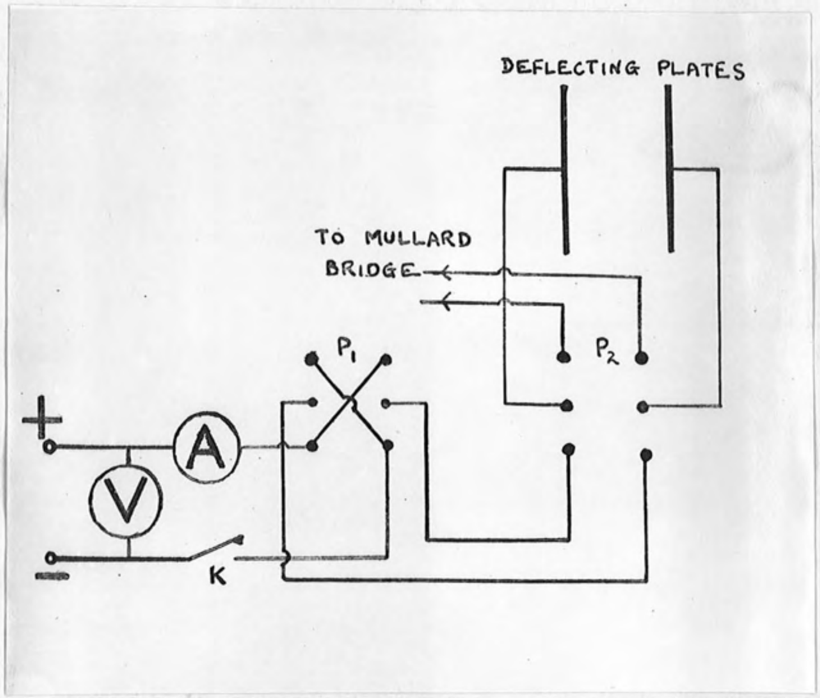

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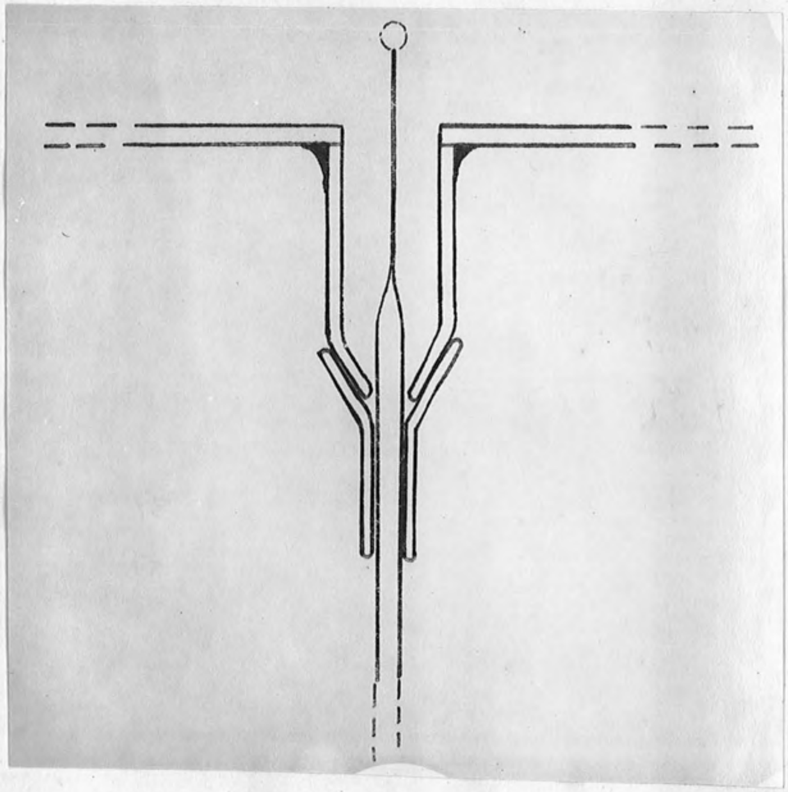

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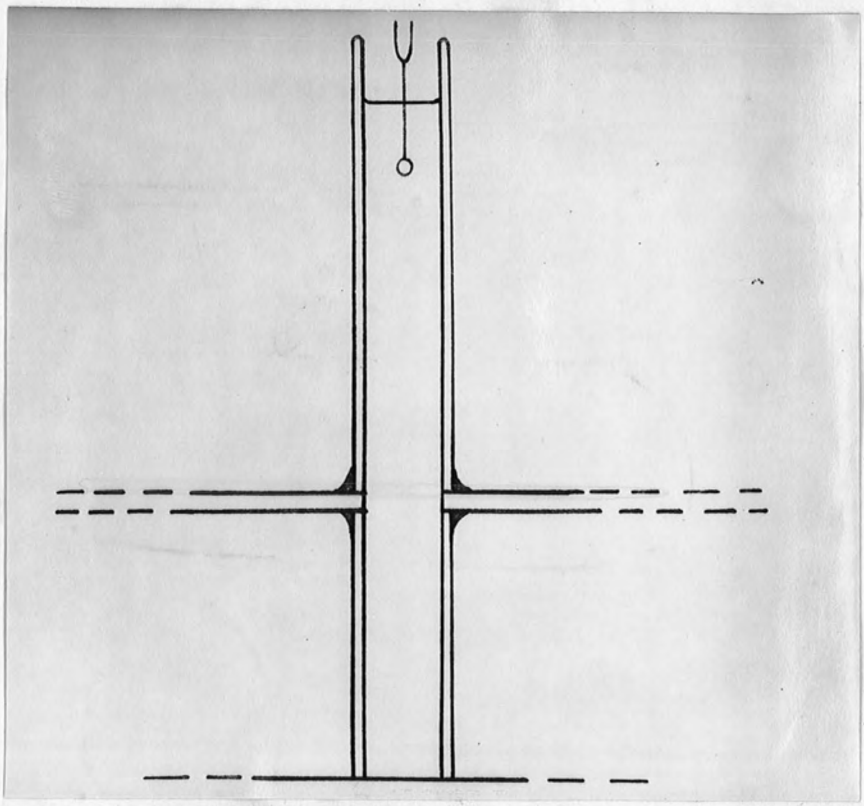

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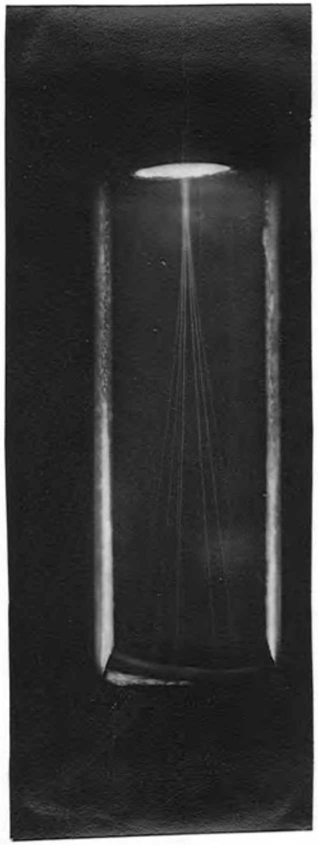

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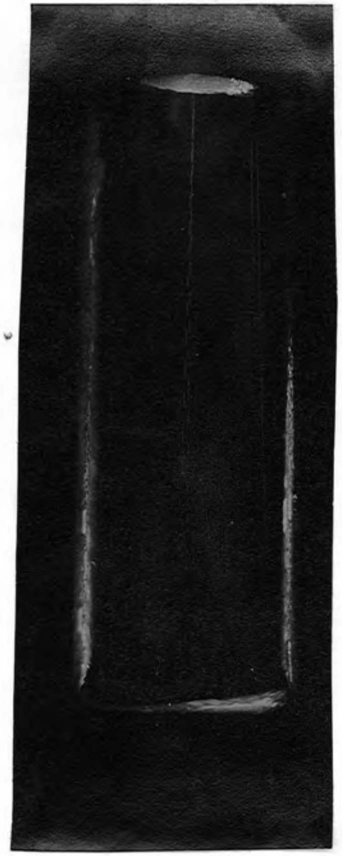

FIG. 22.

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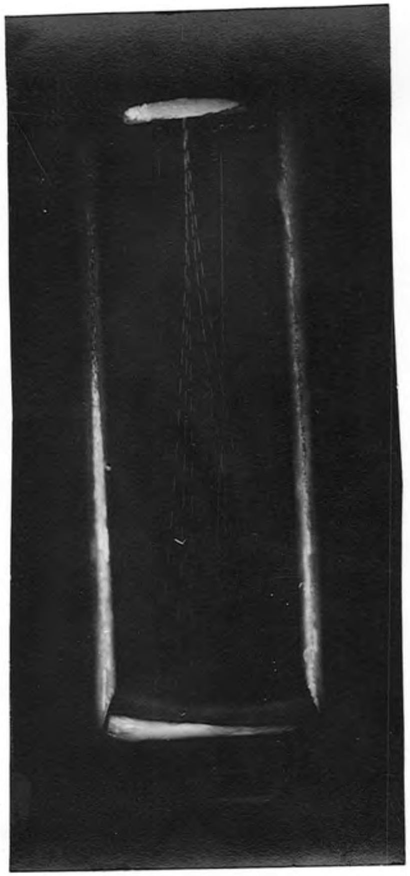


FIG. 24.

FIG. 25.

FIG. 26.

FIG. 27.

FIG. 28.

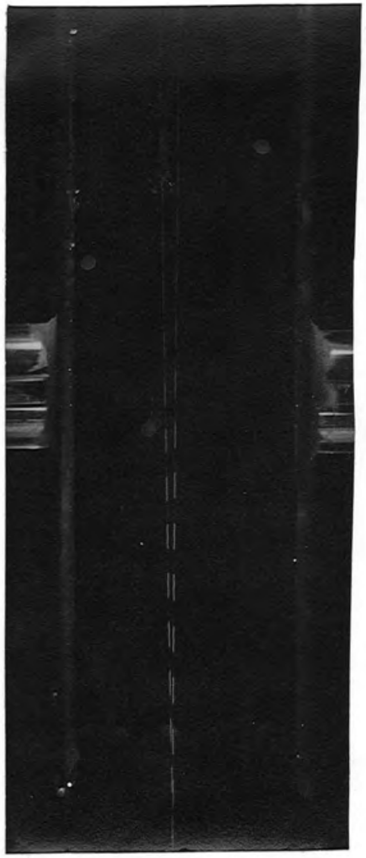
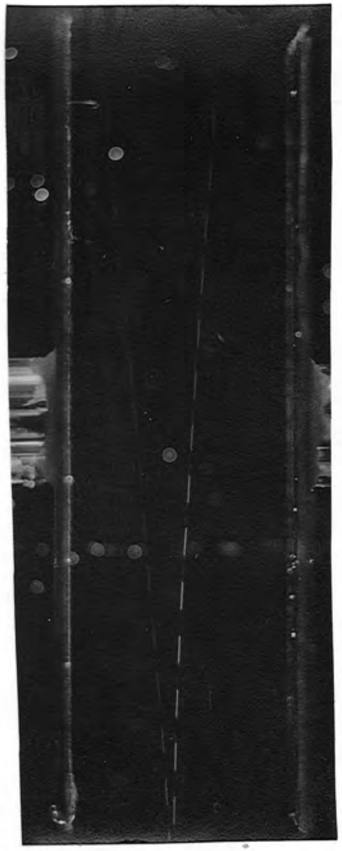


FIG. 29.

FIG. 30.

FIG. 31.



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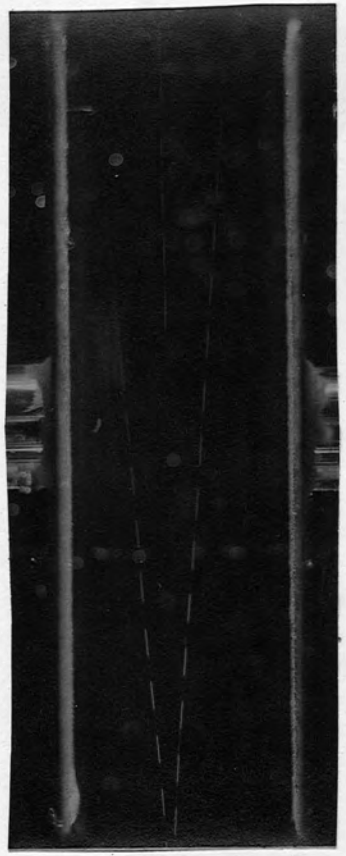

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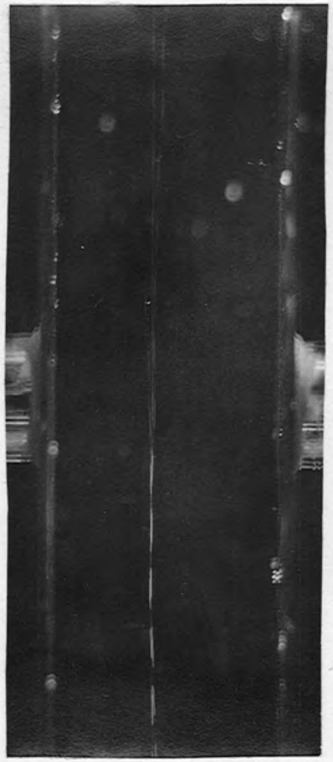
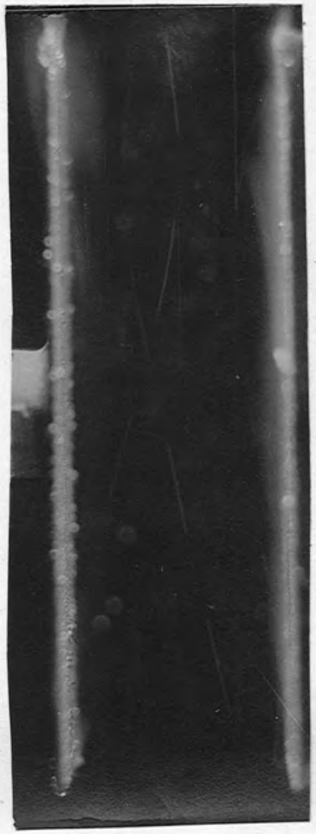


FIG. 34.

FIG. 35.



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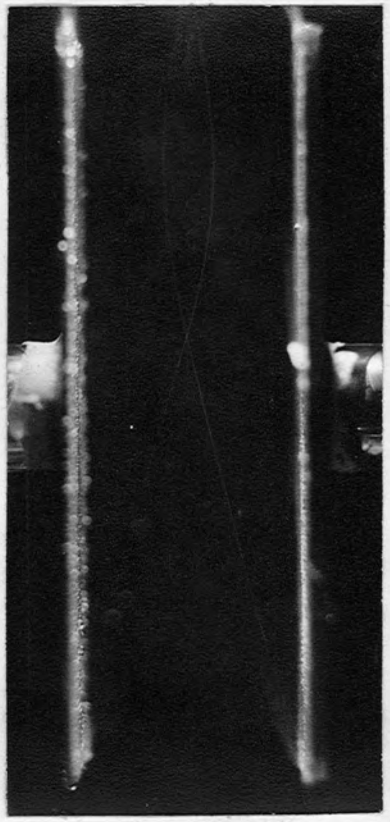

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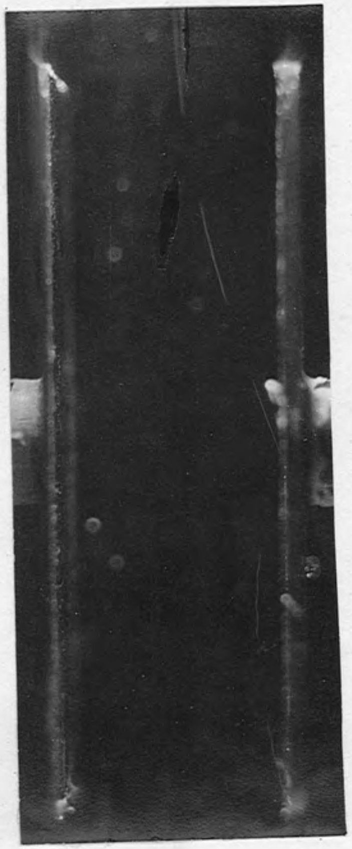

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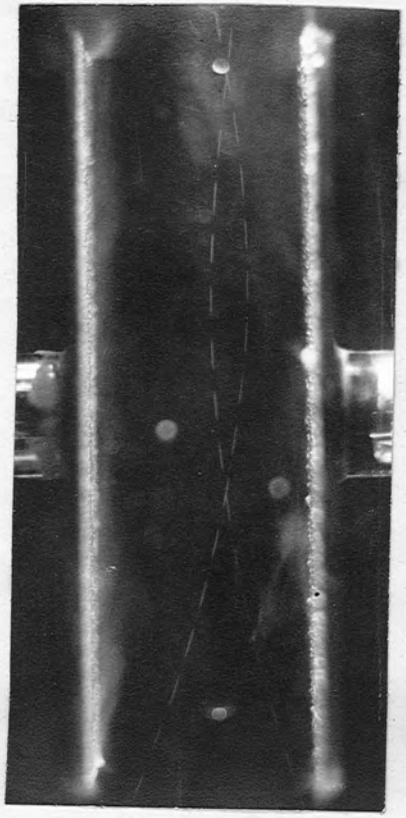

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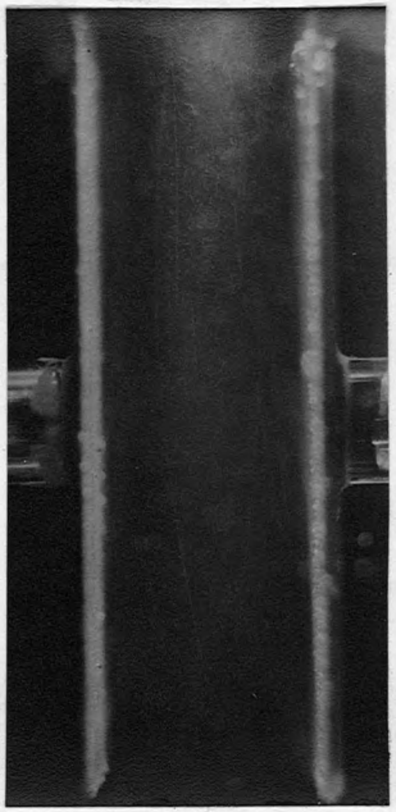

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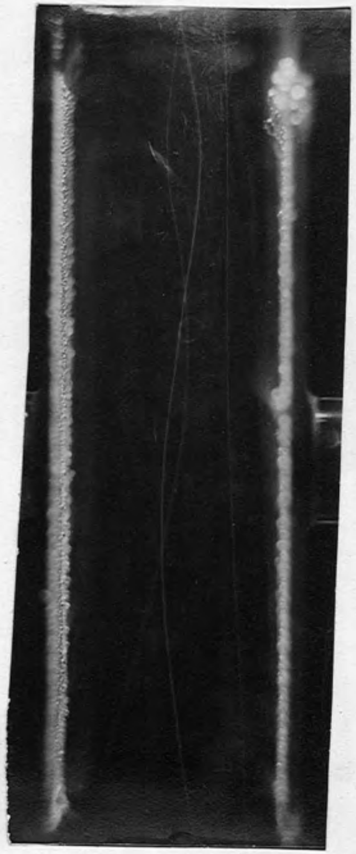

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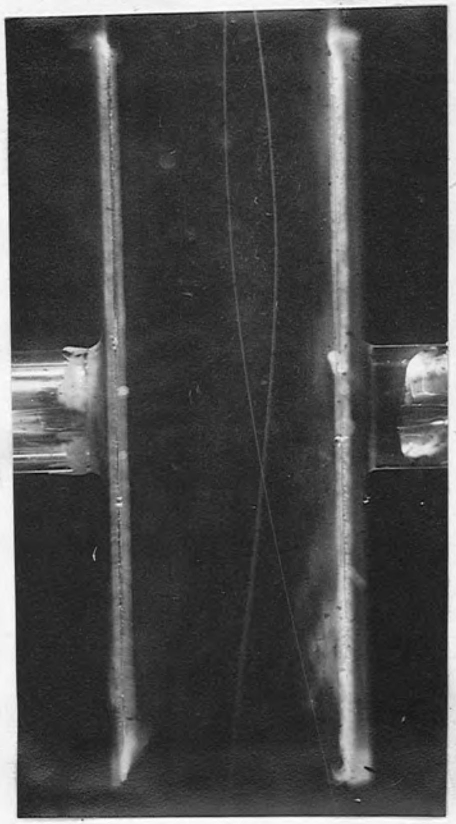

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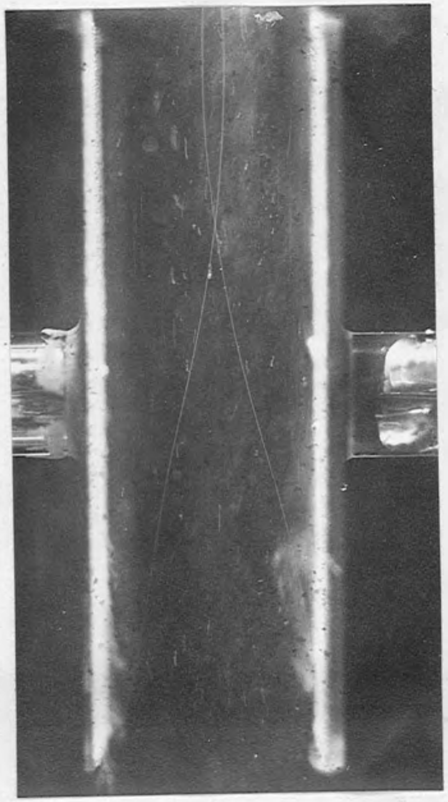

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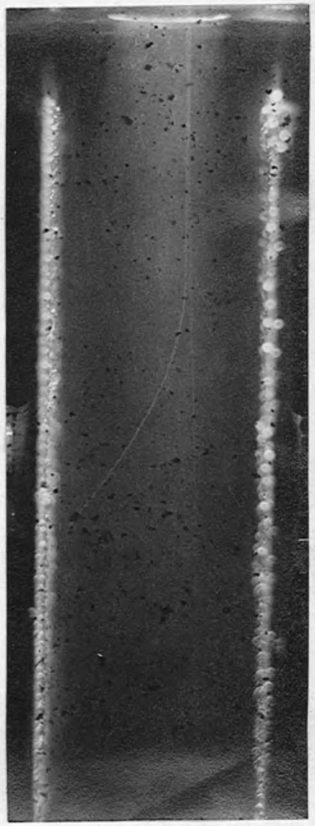

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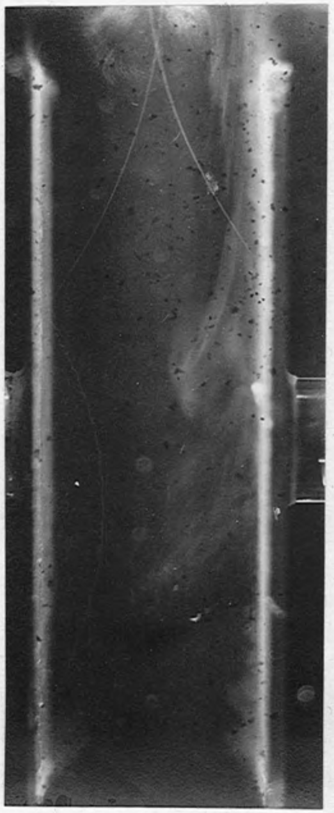

FIG. 45.