Some petrogenetic aspects of the northern basalt plateaux[1]).

By

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In his well known paper from 1918 A. HOLMES (11) wrote on the basalts of Iceland: . . . "the icelandic volcanic rocks belong neither to a typical "alkali" nor to a typical "calc-alkali" series, but share the characters of both".—Later investigations from various parts of the northern basalt plateaux have arrived at similar results. Considering the whole region to-day, however, a logical sequence seems to exist, furthermore mutual lines of genesis may be pointed at within various areas. It is the object of this lecture to call attention to some of these problems, since geological investigations in Greenland, in Iceland and the Faeroes through the last decades have enlarged our knowledge considerably.

West Greenland: The mainland consists of metamorphic rocks of presumably pre-Cambrian age. On this substratum rests in the central part of the coast land a series of sediments of Cretaceous and Tertiary age, which in their turn are covered by the basalt series. The basalts occupy an area of about the size of Jutland. They may be divided into two parts, viz. a lower subaquatic portion consisting of tuffs and pillowlavas and an upper portion consisting of several kilometers of subaëric, basaltic lavas. Besides the surface magmatites two intrusive groups are met with in the Cretaceous-Tertiary sediments, viz. one consisting of rather small, ultrabasic sills and dykes, and another which includes some very big sills—of a quartz-doleritic composition—following a considerable faulting zone, with a height of displacement of about 2 kilometers, running across the eastern part of the Nûgssuaq peninsula.

It had not hitherto been possible to determine the age of the magmatic activity accurately, but during the investigations of the

[1]) A lecture given at the University of Lund on April the 10-th 1946.

Danish Nûgssuaqexpeditions 1938–39 the age has been fixed very exactly (7). The lowest basaltic ash layers are found in marine strata of the Danian age, subsequent ash layers are found in upper Danian and in Paleocene strata. Just below the aforementioned subaquatic part of the surface volcanics, marine lower Eocene strata occur in the interior part of Nûgssuaq. In other words it is safe to say that in West Greenland the volcanism started in the Danian time but, that surface volcanism on a large scale is post lower Eocene.

So far only the succession of the surface lavas in the peninsula of Svartenhuk has been described (22). Here we find above the subaquatic breccias and tuffs, at the bottom picritic basalts which through a diminishing of the olivine content surpass into ordinary olivine rich basalts—with 10–15% olivine—and further into olivine carrying basalts—with 2–3% olivine—and olivine free basalts, among which in an upward direction plagioclase-porphyritic types become dominating, and cover a wide area. Highest up the lava sequence the an-content of the plagioclases falls to the boundary line labradorite/andesine. On top of the plateau—farthest west—some small domes of anorthoclase-trachyte follow (NIELAND, 17). The whole series is about 10 km thick (NOE-NYGAARD, 22).

The evolution in Svartenhuk seems to be this: The lower portion of lavas are of a mildly atlantic type, whereas in the upper portion the plagioclase-porphyritic lavas show that a certain contamination has taken place—calc-alkali-index 56 (22. 24). The explanation I will submit is near at hand; the first lava eruption took place through a comparatively cool sial. Gradually the weight of the produced lavas on the surface brought about a sinking of the area bringing the substratum down into a region with higher temperature, faciliating contamination; further a rise of the thermal front was also faciliated by the lively fissure eruption probably responsible for the continous supply of surface lavas. Since the most acid product of the Tertiary volcanic period in Svartenhuk was the anorthoclase-trachyte the contamination of the Svartenhuk basaltic sequence has not expanded very far.

Each of the two intrusive groups mentioned above (p. 55) behave in a different manner and so to say symbolize the extremes.

We can take the Qaersut sill as an example of the ultrabasic suite, it shows the following trend of differentiation: *Peridotitic* (augite concentrations) via *peridotite-gabbroic* (main rock) to *gabbroic* (irregular pegmatites) and further through *syeno-dioritic* (pegmatitic veins) to *syenitic* (aplites)[1]).

The other intrusive group has been described by S. MUNCK (16) and comprises the big sill system of the Sarqaq valley and the Serfat sill. In both cases the composition of the main rock is quartz-gabbroic; in the rocks of the Sarqaq valley acid segregations occur of a potash-granite-aplite (ab. 10% alkalies), at Serfat segregations with a similar mode of occurrence consist of granodiorite-aplite. The faulting zone along which the sills are located seems to have favoured the selective fusion needed for the contamination of the intruding magma.

In Ubekjendt Island a considerable injection of granophyre was detected by STEENSTRUP (32), it was studied in detail by a British expedition in 1938 led by J. DREVER (9). The results are being worked up at present.

East Greenland: Conditions here must be treated in two parts using the Scoresbysund fjord as the dividing line. The area north of this fjord has been investigated by BACKLUND and MALMQUIST (1. 2), furthermore some of the rocks have been described by RITTMANN (30) and KROKSTRÖM (12); the area to the south has been studied by WAGER (34) and WAGER & DEER (35. 36).

In the northern part only limited areas with surface lavas have been preserved, i. e. Hold-with-hope, Home Forland, the easternmost part of Clavering Island (?), Sabine Island, Little Pendulum Island and Shannon Island. Of great areal significance inland is, however, the occurrence of sills which penetrate the younger palaeozoic and the mesozoic sediments in the fjord zone more than a hundred kilometers from the outer coast. The rock types of the sills and dykes are of various kinds, among which the following can be mentioned: Olivine-trachy-basalt, plagioclase-basalt, olivine dolerite and basalts proper. Their mutual relation and chronological sequence is only known in part, SCHAUB (31). At Kap Franklin rhyolitic rocks are met with as dykes and perhaps as small laccolitic bodies (2). In the region around the mouth of Davy Sund plutonic, syenitic centres occur (see below). Although a complete record of the field

[1]) Some of the statements differ a little from the last paper on the sill by DRESCHER and KRUEGER (8), because of new observations made in course of the Nûgssuaq-expeditions 1938–39. A couple of new chemical analyses have also been made since then.

conditions and the interrelation of the various types cannot be given, it may be stated that uncontaminated as well as contaminated types are found. No systematical investigation has been made as regards the sequence of surface lavas farthest east (Hold-with-hope to Shannon Island).

The sourthern area, viz. the area to the south of the Scoresby-sund fjord is dominated by the surface lavas. They were visited by O. NORDENSKJÖLD and later on investigated by L. R. WAGER (34), who estimates the total thickness at 7 kilometers. Sill systems of the type met with in the northern area have not been recorded, whereas a number of plutonic centres are described; these consist partly of gabbro and granophyre, partly of syenite.

Iceland: In Iceland no substratum of the plateau basalts has been recorded through direct observations, the lowermost strata towards the east and towards the west are basalts. The total thickness seems to amount to at least 3,5 kilometers (HAWKES, 10).

Above the plateau basalts follow the "palagonite system" (PJETURSS (25), PEACOCK (23), NIELSEN and NOE-NYGAARD (18. 20), amounting to at least 1 kilometer in thickness and consisting of tuffs, agglomerates, subglacial pillow lavas and breccias and glacigeneous and fluviatile redeposition products hereof with the post-Glacial lavas on top.

A full treatment of the Tertiary lava sequence has not been undertaken as far as can be ascertained from the literature, but good information is given by PEACOCK (24), who distinguishes four lines of trend within the magmatic evolution in Iceland. The A-series —lavas—consists of: Olivine basalt, basalt, mugearite and rhyolite and is in other words calc-alkalic, the C-series—lavas too—consists of: Trachybasalt, trachyandesite, trachyte, trachy-rhyolite or expressed in other terms alkali-calcic. The B-series is calc-alkalic and comprises the intrusives: gabbro, granophyre. The D-series consists of ultrabasites which are considered to show an alkaline tendency.

The Faeroes: In this area intermediate and acid types of rocks are quite absent and only basalts occur. Roughly speaking a triple division of the lava-pile, which attains a thickness of about 5 kilometers can be made (WALKER and DAVIDSON, 4). The lowest visible strata are made up of a series of mildly atlantic basalts, these are followed by a plagioclase porphyritic series covering more than half

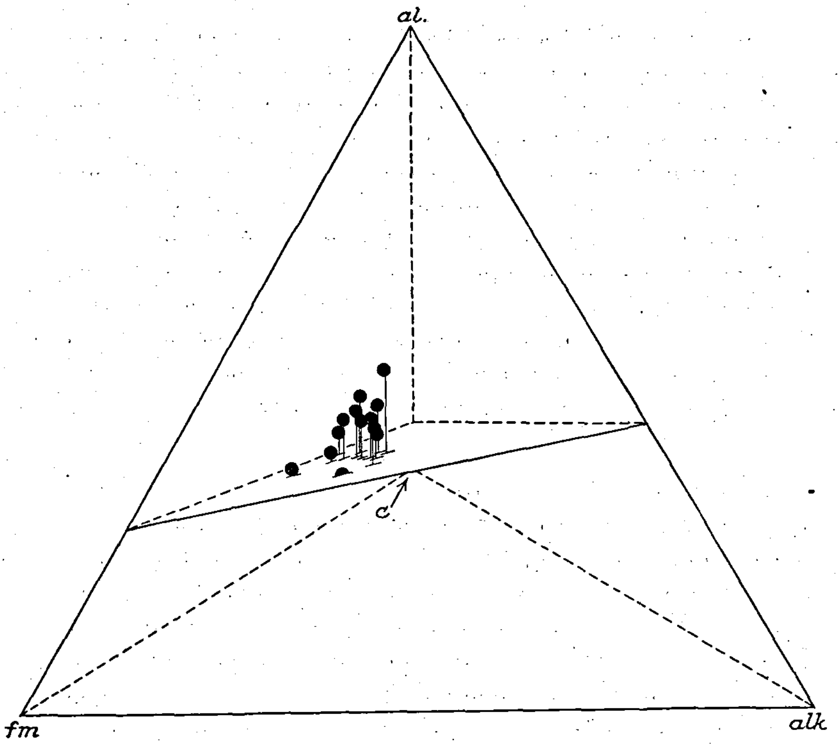

Fig. 1. Tetrahedron illustrating the approximate composition of rocks of basaltic chemistry from the Faeroes. The plane represents the boundary surface which separates those rocks—below the surface—that would precipitate pyroxene first from those that precipitate plagioclase first—above the plane. From the 13 complete analyses now existing from the Faeroes the f (norm) has been computed (BARTH, 3 a) however in stead of presenting the ab', an', di' and hy' values I have recalculated these to NIGGLI symbols. The assimilation of aluminous or clayey sedimentary material will shift the composition of the basaltic magma away from the boundary surface into the plagioclase field. Thus, as far as chemical composition of the magma is concerned, the effect of assimilation is opposite to that of fractional crystallization, which would induce an approach to the boundary surface. Three of the analyses are seen to lie in or very near the boundary surface, whereas the others lie above—some rather considerably—indicating a not neglegible contamination with 'sialic' or sedimentary material.

of the total area. Still higher up follows a third division, which starts with oceanitic types and where mildly atlantic basalts dominate. A certain alternation of types belonging to the various series is conspicuous. Some doleritic sills are found, they may carry olivine or be of a quartz-gabbroic magma type; acid segregations have not been recorded.

The development is likely to have been the following. Volcanic activity started with the outpour of the mildly atlantic olivine-basaltic lavas; successively a selective fusion of sialic material was favoured through the weight of these lavas on the surface causing a downward movement of this part of the sial, and through an elevation of the thermal front owing to the continuation of surface volcanism. The result was the contaminated lavas of the middle group (cf. fig. 1). In my opinion marks the third group, including the oceanitic types at the base, a renewed support of material from deeper sources, or there may have been a stagnation of the volcanic activity, resulting in the lowering of the thermal front favouring a more "pure" type of eruption materials.

Comparison of the various areas: In northern Scotland the lavas have been divided in two main groups, viz. a lower or the plateau group, and an upper or the central group. These may well be paralleled with the two lowermost divisions in the Faeroes (4), the third Faeroese group is missing. Passing on to Iceland we do not with our present knowledge find anything which might equal the bottom series in Scotland and the Faeroes, but start with contaminated lavas which may correspond to the middle group of the Faeroes; this beeing the case the upper Faeroe suite might correspond to the upper group of Iceland, the C-series of PEACOCK (24). The sequence of the plateau lavas of East Greenland is unknown so far, so no parallelization can be made at present. The sequence of West Greenland as examplified through the Svartenhuk basalts, may correspond to the two series in Scotland or the two lower portions of the Faeroese suite. Of course chronology and rock evolution in so big an area as occupied by the "Thulean" basalts is not definitely proved to be the same throughout, consequently the parallisations here set forth must be taken only as an attempt to gain a general wiew on the whole province.

The gabbroic and granophyric intrusives: Intrusive rocks of gabbro and granophyre are met with in West Greenland on Ubekjendt Island (STEENSTRUP, 32, DREVER, 9) in East Greenland at Kap Gustav Holm, Kialineq and Igdlitarajik (WAGER, 34), they may be parallelized with the intrusive rocks of Iceland, the B-series of PEACOCK (24).

The syenitic intrusives: In East Greenland we find a thing unequalled in West Greenland and in Iceland, viz. the plutonic centres with a syenitic composition. A few words shall be said of them. In the above description of East Greenland I spoke of a northern and a southern area, divided by the Scoresbysund fjord, the two parts of the country being of different nature and the volcanic manifestations being somewhat different; they have, however, one thing in common, namely the plutonic centres composed of syenites, resp. nepheline syenites. The occurrences are the following: The Kap Parry complex (TYRRELL 33, SCHAUB 31), and the Kap Simpson-Drømmebugt complex (visited in the field by BACKLUND, KRANCK, NOE-NYGAARD and SAHAMA 1933, mapped by SCHAUB 1936–37 and microscopically examined by REINHARD 1942) on the eastern Traill Island, the Antarctic Havn complex on northern Scoresbyland (NOE-NYGAARD, 21), and the Kangerdlugssuaq and the Lilloise mountains on the Blosseville coast (L. R. WAGER, 34).

On Traill Island quartzfree syenites are rare as they are only seen along the western border of the centers of Kap Parry and Kap Simpson-Drømmebugt, the main rock is in both areas quartziferous syenites which through an increase of the quartz content locally surpasses into alkali-granite, which make up small areas in the east in both places; hereof REINHARD (31) writes as follows: . . . "ob es sich hierbei um eine Differentiationserscheinung handelt, oder ob die Granite aus dem Syenite durch Assimilation von Nebengestein (Sandsteine) entstanden sind, muss dahingestellt werden".

The syenite from Antarctic Havn on Scoresbyland contains ab. 2% quartz as an average, the leucocratic constituents (quartz, perthite, antiperthite and a little andesine), make up from 87–95% of the total volume; the chemical analysis shows ab. 11% alkalies.

The syenites from the Blossville coast contain nepheline and one of them sodalite too; the chemical analysis shows ab. 13% alkalies (WAGER, 34).

Although these syenitic rocks are distributed over a considerable area they have a composition and mode of occurrence, which make a similar or related origin probable. The age relations show that they are younger than the main epoch of basaltic activity. Comparing the northern and the southern area with respect to the substratum of the basalts we find a conspicuous difference. To the North the basalts rest on a variegated post-Caledonian sedimentary series ranging from Devonian through Carboniferous, Permian, Triassic, Jurassic to Cretaceous, to the South the basalts rest on the metamorphic complex as far as our information goes at present. The local conditions i. e. "milieu of intrusion" thus being very different, it lies near at hand to suppose that the higher levels of the sial sphere do not play any considerable rôle in the genesis of the syenites, but that their origin must have more deeplying causes.

Concerning the genesis of the basalts the generally accepted conception is that the parent magma is an olivine basalt of a mildly alkaline character. As was shown in the above in certain parts of the Thulean province a contamination with sialic material is traceable, viz. upper part of the Svartenhuk area in West Greenland, lower parts of the lavas in Iceland and the middle suite of the Faeroes. However, the volcanism as a whole of this type is generated from the simasphere.

Returning to East Greenland and the syenitic centres there, we know that in the period just before the formation and intrusion of the syenites an intensive volcanism was in action producing the plateau basalts; we know further from elsewhere that a syenitic/trachytic end derivate of crystallisation from an uncontaminated basaltic magma is the rule.

As far as I can see conditions in East Greenland can best be explained as follows. The plateau basalts were undoubtedly brought to the surface through fissures, considerable dyke swarms are recorded by WAGER and DEER (35), this mode of intrusion has been able to rise the temperature of the enclosing rock considerably as time goes on (comp. WEGMANN, 38), the thermal front may in this way receive an upward buckle or perhaps an areal rise with local culminations and depressions, depending inter alia on differences in the heat conductivity from place to place. Through variations in the volcanic intensity during the eruption period the thermal front may undergo oscillations within the culminations, in this manner a larger amount of the crystallisation derivate of syenitic/trachytic material, which beforehand must be expected to be especially concentrated here, may be liberated. There may thus be a possibility for generating a magma of syenitic composition in the upper part of the simasphere.

If the thermal front during its oscillation rises into sialic strata a more acid composition—alkaligranitic or granitic—of the resulting magma may be reached.

To resume the above considerations we can say that the "primary"

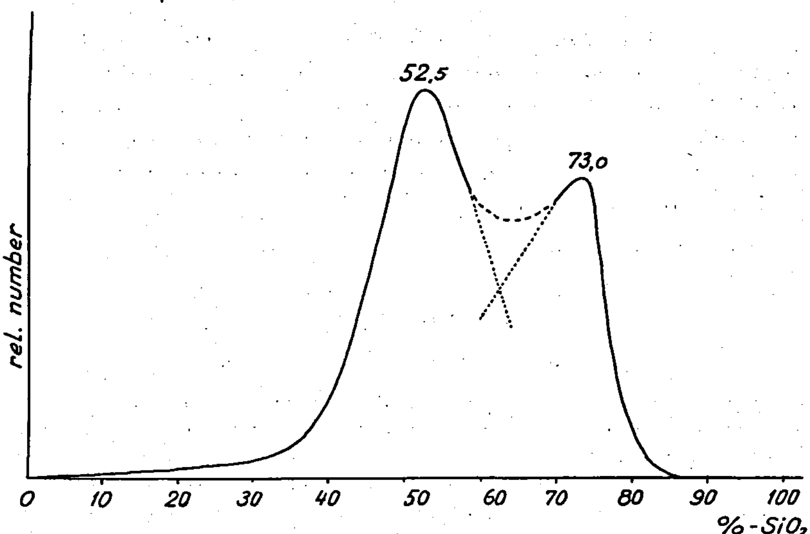

Fig. 2.

type of volcanism is of simatic origin (Rittmann, 29) and starts basaltic, the volcanism generated within the earthcrust will in anorogene areas be able to retain a certain atlantic character—syenites.

The wellknown graph showing the relation of the SiO_2 content and the relative abundance of magmatic rocks shows two summits, at 52.5% and 73% SiO_2 respectively; I would prefer to picture it as shown in fig. 2. The left half indicates the course of the volcanism of simatic, that of the right half of sialic origin. Since only the SiO_2 content is taken into consideration nothing is said of the question pacific/atlantic. Difficulties arise in the boundary zone, with intermediate composition when trying to keep the two curves apart; they may, however, at least to some degree be surmounted through a comparison of the mutual proportions of some of the constituents, which posses an original inclination to behave in a different manner at higher and lower levels (Ramberg, 26 and 27).

If these points of view concerning the East Greenland syenites have a more general significance they should be adaptable to other regions and other periods too. Here attention shall only be drawn to the Oslo region in Norway, where a systematical revision has been started by Holtedahl, and Barth (3). The latter has shown that the post-Permian volcanism in the Oslo fjord field started with kauaitic lavas; through this period the thermal front may have received its upward buckle, which later on favoured the generation of a syenitic magma, the quartz carrying and the nephelite carrying branch of which mark the further course of crystallization. The parallelism between the Tertiary magmatic evolution in East Greenland and the corresponding post-Permian evolution in Norway is in other words conspicuous.

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