

The basaltic rocks of the Arctic region.

(*With Plates VI and VII.*)

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1. INTRODUCTION.

THE widespread basaltic rocks of the Brito-Arctic province, like those of the Deccan and Columbia basalt plateaux, do not seem to have received from petrologists the attention they deserve. Descriptions of particular localities and their rocks are not lacking, and the British region in particular has become classic through the investigations of Judd, Sir A. Geikie, and Dr. Harker, but hitherto no attempt has been made to survey the province as a whole, except in the most general way. Suess has traced the distribution of the plateau basalts that characterize high latitudes, and has pointed out the stratigraphical and

structural significance of the province.¹ From another point of view this has also been done by Prof. J. W. Gregory in his book 'The Nature and Origin of Fiords' (1913). A petrographical review of parts of the province is given by von Wolff,² and this author, considering that the basalts and their associates cannot be referred to either *Atlantic* or *Pacific* types, has proposed to distinguish them as *Arctic*.³ The best account of the Arctic basalts, however, we owe to Sir Jethro Teall,⁴ who analysed a basalt from Cape Flora, Franz Josef Land, and pointed out the wide distribution of the type, while regretting that no recent analyses of other basalts belonging to the Arctic province were then available.

Twenty years have passed, and this reproach still applies to the basalts of the Faroes, Iceland, Jan Mayen, and the east coast of Greenland. It is thus evident that chemically very little is known of the characteristics of the province, while still less is known of its extent in space and time. The object of this paper is to describe typical rocks from each of the chief localities, with chemical analyses by Dr. H. F. Harwood, so as to fill in the gaps, and prepare the foundation for a broad survey of the province with a view to determining such specific features as it may possess, and if possible to define its limits in space and time.

The rock specimens from Hare Island (West Greenland), and most of those from Iceland and the Faroes, were drawn from the petrological collections in the Geology Department of the Imperial College of Science and Technology, and for permission to investigate this material we owe our thanks to the authorities of the College. A collection of rocks that I purchased from Mr. F. H. Butler, Brompton Road, S.W., furnished specimens of basalt from Jan Mayen and Scoresby Sound (East Greenland) as well as others from Iceland and the Faroes. These specimens were obtained with the aid of a Royal Society grant for work on the radio-activity of rocks, and though the present paper is not concerned with that aspect of their study, I wish to acknowledge the assistance thus indirectly afforded. The rocks from Franz Josef Land and Spitzbergen were presented by the Director of H.M. Geological Survey (at

¹ E. Suess, 'The Face of the Earth,' 1909, vol. iv, chap. vii. A very complete bibliography and several excellent maps are given in the French edition 'La Face de la Terre,' 1911, vol. iii, pt. 2, chap. xvi.

² F. von Wolff, 'Der Vulkanismus,' 1914, vol. i (2), p. 427.

³ F. von Wolff, op. cit., 1913, vol. i (1), p. 153.

⁴ E. T. Newton and J. J. H. Teall, Notes on a Collection of Rocks and Fossils from Franz Josef Land. Quart. Journ. Geol. Soc., 1897, vol. liii, pp. 482-493, 1898, vol. liv, pp. 646-647.

the suggestion of Sir Jethro Teall) and by Prof. E. J. Garwood respectively, and to these gentlemen we wish to express our gratitude. Finally our thanks are due to Prof. E. Baker and Prof. W. W. Watts for placing at our disposal every facility for carrying out the analytical and petrological investigation of the rocks in the Chemical and Geological laboratories of the College.

2. HARE ISLAND, WEST GREENLAND.

Hare Island lies at the western entrance of the Vaigat, west of the Nugsuak Peninsula and north of Disco Island. It is described in the 'Arctic Pilot' as a flat-topped basaltic island, descending abruptly to the water's edge on three sides, with a more gradual slope downwards on the north. Along the east coast there are beds of Tertiary lignite, easily accessible to whaling boats in need of fuel.¹ A small collection of rocks and minerals, comprising six different types of basalt and numerous aggregates of calcite (presumably derived from the amygdales of the basalts), was made by Mr. Thos. Reid in 1855. His specimens found their way into the Thomson collection of zeolites which was acquired a few years ago by the Geology Department of the Imperial College. The numbers attached to these and to other rocks described in this paper are those by which they are catalogued in the Imperial College collections.

Basalts free from Olivine.

No. 1554 is a fine-grained, nearly black basalt with rusty amygdales containing (in order of deposition) chlorite, chalcedony, and calcite. Under the microscope (Pl. VI, fig. 1) it is seen to be of uniform intergranular texture,² with here and there microporphyritic laths of labradorite (about $An_{60}Ab_{40}$). The main mass of the rock consists of laths of labradorite (about $An_{50}Ab_{50}$) between which occur granular aggregates of pale-green augite, together with a few slightly larger grains of hypersthene. Scattered profusely among the other constituents are ragged patches of haematite, and minute globules and irregular masses of magnetite and ilmenite. On account of the very fine grain it was found impossible to separate the two black ores magnetically, but in a more coarsely grained rock (1550) it was found after crushing the rock that magnetite could be picked out by a bar magnet, leaving a residuum of ore that was attracted only by an electromagnet. It is therefore likely that in No. 1554 both minerals are actually present, though the magnetite is probably a titaniferous variety.

¹ For a geological map see K. J. V. Steenstrup, Medd. om Grønland, 1883, vol. iv (end of volume).

² See p. 191.

There remains another mineral—the last to crystallize out—whose specific identity is not clear. It forms colourless plates generally surrounded by augite granules, and is certainly an alkali-felspar. The refractive index is less than that of Canada balsam, and, judging from the fact that it gives mottled extinction, it is probably anorthoclase. This diagnosis is supported by the analysis, for unless part of the albite is associated with orthoclase, the soda-lime felspars should be much less calcic than they really are.

The amygdalae are of all sizes, from microscopically minute circular spaces filled with chlorite-stained chalcedony to masses a centimetre or more in diameter. Calcite is present only in the larger vesicles, and this fact explains the absence of carbon dioxide from the analysis.

Chemical analysis.—This rock (No. 1554) was chosen for analysis because of its freshness and comparative freedom from amygdalae. A considerable quantity was crushed, the amygdaloidal portions were picked out by hand, as far as possible, and the remainder was prepared for analysis. Dr. Harwood obtained the following results:

| Percentages. | | | | Molecular Proportions. | Mineral Composition ('Norm'). | |
|--------------------------------|-----|--------|-----|------------------------|-------------------------------|------------|
| SiO ₂ | ... | 48.10 | ... | 0.802 | Quartz | 9.87 |
| Al ₂ O ₃ | ... | 11.22 | ... | 0.110 | Orthoclase | 9.17 |
| Fe ₂ O ₃ | ... | 6.94 | ... | 0.043 | Albite | 21.48 |
| FeO | ... | 8.98 | ... | 0.125 | Anorthite | 14.65 |
| MgO | ... | 3.78 | ... | 0.0945 | | |
| CaO | ... | 8.09 | ... | 0.145 | Diopside | 17.69 |
| Na ₂ O | ... | 2.56 | ... | 0.041 | Hypersthene | 2.65 |
| K ₂ O | ... | 1.55 | ... | 0.0165 | | |
| H ₂ O (>110° C.) | ... | 1.26 | ... | — | Magnetite | 10.21 |
| H ₂ O (at 110° C.) | ... | 0.96 | ... | — | Ilmenite | 10.79 |
| CO ₂ | ... | none | ... | — | Pyrite | 0.06 |
| TiO ₂ | ... | 5.68 | ... | 0.071 | Apatite | 1.24 |
| P ₂ O ₅ | ... | 0.60 | ... | 0.004 | | |
| Cl | ... | trace | ... | — | | 97.81 |
| S | ... | 0.04 | ... | 0.001 | Water + BaO, less O | 2.23 |
| Cr ₂ O ₃ | ... | none | ... | — | | |
| V ₂ O ₅ | ... | 0.06 | ... | 0.001 | | 100.04 |
| NiO | ... | none | ... | — | | |
| MnO | ... | 0.23 | ... | 0.003 | | |
| SrO | ... | trace | ... | — | Class III | Salfemane. |
| BaO | ... | 0.03 | ... | — | Order 4 | Vaalare. |
| | | | | | Rang 3 | Vaalase. |
| | | | | | Subrang 4 | Vaalose. |
| | | 100.03 | | | | |
| less O | ... | 0.02 | | | | |
| | | 100.01 | | | | |

Specific gravity = 2.95

The analysis is remarkable for the high percentage of titanium dioxide that it reveals. This constituent is probably mainly present in the black ores, for there is nothing in the character of the augite to suggest that it is a titaniferous variety. An augite from the basalt of Ovifak (Uifak) on the adjoining island of Disco has been analysed by Nicolau,¹ who found that the percentage of titanium dioxide in the augite was only 0.72. A similar characteristic of the titaniferous basalts of the western Mediterranean has been pointed out by Washington,² though he remarks that one of the pale-green augites of Central Italy carried as much as 2.85 of titanium dioxide.³

The general features of the analysis are reserved for later discussion, though it may be of interest here to point out the chief chemical differences from the neighbouring rocks of Disco, which have been analysed by Lawrence Smith, Nauckhoff, and Nicolau.¹ Both magnesia and lime are more abundant in the iron-bearing lavas of Ovifak, while the alkalis are lower. Alumina appears to be 2 to 4 per cent. higher than in the Hare Island basalt, though this may be due to the non-determination or to a low determination of titanium dioxide. This point requires re-examination, in the light of the results placed on record in this paper.

No. 1550 is much coarser in grain than the rock described above, and contains larger and more numerous amygdalae. In the latter the chief minerals are chalcedony and opal, accompanied as before by chlorite and calcite, which minerals sometimes preceded, sometimes followed, the silica.

Mineralogically the rock closely resembles No. 1554, except that no hypersthene has been detected. In texture it differs in the presence of glomeroporphyritic aggregates of clear labradorite-laths (about $An_{60}Ab_{40}$), while in places there are small cognate inclusions of brown or purple glass penetrated in oplitic fashion by laths of labradorite and carrying abundant rhomb-shaped crystals of ilmenite, which betray their nature by alteration to leucoxene. In the body of the rock the texture is intersertal, and cruciform and radiating arrangements of the feldspars are common, a feature which characterizes almost all the Arctic basalts examined.

No. 1552 is an intergranular basalt in which the feldspars have suffered silicification and zeolitization. Large amygdalae are present, the majority

¹ T. Nicolau, *Medd. om Grönland*, 1901, vol. xxiv, p. 217.

² H. S. Washington, *Quart. Journ. Geol. Soc.*, 1907, vol. lxiii, p. 76.

³ H. S. Washington, *The Roman comagmatic region*. Carnegie Inst. Washington, 1906, Pub. no. 58, p. 134.

of which are filled by radiating masses of analcite (n between 1.472 and 1.488). The smaller vesicles are occupied by clear sparkling crystals of heulandite (average n between 1.494 and 1.508, biaxial, sign +) succeeded and corroded by chalcedony. With the latter mineral granular aggregates of canary-yellow epidote are associated in places. Heulandite is followed by analcite, radiating needles of which can be seen in many of the amygdales growing through clear patches of heulandite. Analcite in turn is followed by chalcedony, and chalcedony by calcite. Many of the feldspars, especially in the neighbourhood of the amygdales, have been veined, corroded, or entirely replaced by heulandite or chalcedony or by both minerals in succession.

No. 1551 represents a still further and almost complete stage of paulo-post alteration, only the iron-ores and small windows of augite crystals remaining. Much of the rock appears originally to have been a brown glass, with small amygdales of opal here and there. Of such minerals as originally existed, the feldspars have been replaced by chlorite-stained chalcedony, and the bulk of the augites are represented by chloritic minerals and perhaps serpentine. Finally, the whole rock is thickly veined with bands of fibrous calcite which cut across all the earlier alteration products.

Taking the series of rocks as a whole it is clear that the order of deposition of the amygdale minerals is as follows: Heulandite, analcite, opal, chalcedony, calcite. Chlorite may either precede the silica minerals or follow them, and in one case it is represented by epidote. Calcite may also precede silica, but the example is exceptional.¹

Olivine Basaltic Rocks.

No. 1555 (Plate VI, fig. 2) is a type differing very considerably from those already mentioned. It is a fine-grained, black, vesicular rock in which the only amygdale mineral is stilbite, occurring as a pale-yellow lining of minute sheaves bordering the walls of some of the vesicles. The only megascopic mineral is olivine, which is present in rounded green phenocrysts 3 or 4 mm. in diameter. In thin section it is seen that both olivine and pale-brown augite occur as microphenocrysts, carrying inclusions of black ores, embedded in a fine-grained intersertal groundmass consisting of laths of labradorite (about $An_{60}Ab_{40}$), vaguely defined grains of brown to purple-madder augite, and innumerable

¹ For a discussion of a similar series of amygdale minerals and their origin see A. Holmes, *The Tertiary volcanic rocks of Mozambique*. *Quart. Journ. Geol. Soc.*, 1917, vol. lxxii, p. 252.

dendritic sprays of iron-ores. Except for slight marginal serpentinization of some of the smaller olivines the rock is perfectly fresh.

No. 1553 (Plate VI, fig. 3) is a dense, black rock free from vesicles, with prismatic phenocrysts of shining black augite, 4 or 5 mm. in length. Under the microscope these are seen to be beautifully idiomorphic and often in glomeroporphyritic groups. The interiors of some of the crystals are green, but the prevailing colours are brown to purple, hour-glass structure being faintly developed. The augites frequently enclose a core of olivine, which in turn includes grains of iron-ore. Olivine is also present in small, fresh, corroded crystals. Ilmenite is abundant, while feldspars are poorly developed, only a few small laths of bytownite (about $An_{80}Ab_{20}$) being seen with a one-inch objective. These minerals are embedded in a dense, dark-brown groundmass thickly speckled with minute black grains and globulites. Under a quarter-inch objective a mass of incipient indeterminable feldspar-laths and brown augite grains is seen merging vaguely into brown glass. The iron-ores, of which ilmenite (not attracted by a bar magnet) is the chief member, were the first minerals to commence crystallization and the last to finish.

The name and classification of this rock present difficulties. It has too little feldspar to be described as olivine-basalt, too much to be styled an augitite, and too little olivine to justify the term picrite-basalt. Lacroix has recently suggested the name ankaramite¹ for mafic basaltic rocks poor in feldspar and olivine; but the analysis of the type rock shows a much higher percentage of magnesia than is present in the Hare Island rock. Quite similar rocks occurring on the shores of Wood Bay, Spitzbergen, have been called trachydolerite, and nearer at hand a trachydolerite of Devonian or Carboniferous age at Nunasarnausak, Greenland, has a comparable composition (though richer in soda and poorer in potash and lime). Thus, unless a new name is to be coined, the rock may be described either as a melanocratic olivine-trachydolerite, or as a felspathic augitite.

Chemical analysis.—Unfortunately the specimen of this rock (No. 1553) was very small and only a few grams were available for analysis. Dr. Harwood was therefore unable to determine some of the rarer constituents such as chlorine and the oxides of chromium, vanadium, nickel, and barium, which were sought for in each of the other rocks analysed. The results obtained are as follows :

¹ A. Lacroix, *Compt. Rend. Acad. Sci. Paris*, 1916, vol. clxiii, p. 182.

| | Percentages. | | Molecular Proportions. | | Mineral Composition ('Norm'). | |
|--------------------------------|--------------|-------|------------------------|--------|-------------------------------|-----|
| SiO ₂ | ... | 42.57 | ... | 0.7095 | Orthoclase | ... |
| Al ₂ O ₃ | ... | 14.40 | ... | 0.141 | Albite | ... |
| Fe ₂ O ₃ | ... | 3.54 | ... | 0.022 | Anorthite | ... |
| FeO | ... | 3.89 | ... | 0.117 | Nepheline | ... |
| MgO | ... | 6.78 | ... | 0.1695 | | ... |
| CaO | ... | 11.71 | ... | 0.209 | Diopside | ... |
| Na ₂ O | ... | 2.70 | ... | 0.044 | Olivine | ... |
| K ₂ O | ... | 2.31 | ... | 0.025 | | ... |
| H ₂ O (>110° C.) | ... | 2.05 | ... | — | Magnetite | ... |
| H ₂ O (at 110° C.) | ... | 0.21 | ... | — | Ilmenite | ... |
| CO ₂ | ... | none | ... | — | Apatite | ... |
| TiO ₂ | ... | 5.07 | ... | 0.064 | | ... |
| P ₂ O | ... | 0.12 | ... | 0.001 | | ... |
| S | ... | none | ... | — | Water | ... |
| MnO | ... | 0.10 | ... | 0.001 | | ... |
| SrO | ... | trace | ... | — | | ... |
| | | 99.98 | | | Class III | ... |
| | | | | | Order 6 | ... |
| | | | | | Rang 8 | ... |
| | | | | | Subrang 4 | ... |
| | | | | | Salfemane. | ... |
| | | | | | Portugare. | ... |
| | | | | | Limburgase. | ... |
| | | | | | Limburgose. | ... |

Specific gravity = 3.06.

Here again the most noteworthy feature of the analysis is the high percentage of titanium dioxide, and in this case the colour of the augites suggests that they may be titaniferous. According to the 'norm' the plagioclase should be as calcic as $An_{87}Ab_{13}$, whereas the actual mineral approximates to $An_{80}Ab_{20}$. This may be due to constituents of the anorthite molecules being present in augite, or to some of the excess of soda (represented in the 'norm' as nepheline) being present as albite in the plagioclase. In any case most of the excess of soda and most of the potash must be present in the glass of the groundmass. The latter cannot be regarded as having the composition of a potassic analcite, for the amount of water liberated above 110° C. is too low.

It is significant that the rock is richer in lime and magnesia and also in alkalis than the basalt, No. 1554. The contrast between the two rocks is very strong, one being thoroughly oversaturated with regard to silica, while the other is markedly undersaturated. In the absence of field evidence and knowledge of the order of extrusion there is no basis for a discussion of their possible genetic relationships.

In addition to the basalts and andesites of Disco, to which references have already been given, basalts have also been described from the north

of the Nugsuak Peninsula.¹ These comprise olivine-free and olivine-basalts (including limburgites) having porphyritic, intergranular, intersertal, radial, and vitrophyric textures in different varieties. On both Disco Island and the Nugsuak Peninsula the basalts are post-Cretaceous and are themselves cut by younger granites, as in Iceland and the Western Isles of Scotland.

3. SCORESBY SOUND, EAST GREENLAND.

The east coast of Greenland from Kangerdlugsuak to Scoresby Sound and Milne Land, a distance of about 250 miles, is characterized by basalt flows almost continuously. Another stretch of basalt fringes the coast for nearly 200 miles from Davy Sound to Shannon Island. Nordenskjöld has given an excellent account of the basalts of the southern belt,² and near Cape Dalton (south of Scoresby Sound) he discovered marine formations of Eocene age which were younger than some of the basalts and older than others. Nordenskjöld points out the remarkable uniformity of the basalts in mineral composition. No olivine was found in any of his specimens, though green alteration products sometimes occur. Red ferric oxide, as well as black ores, is very abundant. The structural varieties distinguished are: (1) dense, compact, black basalts, (2) coarsely crystalline types, (3) porphyritic varieties, (4) red basalts, scoriaceous and slaggy, and (5) amygdaloidal basalts, which are by far the most abundant.

Bøggild has described the amygdale minerals and their distribution, and he concludes that 'the basalt of the northern regions and that of Scoresby Sound seem to agree most closely as regards their minerals with that of West Greenland' (loc. cit., p. 103). The chief characteristic is the small size of the zeolites and the predominance of chabazite. In addition to many varieties of zeolites, chalcedony, quartz, and calcite are also developed. The basalts south of Scoresby Sound resemble more closely the Iceland basalts, and in them stilbite is the chief zeolite and attains a considerable size.

The specimen to be described (No. 1560, Plate VI, fig. 4) is from the south side of Scoresby Sound. It is a purple-brown basalt with small amygdaloids containing heulandite, chlorite, and iron-stained chalcedony, and brownish-green glass or palagonite. In thin section the rock is

¹ M. Belovsky, *Zeits. Deutsch. Geol. Gesellschaft*, 1905, vol. lvii, p. 68.

² O. Nordenskjöld, *Medd. om Grönland*, 1908, vol. xxviii. Map opposite p. 96. For an account of the minerals of the East Greenland basalts see O. B. Bøggild, *ibid.*, p. 100. Nordenskjöld's map is reproduced in Suess, 'La Face de la Terre,' 1911, vol. iii (2), p. 939.

seen to consist of glomeroporphyritic bytownite (about $An_{80}Ab_{20}$) in an intersertal groundmass of small feldspar-laths, grains of green augite and colourless enstatite, and very numerous small crystals of magnetite and ilmenite. Here and there are flakes of bright red haematite, and many of the augites are stained a reddish colour, apparently by the same material. The feldspars of the groundmass are much more sodic than the phenocrysts, being labradorite near to andesine. All the minerals are fresh, though in many places the ultimate base of the rock seems to be chalcedony. Except in the amygdales, however, this constituent is by no means abundant.

Chemical analysis.—An analysis was made by Dr. Harwood of material (No. 1560) freed by hand as far as possible from amygdaloidal infillings. Small quantities of heulandite and of interstitial chalcedony, not visible to the naked eye, were, of course, incapable of separation. The presence of heulandite could not seriously affect the value of the analysis, for the rock as such is richer in lime and alumina than that zeolite, and the somewhat high percentage of water (above 110° C.), if wholly present in heulandite, would imply the presence of nearly 17 per cent. of the latter, which is a figure at least three times too great. The presence of high lime and alumina is, therefore, an intrinsic feature of the rock which, together with low alkalis and comparatively low iron oxides, distinguishes it from the Hare Island basalt.

| Percentages. | | | Molecular Proportions. | Mineral Composition ('Norm'). | | | |
|--------------------------------|-----|--------|------------------------|-------------------------------|--------------------------|-----|------------|
| SiO ₂ | ... | 46.84 | ... | 0.781 | Quartz | ... | 7.88 |
| Al ₂ O ₃ | ... | 17.11 | ... | 0.168 | Orthoclase | ... | 3.89 |
| Fe ₂ O ₃ | ... | 4.95 | ... | 0.031 | Albite | ... | 13.62 |
| FeO | ... | 5.01 | ... | 0.069 | Anorthite | ... | 37.53 |
| MgO | ... | 5.72 | ... | 0.143 | | | |
| CaO | ... | 10.21 | ... | 0.182 | Diopside | ... | 10.15 |
| Na ₂ O | ... | 1.61 | ... | 0.026 | Enstatite | ... | 9.60 |
| K ₂ O | ... | 0.69 | ... | 0.007 | | | |
| H ₂ O (>110° C.) | ... | 2.53 | ... | — | Magnetite | ... | 4.64 |
| H ₂ O (at 110° C.) | ... | 1.63 | ... | — | Haematite | ... | 1.76 |
| CO ₂ | ... | none | ... | — | Ilmenite | ... | 7.60 |
| TiO ₂ | ... | 3.98 | ... | 0.050 | Pyrite | ... | 0.09 |
| P ₂ O ₅ | ... | 0.19 | ... | 0.001 | Apatite | ... | 0.30 |
| Cl | ... | trace | ... | — | | | |
| S | ... | 0.05 | ... | 0.002 | | | 96.56 |
| Cr ₂ O ₃ | ... | trace? | ... | — | Water, less O | ... | 4.14 |
| V ₂ O ₃ | ... | 0.01 | ... | — | | | |
| NiO | ... | none | ... | — | | | 100.70 |
| MnO | ... | 0.16 | ... | 0.002 | | | |
| SrO | ... | none | ... | — | | | |
| BaO | ... | trace | ... | — | Class II | ... | Dosalane. |
| | | | | | Order 5 | ... | Germanare. |
| | | | | | Rang 4 | ... | Hessase. |
| | | | | | Subrang 4 | ... | Hessose. |
| less O | ... | 0.02 | | | | | |
| | | 100.69 | | | | | |
| | | 100.67 | | | | | |
| | | | | | Specific gravity = 2.82. | | |

Specific gravity = 2.82.

4. ICELAND.

The best account in English of the physical geography of Iceland is to be found in Thoroddsen's recent contribution to 'The Botany of Iceland'.¹ Sir A. Geikie has dealt with the volcanoes of the island as modern illustrations of the Tertiary activity of north-western Europe.² A geological map is to be found in the 'Handbuch der Regionalen Geologie',³ where also a list of literature is given. It only remains to mention the recent work of Mr. Leonard Hawkes, whose investigations have been particularly concerned with the liparites of Iceland.⁴

Iceland is almost entirely built of volcanic rocks, of which the foundation is not seen. The following table gives the chief divisions that are recognized :—

| | | |
|----|---|---|
| 4. | Hot Springs | { Siliceous. Alkaline. Sulphur. Carbon dioxide. |
| | Active Volcanoes. | |
| 8. | <i>Post-Glacial</i> Basalts | Alluvium |
| 2 | <i>Quaternary</i> Basalts in part ice striated | { Glacial gravels, conglomerates, and moraine. |
| 1. | <i>Tertiary</i> Basalt Formation with Palagonite Formation near the top (breccias, tuffs, and conglomerates), intruded by innumerable dykes and sheets. Local flows of Liparite, and in the S.E. intrusions of Gabbro and Granophyre. | { Marine <i>Pliocene</i> deposits with molluscan fauna. <i>Miocene</i> and older clay deposits of the N.W. Peninsula with lignite and impressions of plants, leaves, &c. |

¹ T. Thoroddsen, Part I (2), Copenhagen and London, 1914.

² A. Geikie, 'The Ancient Volcanoes of Great Britain,' 1897, vol. ii, chap. xl.

³ H. Pjetursen, Island, 1910, Bd. iv (1), p. 2.

⁴ Mr. Hawkes's detailed results have not yet been published, but the following general papers are of importance :—

The building up of the North Atlantic Tertiary volcanic plateau. Geol. Mag., 1916, p. 385. Some notes on Icelandic geology. Norsk Geol. Tidsskrift, Kristiania, 1916, vol. iv (1).

The following is a list of the Iceland basalts in the Imperial College collections on which the descriptions given below are based :

Tertiary Basalts :

Non-porphyrific :

No. 387, Holmatindur, Eskifjord (Plate VI, fig. 5, Analysis, p. 192).

No. 884, Reydarfjord (south of Eskifjord).

Microporphyritic :

No. 4200, Isafjord, N.W. Peninsula.

Porphyritic, with phenocrysts of Bytownite :

No. 888, Eskifjord (Plate VI, fig. 6).

No. 1572, Isafjord, N.W. Peninsula.

Tertiary Olivine-Basalts :

Non-porphyrific :

No. 1571, Onundafjord, N.W. Peninsula.

No. 4202, " "

Porphyritic with phenocrysts of Olivine :

No. 1570, Onundafjord, N.W. Peninsula.

No. 4204, " "

Porphyritic with phenocrysts of Olivine, Augite, and Bytownite :

No. 838, Onundafjord, N.W. Peninsula.

No. 4203, Isafjord, N.W. Peninsula.

Quaternary Olivine-Basalts :

Porphyritic with phenocrysts of Olivine :

No. 837, Grundafjord, West Peninsula (Plate VII, fig. 1, Analysis, p. 196).

No. 4201, Grundafjord, West Peninsula.

In addition to the porphyritic or non-porphyrific character of the basalts, the following textures are recognized : ophitic, sub-ophitic, intergranular, and intersertal. The term *intersertal* implies a small residuum of glass between the network of feldspars and the grains of augite amongst them, and there has hitherto been no satisfactory term to express the same texture in the absence of glass. The late Prof. Judd used *granulitic* for a 'holocrystalline-intersertal' texture, but this term has already a generally accepted application to granulites, and is therefore unsuitable as applied to basalts. Dr. J. W. Evans has suggested to me the term *intergranular*, and I propose to adopt it in this paper. It may be defined as a texture due to the aggregation of grains of augite, not in parallel optical continuity (as in sub-ophitic texture), between feldspars arranged in a network that may be diverse, or sub-radial, or sub-parallel.

Olivine-free Basalts.

No. 387 is a compact, dark-grey rock free from vesicles and porphyritic crystals. In thin section it is seen to be a fresh and characteristic type

made up of labradorite-laths in sub-ophitic relation to grains and granulated plates of enstatite-augite¹ of a pale-grey to green colour, together with comparatively large skeletal growths of ilmenite, and a small residuum of brown intersertal glass (Plate VI, fig. 5). Here and there interstitial calcite occurs between the felspars. It is evidently a late product of the consolidation of the magma, and not due to subsequent alteration. Apatite needles traversing the felspars are noticeable, and numerous minute inclusions of the same mineral (probably cross-sections of the needles) arranged roughly along the axes of the laths are frequently present.

A determination of the proportions of the minerals by volume was made by the Rosiwal micrometric method with the following results :

| | | | |
|------------------------|-----|-----|----------------|
| Labradorite* | ... | ... | 48.0 per cent. |
| Enstatite-augite | ... | ... | 38.0 |
| Magnetite and Ilmenite | ... | ... | 10.0 |
| Glass | ... | ... | 2.5 |
| Calcite | ... | ... | 1.5 |
| | | | <hr/> 100.0 |

* Including apatite (from analysis nearly 1 per cent.).

Chemical analysis.—This rock (No. 387) was chosen for analysis on account of its freshness and lack of amygdales. Dr. Harwood obtained the following results :

| Percentages. | | | | Molecular Proportions. | Mineral Composition (' Norm). | | |
|--------------------------------|-----|-------|-----|------------------------|--------------------------------|-----|-------|
| SiO ₂ | ... | 48.79 | ... | 0.813 | Quartz | ... | 3.60 |
| Al ₂ O ₃ | ... | 11.96 | ... | 0.118 | Orthoclase | ... | 3.89 |
| Fe ₂ O ₃ | ... | 2.51 | ... | 0.016 | Albite | ... | 20.44 |
| FeO | ... | 12.10 | ... | 0.168 | Anorthite | ... | 20.02 |
| MgO | ... | 5.60 | ... | 0.140 | | | |
| CaO | ... | 10.15 | ... | 0.181 | Diopside | ... | 20.91 |
| Na ₂ O | ... | 2.40 | ... | 0.039 | Hypersthene | ... | 16.98 |
| K ₂ O | ... | 0.70 | ... | 0.007 | | | |
| H ₂ O (>110°C.) | ... | 0.40 | ... | — | Magnetite | ... | 3.71 |
| H ₂ O (at 110°C.) | ... | 0.65 | ... | — | Ilmenite | ... | 8.06 |
| CO ₂ | ... | 0.41 | ... | 0.009 | Pyrite | ... | 0.11 |

¹ W. Wahl, Die Enstatitaugite, Min. Petr. Mitt. (Tschermak), 1907, vol. xxxvi, p. 1. L. Hawkes (loc. cit., Kristiania, 1916) has also noted the presence of enstatite-augite in Icelandic basalts.

| | | Percentages. | | Molecular Proportions. | Mineral Composition (' Norm '). | |
|--------------------------------|-----|--------------|-----|------------------------|---------------------------------|-----------------|
| TiO ₂ | ... | 4.17 | ... | 0.053 | Apatite | ... 0.98 |
| P ₂ O ₅ | ... | 0.37 | ... | 0.003 | Calcite | ... 0.90 |
| Cl | ... | trace | ... | — | | |
| S | ... | 0.06 | ... | 0.002 | | 99.53 |
| Cr ₂ O ₃ | ... | trace | ... | — | Water, less O | ... 1.03 |
| V ₂ O ₅ | ... | 0.11 | ... | 0.001 | | |
| NiO | ... | trace | ... | — | | 99.56 |
| MnO | ... | 0.21 | ... | 0.003 | | |
| SrO | ... | none | ... | — | | |
| BaO | ... | trace | ... | — | Class III | ... Salfemane. |
| | | | | | Order 5 | ... Gallare. |
| | | 100.59 | | | Rang 4 | ... Auvergnase. |
| less O | | 0.02 | | | Subrang 4 | ... Auvergnose. |
| | | | | | | |
| | | 100.57 | | | | |

Specific gravity = 3.03.

Hitherto there have been no complete analyses of Iceland basalts. Bunsen¹ long ago made a series of analyses which are undoubtedly good for their time, but which are now of little more than historic interest. Other old analyses by Kjerulf² and Schirlitz³ are available. In none of these analyses was titanium dioxide determined, and consequently the alumina percentages are all unusually high. Otherwise Bunsen's analyses are substantially similar in their salient features to those of this paper. They indicate that the Quaternary and post-Glacial basalts do not systematically differ in bulk composition from the older basalts. The analyses of Schirlitz are remarkable for the comparatively high soda that they reveal, whereas his analyses of feldspars from the same rocks indicate that the prevailing species vary from labradorite (about An₇₀Ab₃₀) to nearly pure anorthite.

In Dr. Harwood's analysis, the high percentage of titanium dioxide is again a noteworthy feature, and in addition the presence of 0.11 per cent. of vanadium sesquioxide calls for special mention.

No. 384 is more finely grained than No. 387, and otherwise differs from it only in the possession of microscopic amygdaloids of chlorite-stained opal and chalcedony.

No. 4200 is an exceedingly fine-grained (0.04 mm. average), compact rock with a well-marked conchoidal fracture. In thin section it exhibits small microphenocrysts of bytownite, in an intersertal groundmass that

¹ R. W. Bunsen, Ann. Phys. Chem. (Poggendorff), 1851, vol. lxxiii, p. 197.

² T. Kjerulf, Nyt Mag. Naturvid. Kristiania, 1855, vol. viii, p. 72.

³ P. Schirlitz, Min. Petr. Mitt. (Tschermak), 1882, vol. iv, p. 414.

appears to carry an usually high amount of black ores. Specific gravity = 3.02.

No. 883 (Plate VI, fig. 6) carries well-shaped phenocrysts of bytownite, up to 1.5 cm. in length. In thin section the bytownite is seen to be mantled with a narrow fringe of labradorite having the same refractive index as the laths of the groundmass. The latter is identical with that of No. 887, except that it is free from glass and therefore intergranular. Mineral composition, p. 197. Specific gravity = 2.96.

No. 1572 differs from No. 883 only in the possession of an intersertal groundmass and in the fact that the less calcic periphery of the phenocrysts—which are less abundant—is not so conspicuous a feature. Mineral composition, p. 197. Specific gravity = 3.05.

Olivine-Basalts.

No. 1571, like the two specimens next to be described, is a highly vesicular, almost friable rock, but notwithstanding this fact it is seen in thin section to be holocrystalline and ophitic, and, for such a rock, of coarse grain (0.4–0.5 mm. average). The felspar-laths are labradorite near to bytownite; the augite plates between them are grey-green with, in places, a slight purple tint; and the olivine, which was the earliest mineral to crystallize and is slightly larger than the other constituents, is a pale-green variety altered to reddish-brown serpentine around the borders and along cracks. Apart from this slight alteration the rock is beautifully fresh. The mineral composition is stated on p. 197, and it will be noticed that the ore minerals are notably less abundant than in the olivine-free rocks. This difference is reflected in the hand-specimens by their purple-grey or blue-grey colours, the olivine-free basalts being of a much darker hue.

No. 4202 is a similar rock, the grain being slightly coarser.

No. 1570 carries bright olive-green phenocrysts of olivine, which in thin section are seen to be colourless and free from alteration. Mineral composition, p. 197.

No. 4204 differs from the three preceding rocks in its amygdaloidal character. The material of the rock is dark and compact, and is studded with numerous white amygdales varying in size from 2 to 10 mm. In thin section still smaller ones can be detected, and throughout the only mineral infilling is stilbite. Corresponding to this difference, the pyrogenetic minerals are not so fresh as in the friable rocks. Olivine is black-bordered and veined with brown or green serpentine. Augite is

partly replaced by chlorite along cracks, and even labradorite has often a dusky appearance. Mineral composition, p. 197.

No. 838 is a pale-grey rock with large phenocrysts (up to 1 cm. in length) of fresh, transparent, green olivine. In thin section the olivine is seen to be colourless with only slight peripheral alteration, the smaller crystals having green borders. A pale pyroxene of the enstatite-augite variety occurs as small phenocrysts, and there are also a few scattered porphyritic feldspars, the optical characters of which indicate its identity as bytownite, about $An_{80}Ab_{20}$. The groundmass is intergranular to sub-ophitic, and it is remarkable for its high percentage of augite, which occurs in grains or granulated plates between laths of labradorite. The mineral composition of the rock is as follows (percentage by volume):

| | | |
|-------------------------------|------------------------------|-----------|
| Phenocrysts = 40 per cent. | { Olivine | 22 |
| | { Pyroxene | 12 |
| | { Bytownite | 6 |
| Groundmass = 60 per cent. | { Labradorite | 21 |
| | { Augite | 84 |
| | { Magnetite and Ilmenite ... | 5 |
| | | <hr/> 100 |

No. 4203 contains porphyritic crystals (up to 1×0.5 cm.) and glomeroporphyritic aggregates of bytownite. Some of the latter are clustered about a nucleus of olivine, but both olivine and enstatite-augite are small as phenocrysts compared with the feldspar. The groundmass is similar to that of No. 838, and the difference between the two rocks is clearly dependent on the proportion of the phenocrysts of bytownite and olivine.

No. 837 (Plate VII, fig. 1) is almost identical in hand-specimen and in thin section with No. 1570, although the latter belongs to the Tertiary series, while No. 837 is post-Glacial. The rock contains small, light-green, rounded phenocrysts of olivine, which in section are colourless and perfectly fresh. The rest of the rock consists of an ophitic aggregation of augite-plates and bytownite-laths (containing tiny blebs of apatite as inclusions), with small olivine nuclei among the augites, and irregular masses of ilmenite (with a very little magnetite, separable by a bar magnet) interspersed between the feldspars. Part of the pyroxene is of the enstatite-augite variety, but it shades off on the borders and along terminations into augite with a faint purple tint. If this tint is due to enrichment in titanium dioxide, then the succession corresponds with

the fact that ilmenite was on the whole the last mineral to crystallize out. No glass is present.

The mineral composition of the rock (in terms of volume percentages) was determined approximately by the Rosiwal method :

| | | | | |
|---------------------------|-----|-----|-----|-----------|
| Bytownite | ... | ... | ... | 48 |
| Pyroxene | ... | ... | ... | 37 |
| Olivine | ... | ... | ... | 11 |
| Ilmenite and Magnetite... | ... | ... | ... | 4 |
| | | | | <hr/> 100 |

Chemical analysis.—This rock (No. 837) was analysed by Dr. Harwood with the following results :

| Percentages. | | | Molecular Proportions. | Mineral Composition ('Norm'). | | |
|--------------------------------|-----|-------|--------------------------|-------------------------------|-------------|-----------------|
| SiO ₂ | ... | 47.27 | ... | 0.788 | Orthoclase | ... 1.11 |
| Al ₂ O ₃ | ... | 14.44 | ... | 0.142 | Albite | ... 15.72 |
| Fe ₂ O ₃ | ... | 0.97 | ... | 0.006 | Anorthite | ... 30.58 |
| FeO | ... | 10.15 | ... | 0.142 | | |
| MgO | ... | 10.30 | ... | 0.257 | Diopside | ... 21.64 |
| CaO | ... | 11.73 | ... | 0.209 | Hypersthene | ... 11.36 |
| Na ₂ O | ... | 1.86 | ... | 0.030 | Olivine | ... 18.05 |
| K ₂ O | ... | 0.18 | ... | 0.002 | | |
| H ₂ O (>110° C.) | ... | 0.33 | ... | — | Magnetite | ... 1.39 |
| H ₂ O (at 110° C.) | ... | 0.09 | ... | — | Ilmenite | ... 4.56 |
| CO ₂ | ... | none | ... | — | Apatite | ... 0.31 |
| TiO ₂ | ... | 2.36 | ... | 0.030 | | |
| P ₂ O ₅ | ... | 0.12 | ... | 0.001 | | 99.72 |
| Cl | ... | 0.01 | ... | — | Water, &c. | ... 0.44 |
| S | ... | none | ... | — | | |
| Cr ₂ O ₃ | ... | 0.04 | ... | — | | 100.16 |
| V ₂ O ₅ | ... | 0.07 | ... | — | | |
| NiO | ... | 0.01 | ... | — | Class III | ... Salfemane. |
| MnO | ... | 0.19 | ... | 0.003 | Order 5 | ... Gallare. |
| SrO | ... | none | ... | — | Rang 4 | ... Auvergnase. |
| BaO | ... | none | ... | — | Subrang 5 | ... Auvergnose. |
| <hr/> 100.12 | | | Specific gravity = 2.93. | | | |

The analysis faithfully reflects the mineralogical differences between this rock and the olivine-free basalt, No. 387. Magnesia is higher, and, corresponding to the more calcic felspar, lime and alumina are higher, while soda is lower. Ilmenite, however, is much reduced in this rock, and consequently both titanium and iron oxides are lower than in No. 387. Among the rarer constituents it is noteworthy that vanadium

sesquioxide is again comparatively abundant. Evidently the Iceland basalts are richer in this constituent than the other Arctic basalts. Both nickel and chromium oxides are present in appreciable amounts, corresponding to the richness of the rock in olivine, whereas in No. 387 only traces were recorded.

No. 4201. There only remains for mention a dense, black rock which in thin section is seen to consist of fresh, colourless crystals of olivine (some idiomorphic, others corroded) in a dense, brown glass, which clears here and there and exhibits a nest of incipient felspar-laths. It may be described as an olivine-hyalo-basalt.

Mineral Composition of some Iceland Basalts.

The following approximate figures were obtained by the Rosiwal micrometric method for the mineral composition, by volume, of some of the foregoing rocks :

Olivine-free Basalts.

| Minerals. | No. 387.* | No. 383. | No. 1572. | Average. |
|---------------------------|-----------|----------|-----------|----------|
| Bytownite & Labradorite } | 48 | 63 | 49 | 53.3 |
| Pyroxene | 38 | 29 | 41 | 36 |
| Magnetite & Ilmenite } | 10 | 8 | 9 | 9 |
| Glass | 2.5 | — | 1 | 1.2 |
| Specific gravity | 3.03 | 2.96 | 3.05 | |

* Also 1.5 per cent. of calcite.

Olivine-Basalts.

| Minerals. | No. 1571. | No. 1570. | No. 4204. | No. 838. | No. 837. | Average. |
|---------------------------|-----------|-----------|-----------|----------|----------|----------|
| Bytownite & Labradorite } | 43 | 50 | 32 | 27 | 48 | 40 |
| Pyroxene | 33 | 31 | 38 | 45 | 37 | 37 |
| Olivine | 19 | 15 | 24 | 21 | 11 | 18 |
| Magnetite & Ilmenite } | 5 | 4 | 6 | 7 | 4 | 5 |
| Specific gravity | 2.98 | 2.96 | 3.06 | 3.09 | 2.93 | |

The figures indicate that on an average the basalts contain a higher percentage of ores and felspars than the olivine-basalts. With the exception of the felspar content of No. 1570 this generalization is also true of the individual rocks. In each group it is interesting to notice the antipathetic relation of ores and felspars.

Relation of the Basalts to the Rhyolites.

In text-fig. 1 an attempt has been made to construct a differentiation diagram linking up Dr. Harwood's analyses with those of Prof. Bäckström.¹ On the whole the curves fit the plotted analyses very closely, but beyond

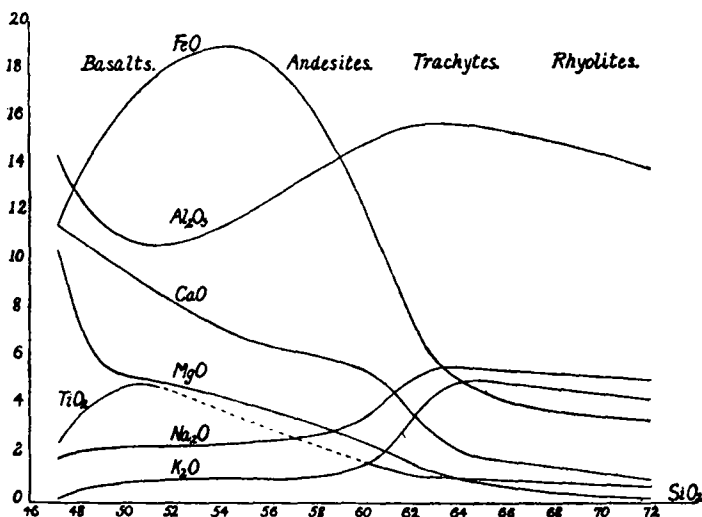


FIG. 1.—Differentiation diagram of the volcanic rocks of Iceland.

70 per cent. SiO₂ the rhyolites are evidently subject to much variation, for some are rich in orthoclase and alumina, others in soda-microcline and iron oxides. It seems clear that the post-Glacial rocks are richer in alkalis, and particularly in soda, than those of the Tertiary series. Similarly, among the basalts there can be no doubt that more analyses would reveal variations that could not be represented linearly, for the mineral composition discloses a contrast between felspathic types on the one hand and olivine-rich varieties on the other. Intermediate rocks,

¹ H. Bäckström, Beiträge zur Kenntniss der Isländischen Liparite. Geol. Fören. i Stockholm Förhandl., 1891, vol. xiii, p. 687.

however, though not known to be widely distributed, are sufficiently represented by analyses to justify the curves drawn. A striking antipathy between the oxides of alumina and iron (calculated as FeO) is displayed. Lime and the alkalis are also antipathetic, while the alkalis themselves vary sympathetically within the limits of the diagram, soda being always more abundant than potash. The crossing of the lime and alkali curves and their marked change of slope in the neighbourhood of 62 per cent. silica are features that are worthy of comparison with the corresponding behaviour in other series of rocks. In 'calc-alkali' series, such as those of the Pacific belt, the curves do not exhibit a sudden change of slope, though the crossing is generally near or at a higher silica percentage than 62. In 'alkali' series, on the contrary, such as those of East Africa and the mid-Atlantic Islands, the curves change slope sharply in the neighbourhood of the crossing, and the latter takes place at a lower (often much lower) silica percentage than 62. Thus the differentiation diagram clearly brings out the fact (to which attention has been drawn by Mr. Leonard Hawkes¹ as a characteristic of the rhyolites) that the Icelandic volcanic rocks belong neither to a typical 'calc-alkali' nor to a typical 'alkali' series, but share the characters of both. Although the Tertiary igneous suite of the British Isles has been complicated by much subsidiary differentiation, the main outlines are clearly similar to those of Iceland, and lead to a similar deduction. The Icelandic basalts are typical of those described in this paper, and thus it would seem that the conception embodied in von Wolff's proposal of an *Arctic* suite, as opposed to both *Atlantic* and *Pacific* suites, is justified. I say the conception is justified rather than the term, because geographical terms have not been successful in petrological generalizations, the reason being partly because of the existence of intermediate and composite suites such as this now being discussed, and the 'spilitic suite', and partly because 'Atlantic' and 'Pacific' series may be closely associated both in time and place.

5. THE FAROE ISLANDS.

The field relations of basaltic flows, tuff partings, and intrusions of the Faroes have been thoroughly described by the late James Geikie.² In three of the islands there occur partings of coal and carbonaceous sediments of Miocene age between the basaltic rocks, the age of which is thus approximately fixed. The basalts are similar to those of Iceland,

¹ L. Hawkes, *Norsk Geol. Tidsskrift*, Kristiania, 1916, vol. iv (1), p. 42.

² J. Geikie, *On the geology of the Farøe Islands*. *Trans. Roy. Soc. Edinburgh*, 1880, vol. xxx, p. 217 (Geological map, Pl. XVI).

comprising olivine and olivine-free varieties and presenting a similar range of textures. A petrological description of a basalt from Kolter, with an incomplete analysis, has been given by Osann.¹

The following is a list of the basalts described below :

Nos. 385 and 1412, Waags-fjord, Suderøe.

Nos. 386, 4007, 4008, Thorshavn, Stromøe.

No. 1413, Osterøe.

Of these, No. 385 is older than the Miocene coal partings, while the rest are of later date. Only No. 1413 carries olivine.

No. 385 is a dark, compact, grey-green rock. Under the microscope (Plate VII, fig. 3) it reveals microphenocrysts of labradorite in glomeroporphyritic aggregation, in a sub-ophitic groundmass consisting of labradorite-laths (having the same average refractive index as the small phenocrysts) and granular plates of pale-green, slightly pleochroic enstatite-augite. Well-shaped and skeletal crystals of ilmenite are very abundant. Minute inclusions of a similar opaque mineral occur in the feldspars, but the great bulk of ilmenite was the last of the essential minerals to crystallize out. Rounded grains of pyroxene (probably hypersthene) and tiny blebs of apatite are also included by the feldspars. There is a small amount of residual glass, sometimes brown and carrying globulites, sometimes green and showing incipient crystallization.

Measured by the Rosiwal method, the mineral composition of the rock by volume is as follows, that of No. 1412 being also given for comparison :

| | No. 385 | No. 1412 |
|------------------------|---------|----------|
| Labradorite | 45* | 42 |
| Pyroxene | 39 | 43 |
| Magnetite and Ilmenite | 12 | 13 |
| Glass | 4 | 2 |
| Specific gravity | 2.89 | 2.92 |

* Including small quantities of the other constituents as inclusions.

No. 1412 is, as the figures show, almost identical with No. 385. Microscopically it differs in having a finer grain and in the complete absence of microphenocrysts.

¹ A. Osann, Neues Jahrb. Min., 1884, vol. i, p. 45.

These rocks are less felspathic than the Icelandic olivine-free basalts, and they carry greater quantities of pyroxene and ilmenite. Nevertheless the analysed rocks, No. 385 (Faroe) and No. 387 (Iceland), are very closely similar, and the similarity is brought out even more closely by the analyses.

Chemical analyses of No. 385.—This rock was analysed by Dr. Harwood with the following results :

| | | Percentages. | | Molecular Proportions. | | Mineral Composition ('Norm'). | |
|--------------------------------|-----|--------------|-----|------------------------|-------------|-------------------------------|------------|
| SiO ₂ | ... | 49.70 | ... | 0.828 | Quartz | ... | 8.06 |
| Al ₂ O ₃ | .. | 10.98 | ... | 0.108 | | | |
| Fe ₂ O ₃ | ... | 8.02 | ... | 0.019 | Orthoclase | ... | 3.72 |
| FeO | ... | 11.19 | ... | 0.156 | | | |
| MgO | ... | 5.34 | ... | 0.1335 | Albite | ... | 18.34 |
| CaO | ... | 9.71 | ... | 0.173 | Anorthite | ... | 18.95 |
| Na ₂ O | ... | 2.22 | ... | 0.035 | | | |
| K ₂ O | ... | 0.63 | ... | 0.007 | Diopside | ... | 22.22 |
| H ₂ O (>110° C.) | ... | 0.96 | ... | — | Hypersthene | ... | 12.88 |
| H ₂ O (at 110° C.) | | 0.92 | ... | — | | | |
| CO ₂ | ... | none | ... | — | Magnetite | ... | 4.41 |
| TiO ₂ | ... | 4.88 | ... | 0.060 | Ilmenite | ... | 9.12 |
| P ₂ O ₅ | ... | 0.35 | ... | 0.008 | Pyrite | ... | 0.24 |
| Cl | ... | 0.02 | ... | 0.0006 | Apatite | ... | 1.01 |
| S | ... | 0.05 | ... | 0.002 | | | |
| Cr ₂ O ₃ | ... | trace | ... | — | | | 98.30 |
| V ₂ O ₃ | ... | 0.03 | ... | — | Water | ... | 1.88 |
| NiO | ... | none | ... | — | | | |
| MnO | ... | 0.22 | ... | 0.003 | | | 100.18 |
| SrO | ... | none | ... | — | less O | ... | 0.02 |
| BaO | ... | 0.01 | ... | — | | | |
| | | | | | | | 100.16 |
| | | 100.18 | | | | | |
| less O for S | ... | 0.02 | | | Class III | ... | Salfemane. |
| | | | | | Order 4 | ... | Vaalare. |
| | | 100.16 | | | Rang 3 | ... | Vaalase. |
| | | | | | Subrang 4 | ... | Vaalose. |

Specific gravity = 2.89.

Corresponding to the greater amount of ilmenite seen in thin section, the analysis reveals a higher percentage of titanium dioxide than in the corresponding Iceland rock. Otherwise the only notable difference is the much lower percentage of vanadium sesquioxide. The analysis closely fits the curves on the Icelandic differentiation diagram, text-fig. 1. The remaining rocks to be described can also be matched by Icelandic types,

the higher percentage of feldspar bringing the two series into detailed parallelism.

No. 386 (Plate VII, fig. 4) is a porphyritic basalt without vesicles, and Nos. 4007-8 are similar rocks, except that they contain vesicles here and there with occasional crystals of stilbite. All these have a groundmass that appears to be identical with that of No. 385, except in the size of grain. The only important difference is, therefore, the possession of porphyritic feldspars up to 1 cm. in length in place of the small glomeroporphyritic aggregates of the analysed rock. The large feldspars are a more calcic variety of labradorite than the laths, and, as in the Iceland rocks, there is often a less calcic fringe of the same composition as the laths. The two varieties are approximately $An_{70}Ab_{30}$ and $An_{50}Ab_{50}$.

No. 1413 is a light-grey, vesicular rock with porphyritic labradorite and small microphenocrysts of corroded olivine, now entirely altered to serpentine. As in the Icelandic olivine-basalts, augite is more abundant than in those free from olivine, but the special characteristic of the Faroe rocks, richness in ilmenite, is still maintained. The groundmass is intergranular with intersertal patches where a little pale-green glass still remains. Specific gravity = 2.86.

6. JAN MAYEN.

Jan Mayen is an inhospitable, fog-ridden island so extremely difficult of access that very little as yet is known about it.¹ It consists of the most northerly active volcano in the world, Beerenberg, rising steeply up from great depths to a height of 8,000 feet above the sea, with a long lava ridge stretching away to the south-west, the total length being about thirty miles. The island was roughly surveyed by the Austrian 'Pola Expedition' of 1882-3, and some rocks were collected, which were described by Scharizer.² These consisted of a porphyritic olivine-basalt from the south of the island, another from Mt. Danielsen, and another from Mary Muss Bay, together with an aegirine-trachyte from 'Eierinsel'. Analyses are given of the four rocks, but they are unreliable and incomplete. They are interesting chiefly in showing that the rocks are much richer in alkalis than any other of the Arctic volcanic rocks yet mentioned,

¹ See W. S. C. Russell, *Bull. Amer. Geogr. Soc.*, 1911, vol. xliii, p. 881.

² R. Scharizer, *Jahrb. geol. Reichsanst. Wien*, 1884, vol. xxxiv, p. 707. See also P. Reusch, 'Det Norske Nordhavs Expedition, 1876-1878,' 1882, p. 5 and fig. 4.

a characteristic that is verified by Dr. Harwood's analysis of the Mary Muss Bay rock (olivine-trachyandesite).

This is a dark-grey, compact, and basaltic-looking rock (No. 4208), with clear glassy idiomorphs of andesine (5×2 mm.; mean n slightly above 1.544; nearly straight extinction on both cleavages; specific gravity = 2.66). The composition is uniform throughout, there being no indications of zoning, but while the formula representing the composition may be partially stated as An_{30} , the analysis shows that the remainder cannot be Ab_{70} , for nearly half the normative alkali feldspar is orthoclase. Possibly the feldspar contains occult molecules of both orthoclase and carnegieite.

Under the microscope (Plate VII, fig. 2) the main body of the rock is seen to consist of small microphenocrysts of fresh colourless olivine, generally rounded and in places penetrated by the groundmass, together with a few faintly zoned pale-brown to purple augites in a very fine groundmass. The latter consists of feldspar-laths (of average $n = 1.544$) finely striated between crossed nicols, grains of green to brown augite, irregular specks of titaniferous magnetite, and a confused residuum containing small quantities of calcite, nepheline, and probably orthoclase. Careful search was made for orthoclase and nepheline in view of the analysis, but very little of either could be detected. Nearly isotropic patches with almost the same refractive index as Canada balsam were referred to nepheline and others with higher birefringence and lower refractive index to orthoclase. Apatite occurs as blebs in olivine, and each of these minerals is included by the larger augites. The rock betrays not the slightest trace of alteration either by weathering or hydrothermal action, and the calcite of the groundmass thus may be interpreted as a final low temperature product of the construction of the rock, rather than the first sign of its destruction.

The classification of this rock presents some difficulty, as it conforms to the demands of neither basalt nor andesite.¹ Iddings has suggested the name hawaïite for 'andesite-basalts' such as are developed in the Hawaiian Islands,² and the Jan Mayen rock resembles many of these sufficiently to fall under the same name. However, the relatively high potash revealed chemically indicates that the rock may be reasonably described as an *olivine-trachyandesite*. Rosenbusch would undoubtedly have called it a trachydolerite, but it seems advisable to retain this term for rocks with plagioclase at least as calcic as $An_{50}Ab_{50}$.

¹ A. Holmes, *Geol. Mag.*, 1917, p. 121.

² J. P. Iddings, 'Igneous Rocks,' 1913, vol. ii, p. 198.

Chemical analysis.—The rock (No. 4208) was analysed by Dr. Harwood with the following results:

| Percentages. | | | | Molecular Proportions. | Mineral Composition (' Norm). | | |
|--------------------------------|-----|--------|-----|------------------------|--------------------------------|-----|-------------|
| SiO ₂ | ... | 45.08 | ... | 0.751 | Orthoclase | ... | 10.56 |
| Al ₂ O ₃ | ... | 14.15 | ... | 0.189 | | | |
| Fe ₂ O ₃ | ... | 2.28 | ... | 0.014 | Albite | ... | 23.71 |
| FeO | ... | 8.59 | ... | 0.120 | Anorthite | ... | 15.29 |
| MgO | ... | 7.01 | ... | 0.178 | | | |
| CaO | ... | 10.20 | ... | 0.182 | Nepheline | ... | 5.62 |
| Na ₂ O | ... | 3.99 | ... | 0.065 | | | |
| K ₂ O | ... | 1.79 | ... | 0.019 | Diopside | ... | 13.74 |
| H ₂ O (>110° C.) | ... | 0.75 | ... | — | Olivine | ... | 14.83 |
| H ₂ O (at 110° C.) | ... | 0.15 | ... | — | | | |
| CO ₂ | ... | 2.42 | ... | 0.055 | Magnetite | ... | 3.25 |
| TiO ₂ | ... | 2.93 | ... | 0.037 | Ilmenite | ... | 5.62 |
| P ₂ O ₅ | ... | 0.62 | ... | 0.004 | Pyrite | ... | 0.18 |
| Cl | ... | trace | ... | — | Apatite | ... | 1.24 |
| S | ... | 0.09 | ... | 0.003 | Calcite | ... | 5.50 |
| Cr ₂ O ₃ | ... | 0.01 | ... | — | | | |
| V ₂ O ₅ | ... | 0.05 | ... | — | | | 99.54 |
| NiO | ... | none | ... | — | Water | ... | 0.90 |
| MnO | ... | 0.22 | ... | 0.003 | | | |
| SrO | ... | 0.05 | ... | 0.001 | | | 100.44 |
| BaO | ... | 0.06 | ... | | less O | ... | 0.03 |
| | | 100.44 | | | | | 100.41 |
| less O for S | ... | 0.03 | | | | | |
| | | 100.41 | | | | | |
| | | | | | Class III | ... | Salfemane. |
| | | | | | Order 5 | ... | Gallare. |
| | | | | | Rang 3 | ... | Camptonase. |
| | | | | | Subrang 4 | ... | Camptonose. |

Specific gravity = 3.01.

The analysis differs from those of the normal Arctic basalts most conspicuously in the high alkalis, and for the first time as we pass from west to east the percentage of titanium dioxide falls below the sum of the alkalis. In view of the fact that Scharizer describes chrome-diopside from his basalts, special care was taken to determine Cr₂O₃ in this rock, but only 0.01 per cent. was found. The olivine-basalt of Iceland—also richer in magnesia—contains four times as much. The oxides of strontium and barium are noticeably abundant, a feature to be correlated with the presence in the rock of relatively high lime and alkalis together.

The analysis corresponds very closely with some of those of the

titaniferous basalts of the western Mediterranean,¹ though mineralogically it differs somewhat, as the rocks described by Washington nearly all have labradorite as their prevailing felspar. The general relation of the Arctic and western Mediterranean titaniferous provinces will be discussed later. The resemblance to the 'andesine-basalts' of Hawaii² has already been mentioned, and, here too, many of the rocks carry a high percentage of titanium dioxide. Moreover, in all these regions, there is a further parallelism in the association of alkali-trachytes with the far more abundant basaltic types. The closest analogues, however, are not so far to seek, for the 'trachydolerites' of the extinct volcano of Mt. Sverre, Wood Bay, Spitzbergen, are very similar rocks, their most calcic plagioclase being $An_{40}Ab_{60}$, and therefore well within the range of olivine-trachyandesite as defined on the felspar basis. Analyses of the Sverre rocks are quoted on p. 206.

7. SPITZBERGEN.

There is a more extensive literature on the petrology of the basaltic rocks of Spitzbergen, and one, moreover, elaborated by several analyses, than can be found for any other of the islands dealt with in this paper. Geographically the volcanic and associated intrusive rocks of Spitzbergen may be divided into three groups: a southern one distributed around the shores of Storfjord in the south-east and described by Backlund;³ a central group along Icefjord and the Sassendal;⁴ and a northern series around the shores of Wood Bay.⁵ To the east of Spitzbergen, the basaltic rocks of King Charles (Kung Karls) Land form a fourth group.⁶

¹ H. S. Washington, *Quart. Journ. Geol. Soc.*, 1907, vol. lxiii, p. 74 (General); *Amer. Journ. Sci.*, 1907, vol. xxiv, p. 217 (Catalonia); *Journ. Geol.*, 1908, vol. xvi, p. 1 (Linosa); *Amer. Journ. Sci.*, 1909, vol. xxvii, p. 131 (Submarine Eruptions); *Journ. Geol.*, 1914, vol. xxii, p. 16 (Pantelleria).

² W. Cross, *U.S. Geol. Survey, Prof. Paper No. 88*, 1915.

³ H. Backlund, *Les Diabases du Spitzberg oriental. Missions scientifiques pour la mesure d'un arc de méridien au Spitzberg. 1899-1901, Mission Russe*, 1907, II, ix, B, 1.

⁴ A. E. Nordenskiöld, *Geol. För. i Stockholm Förh.*, 1874 5, vol. ii, p. 259. Sir Martin Conway, 'The first crossing of Spitzbergen,' London, 1897.

⁵ A. Hoel and O. Holtedahl, *Les nappes de lave, les volcans, &c., de la Baie Wood. Skrifter Vidensk.-Selsk. Christiania, Math.-Naturv. Kl.*, 1911, No. 8 (Geol. map opp. p. 18).

V. M. Goldschmidt, *Petrographische Untersuchungen*, *ibid.*, 1911, No. 9.

⁶ A. Hamberg, *Über die Basalte des König Karls Landes. Geol. För. i Stockholm Förh.*, 1899, vol. xxi, p. 509.

A. G. Nathorst, *Einiges über die Basalte des Arktischen Gebietes. Ibid.*, 1892, vol. xiv, p. 69.

See also *ibid.*, 1901, vol. xxiii, p. 341, and *Bull. Geol. Inst. Univ. Upsala*, 1910, vol. x, p. 316.

Backlund states that the diabases of Storfjord occur as sills of remarkable regularity cutting schists of the Permo-carboniferous and Jurassic strata, but never beds of younger age. Structurally both intergranular and intersertal types occur, porphyritic plagioclase being more evident in the latter. The porphyritic crystals are zoned, the cores being about $An_{70}Ab_{30}$, while the envelopes range from $An_{40}Ab_{60}$ to $An_{30}Ab_{70}$. The order of crystallization is given as follows: olivine (when present), magnesian-diopside, cores of plagioclase, augite, envelopes of plagioclase, titaniferous magnetite. Chemically, the rocks differ in three chief ways from those of other analysed Arctic rocks. Alumina is high (19–21 per cent.) and calcium is low. This combination is significant, for with it, and also with the presence of olivine, goes low titanium dioxide (not exceeding 1.2 per cent. in five analyses). The difference may be correlated with the richness of the rocks analysed in porphyritic plagioclase, for the only rock of a similar character analysed by Dr. Harwood contains more than 17 per cent. of alumina (Scoresby Sound, see p. 189).

Around Wood Bay the igneous history is longer and more interesting. It began in the Jurassic or Cretaceous with lava flows and sheets of basalt containing purple-brown augite and generally a little olivine. The composition of two examples is given below (A and B) with analyses of later rocks from the same neighbourhood.

| | A | B | C | D | E | F |
|------------------------------------|-------|-------|-------|-------|-------|-------|
| SiO ₂ ... | 49.75 | 50.19 | 44.49 | 45.12 | 45.88 | 44.66 |
| Al ₂ O ₃ ... | 12.96 | 12.37 | 10.98 | 13.63 | 13.52 | 12.97 |
| Fe ₂ O ₃ ... | 3.45 | 2.04 | 2.78 | 3.20 | 2.48 | 3.84 |
| FeO ... | 8.80 | 9.60 | 8.24 | 7.84 | 7.74 | 7.55 |
| MgO ... | 8.92 | 8.99 | 11.22 | 9.37 | 9.09 | 9.35 |
| CaO ... | 7.69 | 7.93 | 8.58 | 8.93 | 8.55 | 8.82 |
| Na ₂ O ... | 3.15 | 3.20 | 3.16 | 4.68 | 4.53 | 4.24 |
| K ₂ O ... | 0.97 | 0.87 | 2.25 | 2.05 | 2.52 | 2.78 |
| H ₂ O (>110° C.) | 0.44 | 0.12 | 0.76 | 0.43 | 0.74 | 0.69 |
| H ₂ O (at 110° C.) | 0.25 | 0.08 | 0.55 | 0.36 | 0.17 | 0.48 |
| CO ₂ ... | trace | trace | 0.86 | trace | trace | none |
| TiO ₂ ... | 1.38 | 1.47 | 2.60 | 2.69 | 2.87 | 2.76 |
| ZrO ₂ * ... | 1.18 | 2.02 | 2.10 | — | — | — |
| P ₂ O ₅ ... | 0.62 | 0.63 | 0.92 | 0.93 | 1.19 | 1.10 |
| Cr ₂ O ₃ ... | 0.02 | 0.03 | 0.02 | 0.01 | 0.01 | 0.01 |
| NiO ... | 0.02 | 0.11 | 0.07 | 0.48 | 0.14 | 0.26 |
| MnO ... | 0.16 | 0.18 | 0.17 | 0.23 | 0.22 | 0.21 |
| | 99.96 | 99.83 | 99.71 | 99.95 | 99.64 | 99.71 |

A, B, Cape Augusta Victoria, Spitzbergen. }
 C, Volcanic neck, Mt. Halvdan. } Dittrich,
 D, E, F, Mt. Sverre. } Analyst.

* Unfortunately this improbable constituent is described as the 'différence entre la détermination colorimétrique et gravimétrique de TiO₂'. Goldschmidt accepts the colorimetric estimation and adds the difference to Al₂O₃, which, probably, it is more likely to be than anything else.

On the west of Wood Bay there occurs a volcanic neck of olivine-trachydolerite of Tertiary or early Quaternary age (analysis C). The later Quaternary volcano of Mt. Sverre is built of rocks which have been termed olivine-trachydolerite and nepheline-basanite (analyses D-F). In most specimens the nepheline is accessory, and the rocks recall the olivine-trachyandesite of Jan Mayen. The feldspar being andesine, that term should replace trachydolerite. With increasing nepheline the rocks pass into basanite, in which a range of feldspar from andesine to bytownite is sanctioned by custom.

The three series of rocks demonstrate that their parent magmas became steadily richer in alkalis, and particularly in potash, as Recent time was approached. The last phase of volcanic activity is represented by thermal springs, probably the most northerly examples in the world.

The basalts of King Charles Land (Kap Weissenfels) resemble those of Hare Island, but magnetite largely takes the place of ilmenite, and the rocks have low titanium dioxide and high iron oxides.

Basalt (Dolerite) from the Sassendal, Central Spitzbergen.

This rock, like the diabase of Storfjord, occurs as an intrusive sheet in the Jurassic beds of the Sassendal. It was sent to us by Prof. E. J. Garwood, from his collection made on the Conway Expedition to central Spitzbergen.

In the hand-specimen it is a grey, granular rock of 0.5 mm. grain. Specific gravity = 2.86. In thin section (Plate VII, fig. 5) it is seen to be ophitic in texture and by no means free from interstitial glass. The feldspar-laths are of labradorite, approximately $An_{85}Ab_{15}$, arranged in radial groupings and often penetrating pyroxene, which is a nearly colourless variety belonging to the enstatite-augite series, and having a low optic axial angle. The pyroxene is generally in irregular plates, but a few idiomorphic crystals may be seen. It is clear that olivine originally crystallized from the magma, but now only a few rare serpentinized and deeply corroded relics remain. Titaniferous magnetite and apatite occur as accessories, the former being definitely of later crystallization than most of the feldspar, and the latter in part of earlier crystallization, since it is sometimes present in tiny prisms as inclusions. There are also later apatites of needle-like and acicular habit clinging to the edges of the feldspar-laths and associated particularly with the interstitial materials of the rock. These are of three kinds: in order of consolidation, brown glass, pale-grey chalcedony, sometimes chlorite-stained, and calcite. The calcite occurs partly as interstitial matter

associated with chalcedony, and in one slide a small amygdale was seen lined with quartz and otherwise filled with calcite.

The mineral composition by volume is approximately as follows :

| | | | | |
|----------------------------------|-----|-----|-----|-------|
| Labradorite | ... | ... | ... | 40 |
| Enstatite-augite | ... | ... | ... | 28 |
| Serpentine | ... | ... | ... | 1.5 |
| Titaniferous Magnetite | ... | ... | ... | 8 |
| Apatite | ... | ... | ... | n. d. |
| Glass | ... | ... | ... | 16 |
| Quartz, Chalcedony, and Chlorite | ... | ... | ... | 4.5 |
| Calcite | ... | ... | ... | 2 |
| | | | | 100 |

Chemical analysis.—The rock was analysed by Dr. Harwood with the following results :

| Percentages. | | | Molecular Proportions. | Mineral Composition ('Norm'). | | | |
|--------------------------------|-----|-------|------------------------|-------------------------------|-------------|-----|-------------|
| SiO ₂ | ... | 50.17 | ... | 0.836 | Quartz | ... | 10.74 |
| Al ₂ O ₃ | ... | 13.66 | ... | 0.135 | Orthoclase | ... | 6.12 |
| Fe ₂ O ₃ | ... | 5.40 | ... | 0.084 | | | |
| FeO | ... | 6.59 | ... | 0.094 | Albite | ... | 17.29 |
| MgO | ... | 5.31 | ... | 0.133 | Anorthite | ... | 25.30 |
| CaO | ... | 9.26 | ... | 0.166 | | | |
| Na ₂ O | ... | 2.06 | ... | 0.033 | Diopside | ... | 12.96 |
| K ₂ O | ... | 1.00 | ... | 0.011 | Hypersthene | ... | 9.68 |
| H ₂ O (>110° C.) | ... | 1.28 | ... | — | | | |
| H ₂ O (at 110° C.) | ... | 1.02 | ... | — | Magnetite | ... | 7.89 |
| CO ₂ | ... | 0.44 | ... | 0.010 | Ilmenite | ... | 5.62 |
| TiO ₂ | ... | 2.98 | ... | 0.037 | Pyrite | ... | 0.48 |
| P ₂ O ₅ | ... | 0.28 | ... | 0.002 | Apatite | ... | 0.66 |
| Cl | ... | trace | ... | — | Calcite | ... | 1.00 |
| S | ... | 0.24 | ... | 0.008 | | | |
| Cr ₂ O ₃ | ... | none | ... | — | | | 97.74 |
| V ₂ O ₅ | ... | 0.05 | ... | — | Water | ... | 2.80 |
| NiO | ... | none | ... | — | | | |
| MnO | ... | 0.15 | ... | 0.002 | | | 100.04 |
| SrO | ... | 0.05 | ... | } 0.0006 | less O | | 0.09 |
| BaO | ... | 0.03 | ... | | | | |
| | | | | | | | 99.95 |
| | | | 100.02 | | Class III | ... | Salfemane. |
| less O for S | ... | 0.09 | | | Order 5 | ... | Gallare. |
| | | | | | Rang 4 | ... | Auvergnase. |
| | | | 99.93 | | Subrang 4 | ... | Auvergnose. |

Specific gravity = 2.86.

The analysis shows that the rock has the general character of the

saturated non-porphyrific type of Arctic basalt, except that titanium dioxide is—in common with other Spitzbergen rocks—considerably reduced.¹ Remembering this minor difference, which is possibly geographical, it is interesting to notice that Spitzbergen possesses all the chief mineralogical and chemical types of the Arctic basalts. The saturated types differ mainly according to the absence or presence of porphyritic feldspars, those with phenocrysts always being much richer in alumina. The undersaturated types may be similarly divided, while the normal olivine-basalts must be distinguished from the more alkaline rocks that constitute the series trachyandesite, trachydolerite, nepheline-basanite.

8. FRANZ JOSEF LAND.

A detailed account of the basaltic rocks (whether they are lava flows or intrusions is not yet known) collected by the Jackson-Harmsworth Expedition of 1894–6 has already been published by Sir Jethro Teall² and at his kind suggestion a specimen from Hooker Island (811, Old Depot) was sent to us by the Director of the Geological Survey.

The specimen analysed by Teall³ was an undersaturated basalt (with normative olivine) from Cape Flora, Northbrook Island, whereas that analysed by Harwood, from Hooker Island, is a saturated basalt (with normative quartz). With the exception of minor chemical differences the two rocks are remarkably similar, and only a brief description of the Hooker Island specimen need be given (Plate VII, fig. 6).

The rock is a massive coarse-grained basalt (2 mm. grain with a sprinkling of slightly larger glomeroporphyritic crystals) which in thin section is seen to be ophitic, and to carry a residuum of brown interstitial glass. The larger feldspars are slightly zoned, the composition ranging from approximately $An_{70}Ab_{30}$ down to $An_{50}Ab_{50}$. The pyroxene belongs partly to the enstatite-augite series, having a hypersthene-like aspect in all but pleochroism, which is feeble. This merges vaguely into a brown-green type of later consolidation. Olivine and its alteration products were sought for in two sections, but none was found. About 7 per cent. of titaniferous magnetite occurs, chiefly of late crystallization.

¹ A very similar rock occurs on Gans Island, Spitzbergen. As far as Lindström's (1867) analysis goes (for the alkalis were not determined) it is closely like the Sassendal basalt and 2.97 per cent. of TiO_2 is recorded. See R. von Drasche, *Tschermak's Min. Mitth.*, 1874, pp. 263–265. Most of the analyses, however, show a lower content of titanium dioxide.

² J. J. H. Teall, *Quart. Journ. Geol. Soc.*, 1897, vol. liii, p. 482 (Locality map, p. 478).

³ J. J. H. Teall, *ibid.*, 1898, vol. liv, p. 646.

The interstitial matter is of the kinds described by Teall, brown glass locally passing into grey, and small patches of deep brown palagonite exhibiting aggregate polarization between crossed nicols.

The mineral composition by volume is approximately as follows :

| | | | | |
|------------------------|-----|-----|-----|-----|
| Labradorite | ... | ... | ... | 45 |
| Pyroxene | ... | ... | ... | 34 |
| Titaniferous Magnetite | ... | ... | ... | 7 |
| Glass and Palagonite | ... | ... | ... | 14 |
| | | | | 100 |

It may be noticed here, and also in the Sassendal basalt, that the normative magnetite and ilmenite considerably exceeds the amount of titaniferous magnetite found by measurement. The difference is probably to be found in the glass or palagonite of the rocks, and it is interesting to note that Teall's analysis of palagonite¹ reveals a marked concentration of iron oxides (26 per cent. in the latter).

Chemical analysis.—Dr. Harwood analysed the Hooker Island basalt with the following results :

| Percentages. | | | Molecular Proportions. | Mineral Composition ('Norm'). | | |
|--------------------------------|-----|-------|--------------------------|-------------------------------|-------------|-----------------|
| SiO ₂ | ... | 48.89 | ... | 0.813 | Quartz | ... 4.10 |
| Al ₂ O ₃ | ... | 14.80 | ... | 0.140 | Orthoclase | ... 2.78 |
| Fe ₂ O ₃ | ... | 4.71 | ... | 0.029 | | |
| FeO | ... | 7.60 | ... | 0.110 | Albite | ... 19.89 |
| MgO | ... | 6.11 | ... | 0.152 | Anorthite | ... 27.24 |
| CaO | ... | 11.04 | ... | 0.197 | | |
| Na ₂ O | ... | 2.81 | ... | 0.087 | Diopside | ... 20.83 |
| K ₂ O | ... | 0.47 | ... | 0.005 | Hypersthene | ... 12.08 |
| H ₂ O (>110° C.) | | 0.72 | ... | — | | |
| H ₂ O (at 110° C.) | | 1.57 | ... | — | Magnetite | ... 6.73 |
| CO ₂ | ... | trace | ... | — | Ilmenite | ... 4.41 |
| TiO ₂ | ... | 2.29 | ... | 0.029 | Apatite | ... 0.64 |
| P ₂ O ₅ | ... | 0.24 | ... | 0.002 | | |
| Cl | ... | trace | ... | — | | 98.20 |
| S | ... | trace | ... | — | Water | ... 2.29 |
| Cr ₂ O ₃ | ... | 0.02 | ... | — | | |
| V ₂ O ₅ | ... | 0.06 | ... | — | | 100.49 |
| NiO | ... | trace | ... | — | Class III | ... Salfemane. |
| MnO | ... | 0.18 | ... | 0.003 | Order 5 | ... Gallare. |
| SrO | ... | none | ... | — | Rang 4 | ... Auvergnase. |
| BaO | ... | trace | ... | — | Subrang 5 | ... Auvergnose. |
| 100.51 | | | Specific gravity = 2.91. | | | |

¹ J. J. H. Teall, loc. cit., 1897, p. 485.

Sir Jethro Teall's analysis of the Cape Flora specimen is given below for comparison :

| | Percentages. | | Molecular Proportions. | Mineral Composition (' Norm '). | |
|--------------------------------|--------------|-------|------------------------|---------------------------------|---------------------------|
| SiO ₂ | ... | 47.28 | ... | 0.788 | Orthoclase ... 1.67 |
| Al ₂ O ₃ | ... | 18.24 | ... | 0.180 | Albite ... 22.01 |
| Fe ₂ O ₃ | ... | 4.44 | ... | 0.027 | Anorthite ... 23.63 |
| FeO | ... | 10.50 | ... | 0.146 | |
| MgO | ... | 5.94 | ... | 0.149 | Diopside ... 25.57 |
| CaO | ... | 11.04 | ... | 0.197 | Hypersthene ... 12.63 |
| Na ₂ O | ... | 2.62 | ... | 0.042 | Olivine ... 2.68 |
| K ₂ O | ... | 0.31 | ... | 0.003 | |
| Loss on Ignition | ... | 2.00 | ... | — | Magnetite ... 6.26 |
| TiO ₂ | ... | 1.48 | ... | 0.018 | Ilmenite ... 2.74 |
| MnO | ... | 0.40 | ... | 0.006 | |
| | | <hr/> | | | Loss on Ignition ... 2.00 |
| | | 99.25 | | | <hr/> |
| | | | | | 99.19 |

III, 5, 4, 5, Auvergnose.

The chief differences between the analyses are that the Hooker Island specimen is richer in silica, alumina, and titanium dioxide than that from Cape Flora, while the latter is richer in ferrous oxide. The characteristic antipathetic relation between alumina and iron oxides is thus exemplified, while the behaviour of titanium dioxide illustrates a rule that applies to every individual locality described: that the saturated type of basalt is richer in that constituent than the under-saturated type.

9. CLASSIFICATION OF THE ARCTIC BASALTIC ROCKS.

In the preceding descriptions various classifications, textural and mineralogical, have been made use of, but that summarized to fit the Spitzbergen rocks seems to be the most suitable for a general review. The first division into saturated (or oversaturated) and undersaturated types is probably most fundamental, separating rocks with actual or normative quartz from those containing olivine. The latter may be further divided according to the presence or absence of actual or normative nepheline. Each of the three groups may be indefinitely subdivided according to texture and mineral composition, but the outstanding feature of classificatory importance is the presence or absence of macroporphyrific plagioclase. Six series of rocks are thus formed, within each of which the rocks have a marked chemical and mineralogical resemblance.

Classification and Distribution of the Arctic Basaltic Rocks.

| | SATURATED. | UNDERSATURATED. | |
|--|---|--|---|
| Characteristic Minerals of 'Norm' or 'Mode'. | Quartz. | Olivine. | Olivine and Nepheline. |
| Without Phenocrysts of Plagioclase. | <i>Basalts.</i> All Localities, except Jan Mayen. | <i>Olivine-Basalts.</i> All Localities. | <i>Trachydolerite.</i> Hare Is. |
| With Phenocrysts of Plagioclase. | All Localities, except Jan Mayen. | All Localities, but not abundantly developed. | <i>Trachyandesite.</i> Spitzbergen, Jan Mayen. <i>Trachydolerite.</i> Spitzbergen. <i>Nepheline-basanite.</i> Spitzbergen. |
| Amygdale Minerals. | Forms of Silica. Zeolites, Calcite. | Forms of Silica only present in hydrothermally altered rocks. Zeolites and Calcite. | |
| Rock Associations. | <i>Andesite</i> (Disco, Iceland, King Charles Land). <i>Rhyolite</i> (Iceland). <i>Granite</i> (Nugsuak Peninsula, Disco, and Iceland). | | <i>Alkali-Trachyte</i> (Jan Mayen). |

In the American quantitative classification the distinctions recognized above are clearly brought out, except that in Order 5 (which means that the ratio of normative quartz or feldspathoid to total feldspar is less than 1:7) both saturated and undersaturated rocks may occur, the presence or absence of small quantities of quartz, feldspathoid, or olivine being ignored as without significance.¹ The magmatic symbols for the rocks analysed by Dr. Harwood and others are as follows:

- III, 4, 3, 4. Basalt: Hare Island, Greenland.
Basalt: Suderøe, Faroe Islands.
III, 5, 3, 4. Olivine-basalt: Wood Bay, Spitzbergen.
Olivine-trachyandesite: Jan Mayen.

¹ For a development of this criticism see A. Holmes, A mineralogical classification of igneous rocks. Geol. Mag., 1917, pp. 115-180.

- III, 6, 3, 4. Olivine-trachydolerite: Hare Island, Greenland.
Nepheline-basanite: Wood Bay, Spitzbergen.
- III, 4, 4, 4. Diabase: Kuzkin Island, Siberia.¹
- III, 5, 4, 4. Diabase: Kuzkin Island, Siberia.¹
Diabase: Sassendal, Spitzbergen.
Basalt: Disco Island, Greenland.
- II, 5, 4, 4. Porphyritic-basalt: Scoresby Sound, Greenland.
Porphyritic-diorite: Storfjord, Spitzbergen.
- III, 5, 4, 5. Basalt: Disco Island, Greenland.
Basalt: Iceland.
Olivine-basalt: Iceland.
Basalt: Cape Flora, Franz Josef Land.
Basalt: Hooker Island, Franz Josef Land.

Throughout, the rocks have approximately equal amounts of 'salic' and 'femic' minerals (III) except in the markedly porphyritic rocks of Scoresby Sound and Spitzbergen, where 'salic' dominates (II). The rocks range from oversaturated (Orders 4, 5) to undersaturated (Orders 5, 6) types; alkalis are always subsidiary to lime (Rangs 3 and 4), and of the alkalis soda is always dominant or predominant (Subrangs 4 and 5).

10. REVIEW OF THE CHEMICAL CHARACTERS.

In the table given below the chief constituents of the nine analyses made by Dr. Harwood are averaged, and similar averages for the basalts of the British area,² of Washington's western Mediterranean province³ (Linosa, Pantelleria, Sardinia, and Catalonia), and of those of the Hawaiian Islands⁴ are listed for comparison, together with the average of all basalts computed by Osann and Daly.⁵

¹ H. Backlund, *Kristalline Gesteine von der Nordküste Sibiriens. I. Die Diabase der Kusjkin-Insel.* Mém. Acad. Sci. St. Pétersbourg, 1910, vol. xxi, No. 6.

² A. Harker, *Geology of the Small Isles of Inverness-shire.* Mem. Geol. Survey Scotland, 1908; *Summ. Progr. Geol. Survey Great Britain*, for 1915, 1916, pp. 26-27.

³ H. S. Washington, *Quart. Journ. Geol. Soc.*, 1907, vol. lxiii, pp. 74-75.

⁴ W. Cross, *U.S. Geol. Survey, Prof. Paper No. 88*, 1915.

⁵ R. A. Daly, *'Igneous Rocks and their Origin'*, 1914, p. 27.

| | | Arctic. | | British. | | W. Med. | | Hawaiian. | | Average Basalt. |
|--------------------------------|-----|---------|-----|----------|-----|---------|-----|-----------|-----|-----------------|
| SiO ₂ | ... | 47.49 | ... | 47.52 | ... | 47.85 | ... | 48.69 | ... | 49.06 |
| Al ₂ O ₃ | ... | 18.24 | ... | 16.59 | ... | 14.90 | ... | 14.00 | ... | 15.70 |
| Fe ₂ O ₃ | ... | 3.81 | ... | 3.91 | ... | 2.82 | ... | 5.03 | ... | 5.33 |
| FeO | ... | 8.73 | ... | 7.05 | ... | 7.44 | ... | 8.01 | ... | 6.87 |
| MgO | ... | 6.22 | ... | 6.72 | ... | 7.32 | ... | 7.12 | ... | 6.17 |
| CaO | ... | 10.23 | ... | 9.90 | ... | 8.48 | ... | 9.00 | ... | 8.95 |
| Na ₂ O | ... | 2.41 | ... | 2.64 | ... | 3.63 | ... | 3.55 | ... | 3.11 |
| K ₂ O | ... | 1.04 | ... | 0.74 | ... | 1.67 | ... | 1.24 | ... | 1.52 |
| TiO ₂ | ... | 3.81 | ... | 1.99 | ... | 4.27 | ... | 2.29 | ... | 1.86 |

From these figures it is clear that the outstanding features of the Arctic basalts are low silica, alumina, and alkalis, and high titanium dioxide, iron oxides, and lime. A peculiarity arising out of these general characters is that many of the basalts contain actual or 'occult' free silica in spite of the low total percentage of that constituent. The western Mediterranean basalts, for example, have more silica and yet are nearly all olivine-bearing rocks.

Turning to details it may be noticed that the basalts with macrophyritic plagioclase form a series with higher alumina and lower titanium dioxide (cf. Scoresby Sound) than those without noticeable phenocrysts. Throughout the whole series soda is much more abundant than potash. It is interesting, moreover, to find that, except in Iceland, the olivine rocks are those with most potash, though if magnesia and potash are compared they are seen to vary not sympathetically, but rather otherwise. On the other hand, the suggested relation between soda and iron oxides¹ holds with considerable faithfulness. Ferrous oxide is always in excess of ferric, and unusual abundance of the latter is found, not in the rocks with most magnetite, but in those containing most water (above 110° C.), such rocks being generally amygdaloidal.

Among the minor constituents, barium varies with potash, but strontium has no recognizable associate. Phosphorus also varies with potash except in the Hare Island picrite-basalt. This correlation also applies to the basalts of Catalonia, Sardinia, and Linosa, taking each locality by itself, and seems to hold more consistently than the association with iron suggested by Washington (loc. cit., 1907, p. 76). The Wood Bay rocks of Spitzbergen (see p. 206) are relatively richer in phosphorus than the other Arctic basalts, and even more do they differ in the high nickel contents recorded by Dittrich. Among the eight rocks in which nickel was sought by Dr. Harwood it was found in only three, and only

¹ See H. S. Washington, loc. cit., 1907.

in the olivine-basalt of Iceland—containing also a maximum amount of magnesia—was it determinable (0.01 per cent.). Chromium appears to accompany high olivine and hypersthene (normative or present in the enstatite-augite series of pyroxenes). However, the chrome-diopside found by Teall in Franz Josef Land and by Scharizer in Jan Mayen can scarcely be considered a general characteristic of the Arctic basaltic rocks. Vanadium is present in much greater quantity than chromium, but no relation can be detected. It is probably a constituent of the pyroxenes, a remark applying also to the habitat of manganese, which varies throughout the region within narrow limits.

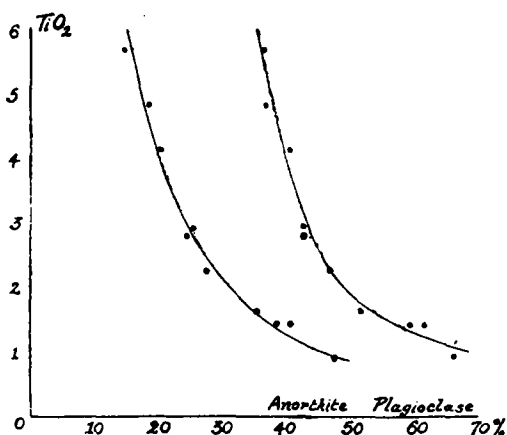


FIG. 2.—Diagram to illustrate the antipathy between titanium dioxide and feldspars in the Brito-Arctic saturated basalts. (See p. 216.)

Consideration of titanium dioxide has been left till last, because its abundance and variation from place to place give it a special interest. In a way it may be regarded as a hall-mark of the whole series of rocks with which we are here concerned, as it is of the still more markedly titaniferous basalts of the western Mediterranean. The constituent itself is present chiefly as ilmenite or titaniferous magnetite. In the saturated rocks it shows no signs of being present to any notable extent in pyroxene, whereas in the olivine-bearing rocks the pyroxenes have generally a slight purple tint,¹ which becomes more pronounced in the rocks containing relatively high alkalis. Looking for other mineral associations,

¹ This colour in pyroxenes is almost certainly due to titanium in the presence of soda. The alternative suggestion that it is due to manganese is negatived by chemical evidence.

it is easily seen that in each locality where both saturated and under-saturated rocks occur, the former are richer in titanium dioxide than the latter. Among the saturated rocks those with porphyritic plagioclase contain less titanium dioxide than those without phenocrysts. In a general way titanium dioxide varies inversely as the plagioclase-felspar, but this only holds for the porphyritic rocks if the phenocrysts are left out of account (as, for example, in the basalt from Scoresby Sound). Between felspars and ores the same relation also holds for the basalts of Iceland and the Faroes that have been micrometrically analysed (see pp. 197 and 200). The antipathy between titanium dioxide and normative anorthite and plagioclase is illustrated by the adjoining table and diagram (text-fig. 2, p. 215). The only serious exception is in the Scoresby Sound basalt, which has too much titanium dioxide to fit into the scheme.

| Locality. | | Titanium Dioxide. | | Normative Anorthite. | | Normative Plagioclase. |
|-------------------|-----|----------------------|-----|-------------------------|-----|---------------------------|
| Hare Island | ... | 5.68 | ... | 14.65 | ... | 36.13 |
| Faroe Islands | ... | 4.83 | ... | 18.35 | ... | 36.69 |
| Iceland | ... | 4.17 | ... | 20.02 | ... | 40.46 |
| Scoresby Sound | ... | 3.98 | ... | (37.53) | ... | (51.15) |
| Spitzbergen | ... | 2.93 | ... | 25.30 | ... | 42.59 |
| Mull ¹ | ... | 2.80 | ... | 24.63 | ... | 42.42 |
| Franz Josef Land | ... | 2.29 | ... | 27.24 | ... | 46.63 |
| Kuzkin Island | ... | 1.63 | ... | 35.58 | ... | 51.30 |
| Mull ¹ | ... | 1.46 | ... | 38.92 | ... | 59.36 |
| Mull ¹ | ... | 1.46 | ... | 40.87 | ... | 61.83 |
| Mull ¹ | ... | 0.93 | ... | 47.82 | ... | 66.16 |

It is interesting to find that the saturated basalts of the Pantelleria district also exemplify the same antipathetic relation.² The relation may be significant, for in these saturated rocks, plagioclase had almost completed its crystallization while the bulk of the titanium dioxide was still in the magma. The idea thus suggests itself that the basalts may be derivatives from a common type of magma in which some process of partial separation has taken place between plagioclase and the residual magma.

Among the undersaturated basalts the relations are less simple. In the olivine-basalts of Iceland (p. 197) micrometric analysis reveals an antipathy between felspars and ores, but the suggestion made above cannot apply here, for olivine is the first mineral to crystallize, and

¹ See Summ. Progr. Geol. Survey, Great Britain, for 1915, 1916, pp. 26-27.

² H. S. Washington, Quart. Journ. Geol. Soc., 1907, vol. lxiii, pp. 74-75 (Norms 6-8).

there is no antipathy between olivine and ores. The alkaline series of undersaturated rocks (Jan Mayen, Wood Bay, &c.) carry a much higher percentage of titanium dioxide than the normal olivine-basalts. Chemically these rocks resemble the titaniferous olivine-basalts of Catalonia, Sardinia, and Linosa, and in each individual locality considered alone the antipathy between titanium dioxide and anorthite is marked.

The geographical distribution of titanium dioxide among the Brito-Arctic basaltic rocks is very curious. Hare Island (5.68 per cent.), Scoresby Sound (3.98 per cent.), Iceland (4.17 per cent.), and Farøe (4.83 per cent.) lie in a belt characterized throughout by high percentages. Towards the north-west one finds a 'diorite-porphyr' at Skreia, Havnefjord, Jones Sound, having 4.87 per cent., while the older Palaeozoic complexes of alkaline rocks occurring in South Greenland include highly titaniferous types (3.82 per cent. in trachydolerite, Narsak; 4.25 per cent. in 'Ilimausak porphyry'; and 4.41 per cent. in trachydolerite, Nunasarnausak). It thus appears that the belt represents a region underlying which the magmatic sources are particularly titaniferous, either because the materials of the sub-crust have possessed that peculiarity as an original characteristic, or because they have been endowed with it by differentiation taking place during a former period, Devonian or older, of widespread and deep-seated fusion.

Many of the British Tertiary basaltic rocks contain more than 2 per cent. TiO_2 , and exceptionally nearly 4 per cent., and on an average they thus compare favourably with the Iceland olivine-basalt (2.36 per cent.). The saturated basalts of Mull (called 'augite-andesite') show a marked falling off, corresponding with a concomitant increase in felspar. On the other side of the belt the richness in titanium dioxide also fades out: to 2.98 per cent. in Spitzbergen, 2.29 per cent. in Franz Josef Land, 2.02 per cent. in Kuzkin Island, and 0.36 per cent. in the basaltic plateau of the Yenisei River.

Turning now to variation in time, it is only in Spitzbergen that a strict comparison between older and younger rocks is possible. There the tendency has obviously been to produce more alkaline types in later times. The trachyandesite of Jan Mayen is a Quaternary or Recent flow from the still active Beerenberg. In Iceland the basaltic flows of modern times¹ do not seem to differ in any marked way from their oldest predecessors, and one can only say that the younger rhyolites seem to be more alkaline than the older, which are associated with andesite

¹ See analysis quoted by H. Rosenbusch, 'Elemente der Gesteinslehre,' 1910, p. 399.

and dacite. Among the other localities no evidence is yet available. The British area is so complex that it is unsafe to generalize, for the later basaltic rocks are sometimes richer, sometimes poorer in their alkali content. However, further south the later rocks of the Atlantic Islands are distinctly of a more alkaline character than their older associates.

Thus in the Atlantic-Arctic region the highly titaniferous belt gives little evidence of a change in time towards an alkaline facies, whereas on each side the rocks become less titaniferous and show a progression in time in the direction of increasing alkalis, wherever younger rocks are exposed.

11. REMARKS ON THE CONCEPTION OF 'PETROGRAPHIC PROVINCES'.

The conception of 'Petrographic Provinces' was suggested by Vogelsang in 1872,¹ and independently by Judd in 1886,² and it has since been developed by Harker,³ Iddings,⁴ Washington,⁵ and other petrographers. It is clear that a consideration of the rocks of a large area such as that dealt with in this paper implies a study of their variation in three dimensions, two representing the surface of the earth and the third progression in time. In an ideal petrographic province variation in time should follow closely similar lines of evolution at different centres of activity, and variation in place, for any given stage in the parallel lines of evolution, should be slight. The province should, moreover, be bounded by regions having different rock-series, and in time the period of activity should have recognizable limits. Such an ideal province thus demands that similar rocks belonging to similar series (defined by their range of chemical and mineral composition and textures) must be produced in adjacent centres of igneous activity during the same period. This implies that the processes by which the rocks are formed must be similar throughout the province, and that the distribution of rock materials in depth, on which the processes act, must also be similar. One condition alone satisfies these requirements, namely, that all the parts of the province have had a parallel geological history, as regards denudation and

¹ H. Vogelsang, *Zeits. Deutsch. Geol. Gesell.*, 1872, vol. xxiv, p. 525.

² J. W. Judd, *Quart. Journ. Geol. Soc.*, 1886, vol. xlii, p. 54.

³ A. Harker, 'Natural History of Igneous Rocks,' 1909, p. 88; *Pres. Add. Sect. C, Rep. Brit. Assoc.* for 1911, 1912, p. 372.

⁴ J. P. Iddings, *Bull. Phil. Soc. Washington*, 1892, vol. xii, p. 128; 'Igneous Rocks,' 1913, vol. ii, p. 345.

⁵ H. S. Washington, *Carnegie Inst. Washington*, Pub. No. 57, 1906.

sedimentation, earth movements and former periods of igneous activity. Both denudation and sedimentation affect the distribution of temperature and pressure in depth, the more so because of the influence of radio-activity.¹ Earth movements, according as they compress or stretch the rocks, inhibit or promote fusion, respectively, so that compression allows fusion to begin only at much greater depths than tension. Previous igneous activity may have profoundly affected the nature and distribution of rock material in depth by differentiation (and perhaps also by assimilation) and movement of magmas, so that a renewal of fusion and a repeated differentiation under different circumstances may give rise to rocks quite distinct from those of an earlier period.²

It is obvious that the realization of all these factors in a common geological history is likely to be difficult of accomplishment except over comparatively small areas. Denudation and sedimentation merge into each other and overlap in time, so that the boundaries of future provinces become blurred. Earth movements, though often of similar type throughout long belts of the crust, vary greatly in intensity, and so presumably the depth of fusion and degree of differentiation may vary to a corresponding extent from one centre of vulcanism to another. As Harker has pointed out, referring to the British Tertiary province,³ rocks may belong to two distinct categories: 'The *regional*, distributed over the length and breadth of the province, and the *local*, limited to the neighbourhood of the special centres', where local disturbances have diverged more or less from the prevalent type of movement. As in the British province, so throughout the Arctic region 'the connexion of igneous action . . . with the subsidence of faulted blocks of country is too plain to be missed'. This prevalent movement is doubtless to be correlated with the basalts regionally developed from West Greenland and the off-lying islands to the British area in the south and to the mouth of the Yenisei in the east. Throughout this region, except perhaps at Jan Mayen, basalts belonging to each of the four types distinguished on p. 212 are developed. If no other rocks were associated with these, it might be possible to assert that the region so outlined constitutes a single province, but it would still be necessary to point out that there is a regional variation of composition from the transverse titaniferous belt, to less titaniferous and on the whole more felspathic

¹ See A. Holmes, *Geol. Mag.*, 1916, p. 265.

² See J. W. Evans, *Geol. Mag.*, 1916, p. 189.

³ A. Harker, 'Natural History of Igneous Rocks,' 1909, p. 104.

⁴ A. Harker, *Pres. Add. Sect. C, Rep. Brit. Assoc. for 1911, 1912*, p. 377.

types on either side. When other rocks than normal basalts are considered, however, it becomes clear that to frame a definition of the province in terms of its characteristics and limits in space and time is a difficult and delicate task.

We are, moreover, greatly handicapped by lack of an appropriate nomenclature to apply to such types of provinces as have already been recognized. Terms such as Atlantic and Pacific, alkaline and calc-alkaline, are not suitable, the former pair for geographical reasons, and the latter because series of rocks should be considered rather than individual varieties, stress being laid on the direction and degree of differentiation; in an 'alkaline' volcanic series for example, basalts of undoubted 'calc-alkaline' character may be the most abundant rocks. If for convenience we designate series of rocks by one of their characteristic members, as Rosenbusch has done, we may usefully distinguish andesitic, spilitic, trachydoleritic, and tephritic series. The first of these is associated generally with compressional and upward movements, and the second with compressional and downward movements in regions undergoing sedimentation. The others are generally associated with differential movement of faulted blocks, the possible significance of dominant uplift or subsidence in connexion with depth of fusion and kind of differentiation not yet having been distinguished.

To all four series normal basalts serve as a common foundation, and in general basalts alone do not suffice to determine the series. When we examine the associated rocks, developed at special centres, in order to ascertain the series actually represented in the Arctic region, it becomes clear that two series are present—the andesitic and the trachydoleritic. In the British area the two series have been distinguished by Harker and related respectively to local Pacific and regional Atlantic types of earth movement. In the absence of detailed field evidence in the Arctic localities it is not yet possible to draw a similar conclusion, but one may point out that the area broadly surveyed in this paper lies between two well-marked types of petrographic provinces: the tephritic of the Atlantic Islands and the andesitic of the Pacific borders.

To sum up, the Brito-Arctic region may be described as a composite province, characterized throughout by basaltic rocks with a regional variation of composition, that are for the most part of Tertiary age, but which have forerunners of late Jurassic or Cretaceous age in the east, and modern representatives in Iceland. Among the olivine-free basalts consanguinity is indicated by the antagonistic relation between feldspars and titanium dioxide, by the regional variations of both, and by the

usual presence of pyroxene belonging to the enstatite-augite or magnesian-diopside series. The olivine-basalts differ consistently from their saturated associates, with which they have no special relationships. Locally, andesites, dacites, rhyolites, and granite (or granophyre) are developed, and elsewhere more alkaline rocks ranging in composition from olivine-trachydolerite and nepheline-basanite to trachyte and soda-rhyolite are found, the latter series being, as far as the evidence permits of a statement, among the youngest rocks of the region.

This large composite province may be conveniently divided into a number of sub-provinces; each of which corresponds more closely than the whole to the demands of an ideal petrographic province, viz.:

1. The British area, itself composite.
2. The highly titaniferous belt stretching from Hare Island, Disco, and the Nugsuak Peninsula to Scoresby Sound, Iceland, and the Faroes.
3. Jan Mayen, which may perhaps be grouped with the Quaternary volcanoes of Wood Bay, Spitzbergen.
4. Spitzbergen (older rocks), Franz Josef Land, and Kuzkin (or Sibirakov) Island at the mouth of the Yenisei. The plateau basalts of the Yenisei-Tunguska region may also belong to this group, but such descriptions and analyses as are now available are not decisive.

It is interesting to notice that the grouping suggested above is one that would naturally be made geographically (except in 3, which is a time association) from inspection of a bathymetrical chart. The Greenland-Faroes belt lies on a partly submerged ridge separated by deeper water from the British area on the one side, and the localities of sub-province 4 on the other. The latter are nowhere separated from each other or the Siberian mainland by depths exceeding 100 fathoms.

12. NOTE BY DR. H. F. HARWOOD ON A METHOD OF ESTIMATING NiO , Cr_2O_3 , AND V_2O_5 IN A SINGLE PORTION OF ROCK.

The methods employed in carrying out the foregoing analyses were essentially those described by Hillebrand,¹ the only modifications being (1) the use of perchloric acid in place of platinum chloride in the estimation of the alkalis,² and (2) the estimation of NiO , Cr_2O_3 , and V_2O_5 in one and the same portion of rock by the following method:

Five grams of the rock were treated in a platinum basin with sulphuric and hydrofluoric acids until completely decomposed. The whole was

¹ W. F. Hillebrand, *The analysis of silicate and carbonate rocks*. Bull. U. S. Geol. Survey, 1910, No. 422.

² R. G. Thin and A. C. Cumming, *Journ. Chem. Soc. Trans.*, 1915, vol. cvii, p. 861.

then evaporated until the sulphuric acid fumed strongly. After cooling, the mass was digested with hot water and filtered. The residue, mainly calcium sulphate, was ignited, fused with sodium carbonate, the melt taken up with dilute sulphuric acid, and added to the previous solution. Bromine water was now added to oxidize any ferrous iron, the excess removed by boiling, and the solution precipitated by ammonia. Blank experiments on mixtures of known composition showed that this ammonia precipitate carried down with it the whole of the chromium and vanadium present in the rock. The precipitate was well washed, dried, and fused in a nickel crucible with caustic soda and sodium peroxide, the melt extracted with water, the solution boiled, filtered, and the vanadium and chromium in the filtrate estimated by Hillebrand's method (precipitation with mercurous nitrate, &c.). The nickel was estimated in the filtrate from the ammonia precipitate by concentrating this to a small bulk and adding a solution of dimethylglyoxime and (if necessary) ammonia to alkaline reaction. After standing overnight, the scarlet precipitate was filtered off, dissolved in hydrochloric acid, the solution well boiled, and the nickel re-precipitated with dimethylglyoxime and ammonia. The precipitate of nickel dimethylglyoxime was filtered off on a platinum Munro crucible and weighed.

EXPLANATION OF PLATES VI AND VII.

Plate VI. (Ordinary Light. Magnification $\times 25$, except in fig. 1 which is $\times 45$.)

Fig. 1.—*Basalt* (No. 1554), Hare Island, West Greenland, Microporphyrritic labradorite in a base of labradorite-laths, augite-granules, and magnetite and ilmenite. (Analysis, p. 183.)

Fig. 2.—*Olivine-Basalt* (No. 1555), Hare Island. Microphenocryst of olivine and minute laths of labradorite in a base of augite and iron-ores.

Fig. 3.—*Melanocratic Olivine-Trachydolerite* or *Felspathic Augite* (No. 1553), Hare Island. Idiomorphic phenocrysts of brown to purple augite, with microphenocrysts of olivine (under the crack, on the left of the field) and laths of bytownite in a dark-brown base. (Analysis, p. 187.)

Fig. 4.—*Porphyritic Basalt* (No. 1560), South side of Scoresby Sound, East Greenland. Phenocrysts of bytownite in a fine-grained intersertal groundmass broken by amygdales. (Analysis, p. 189.)

Fig. 5.—*Sub-ophitic Basalt* (No. 387), Holmatindur, Eskifjord, Iceland. Labradorite-laths, enstatite-augite, and large skeletal crystals of ilmenite. (Analysis, p. 192.)

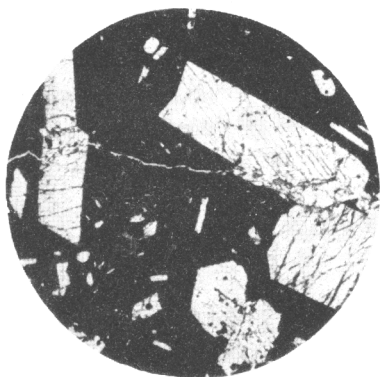
Fig. 6.—*Porphyritic Basalt* (No. 383), Eskifjord, Iceland. Phenocrysts of bytownite mantled with labradorite in an intergranular groundmass rich in ilmenite.



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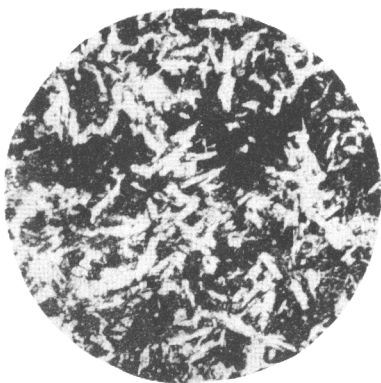
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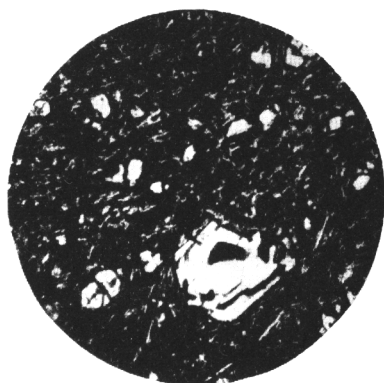
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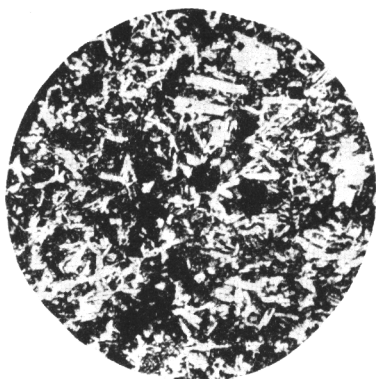
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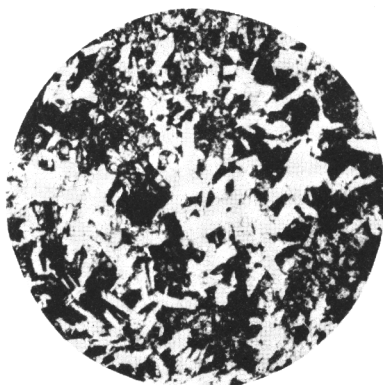
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Plate VII. (Ordinary light. Magnification $\times 25$, except in fig. 2 which is $\times 45$.)

- Fig. 1.—*Olivine-Basalt* (No. 837), Grundarfjord, West Peninsula, Iceland. The rock contains porphyritic olivines not visible in the field, which shows the ophitic texture and peculiar vesicular character of the rock. The minerals seen are bytownite, augite (with olivine-nuclei), and ilmenite. (Analysis, p. 196.)
- Fig. 2.—*Olivine-Trachyandesite* (No. 4208), Mary Muss Bay, Jan Mayen. Microphenocrysts of corroded olivine and of smaller augites in a fine groundmass containing andesine. The rock also contains idiomorphs of andesine too large to be shown in the field. (Analysis, p. 204.)
- Fig. 3.—*Sub-ophitic Basalt* (No. 385), Waags-fjord, Suderøe, Faroe Islands. Labradorite, enstatite-augite, and ilmenite. Apatite inclusions can be seen in some of the feldspars. (Analysis, p. 201.)
- Fig. 4.—*Porphyritic Basalt* (No. 386), Thorshavn, Stromøe, Faroe Islands. Similar to No. 885, but contains phenocrysts of calcic labradorite and large crystals of ilmenite.
- Fig. 5.—*Ophitic Basalt* or *Dolerite* (No. 4209), Sassendal, Central Spitzbergen. Contains labradorite enstatite-augite, titaniferous magnetite, and glass. (Analysis, p. 208.)
- Fig. 6.—*Ophitic Basalt* or *Dolerite* (No. 311), Old Depot, Hooker Island, Franz Josef Land. Constituents as in fig. 5, but with coarser grain. (Analysis, p. 210.)

The photomicrographs here produced were prepared by Mr. G. S. Sweeting, of the Geology Department of the Imperial College, from thin sections which, with a large number of others, were made for this investigation by Mr. E. J. Tallin (of the same Department). For the valuable assistance thus afforded I wish in conclusion to express my thanks.
