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GEOLOGICAL INVESTIGATIONS IN EAST GREENLAND

PART VI

A DIFFERENTIATED BASIC SILL ENCLOSED
IN THE SKÆRGAARD INTRUSION, EAST GREENLAND AND
RELATED SILLS INJECTING THE LAVAS

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WITH 7 FIGURES IN THE TEXT

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Abstract.

Three basic sills are described from the Skærgaard area of East Greenland. Two are intrusive into Tertiary lavas; parts of the third, the Basistoppen Raft, are preserved as a large inclusion in the Skærgaard gabbro complex. All three have a basal picrite resulting from gravity settling of early olivine crystals. The subsequent course of crystallization is described from the least altered sill, the Basistoppen Raft, in which the mineral sequence is closely similar to that of the Palisades Sill.

I. INTRODUCTION AND ACKNOWLEDGEMENTS

During the Scoresby Sound Committee's second East Greenland Expedition under Captain EJNAR MIKKELSEN and the British East Greenland Expedition of 1935-36, three thick gabbro sills, Hængefjældet, Hammersdal and the Basistoppen Raft were found and mapped in the Skærgaard area. The Basistoppen Raft was shown to be a large inclusion within the Skærgaard intrusion, of similar material to the other two sills which are intrusive into the lava series (WAGER and DEER, 1939, pp. 18-19, 57-58, 199-200).

In the summer of 1953 the Kangerdlugssuaq area was revisited by a geological expedition under the leadership of Professor L. R. WAGER and Professor W. A. DEER. The object was to undertake further field work on the Skærgaard, Kangerdlugssuaq and Kap Edvard Holm igneous complexes of Tertiary age. All except one of the accessible exposures in the Raft inclusion were revisited and further collections were made on traverses of Kobbernunatak and Skillenunatak. Mapping was done on aerial photographs and heights were estimated using a pair of aneroid barometers.

The localities of the sills and positions relative to the crustal flexure are shown in the accompanying map, Fig. 1, which is based on that appearing in the Skærgaard memoir (WAGER and DEER, 1939) with minor improvements due to the work of the later expedition.

The petrology of the sills based on material collected by the several expeditions has been investigated by the author with the general help and advice of Professor L. R. WAGER. The author is very grateful to the leaders of the 1953 expedition for including him in the party and he also wishes to express his thanks to them for permission to work on part of the collections.

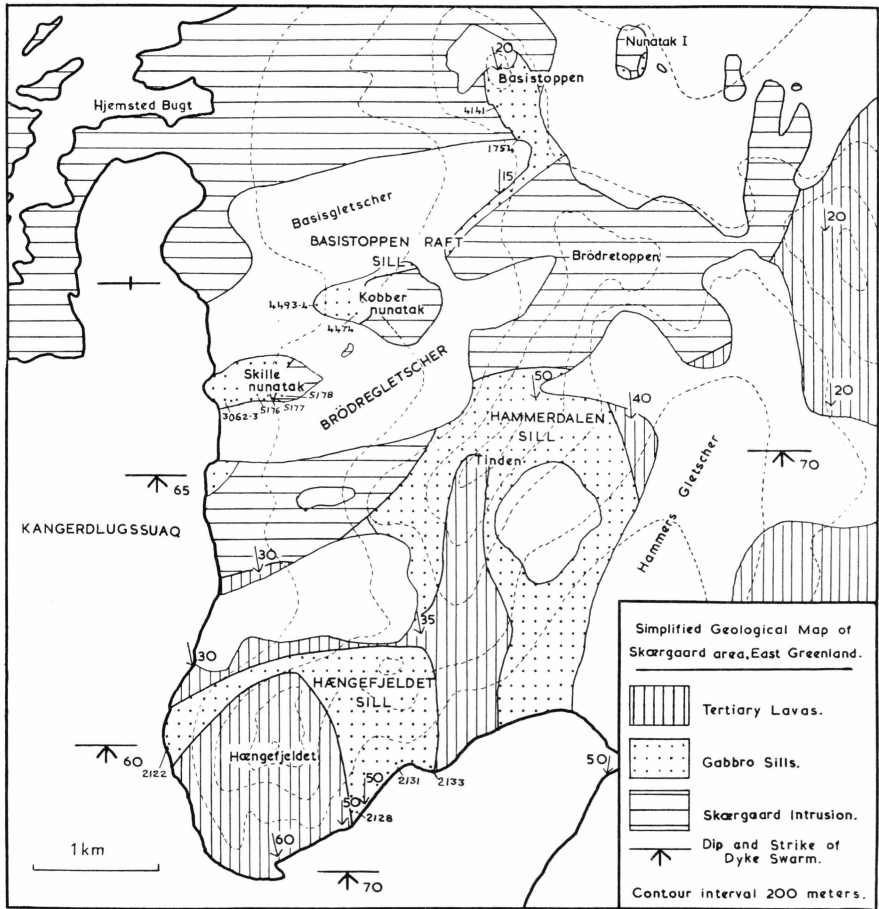


Fig. 1. Map showing relative positions of sills to the Skærgaard intrusion and crustal flexure.

II. BASISTOPPEN RAFT SILL

1) Field Description.

A large mass of this sill is exposed on Basistoppen, Kobbernunatak and Skillenunatak; two smaller masses occur on Nunatak I (see Fig. 1). The present position of these masses is in the complicated central part of the Skærgaard intrusion where the upper layered rocks, the Unlaminated Layered Series, give place to the Upper Border Group of the complex. The estimated original relative positions of the several parts of the sill are indicated in Fig. 3, as are also relative specimen locations.

The thickness of the sill now visible is about 800 feet. There is the possibility of some error in correlating the sections, and the sill is not seen in its entirety. Original chilled margins of the sill are not seen although the mineralogy of the highest and lowest exposed rocks suggest that these are not far removed from the original margins.

The lowest part of the sill now preserved is a picrite, exposed only on Basistoppen where it is veined by andesinite belonging to the upper part of the Skærgaard layered series. Detached blocks of picrite are enclosed in the andesinite, leaving no doubt as to the earlier age of the Raft Sill but making estimation of the original thickness of the picrite impossible.

On Nunatak I where the lower contacts between sill inclusions and Skærgaard layered rocks are again visible, no picrites are present, presumably as a result of the original olivine-rich layer having broken away and sunk deeper into the Skærgaard magma chamber. The contact rock here is a fine grained granulitised gabbro veined by Skærgaard ferro-gabbros.

The characteristic rock type of the sill is a spotted gabbro immediately distinguishable from the upper gabbros of the Skærgaard intrusion. The spotted character is due to prominent bastite pseudomorphs together with areas of secondary chlorite, contrasting with areas containing fresh, often poikilitic clinopyroxene. In the upper third of the sill, which is well exposed but not easily accessible in the vertical

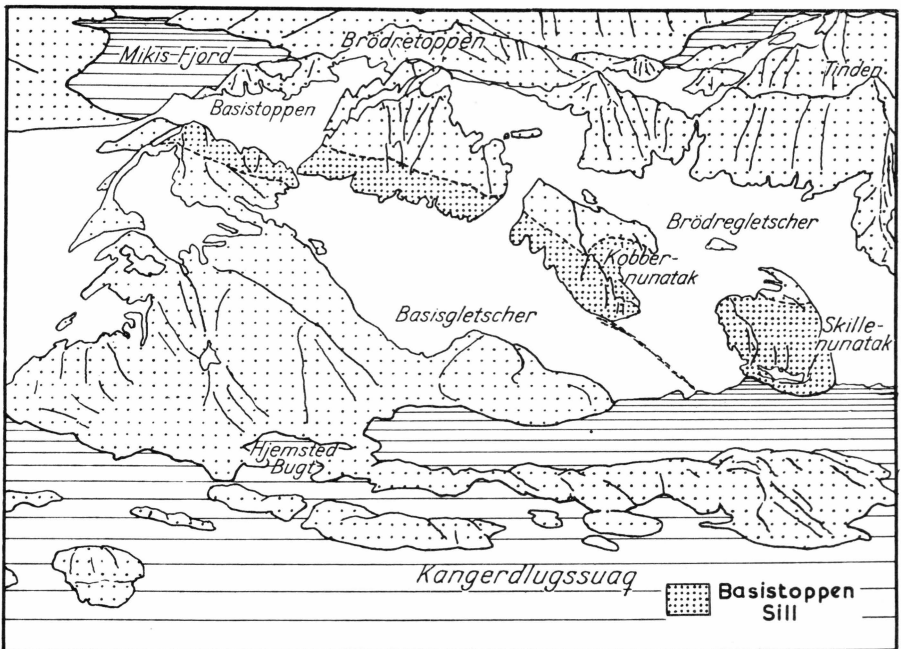


Fig. 2a & 2b. Oblique air-view and sketch of area, showing position of Basistoppen Raft (Part of a Watkins air photograph from 10,000 feet).

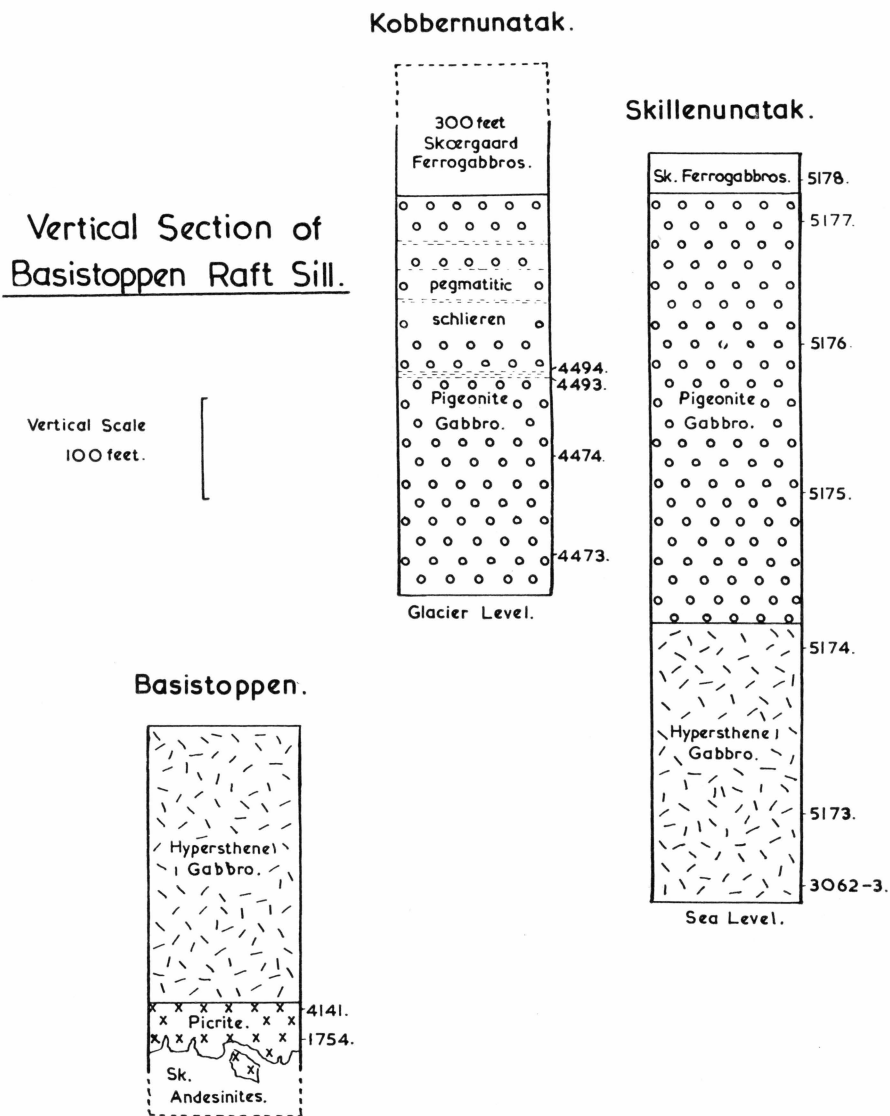


Fig. 3. Vertical sections of the Basistoppen Raft Sill, showing thicknesses of the different sill units and relative heights in the sill of the described rocks.

face of Kobbernunatak, there are several thin sheets of pegmatite containing augite and plagioclase crystals up to 3 cm in size. These sheets in some cases consist of a coarse gabbro below and a thicker, rusty weathering gabbro above.

The upper part of the sill consists of a quartz gabbro without the characteristic spotting of the lower part and contains ore; in hand specimen, it is not unlike the average Skærgaard gabbro at this level.

The upper junction of the sill against Skærgaard ferrogabbro was crossed on traverses of Kobbernunatak and Skillenunatak but could not be precisely defined in the field, despite generally excellent exposures. Examination of thin sections, however, has revealed essential differences between the rocks belonging to the sill and those of the Skærgaard intrusion, enabling the position of the junction to be defined within narrow limits.

2) Petrography.

From over twenty well located specimens, nine examples representing increasing height in the sill have been chosen to illustrate the systematic variation present in the Raft rocks. The approximate heights of these rocks in the sill are indicated in Figure 3 and their modes and the composition of their minerals are given in Table 1.

a) Picrites.

Of two rocks chosen as examples of the basal olivine-rich rocks the lowermost, 1754¹, contains 43 % by volume of equidimensional olivine crystals, averaging 1 mm in diameter, poikilitically enclosed by plagioclase and augite. Minute euhedral crystals, about 0.06 mm across, of a black opaque spinel occur within both the olivine and the other minerals.

The olivine and augite are unzoned, whereas the plagioclase exhibits slight normal zoning.

The second picrite, 4141, representing a slightly higher horizon in the sill, differs significantly from E.G. 1754 in containing orthopyroxene and a lower percentage of olivine.

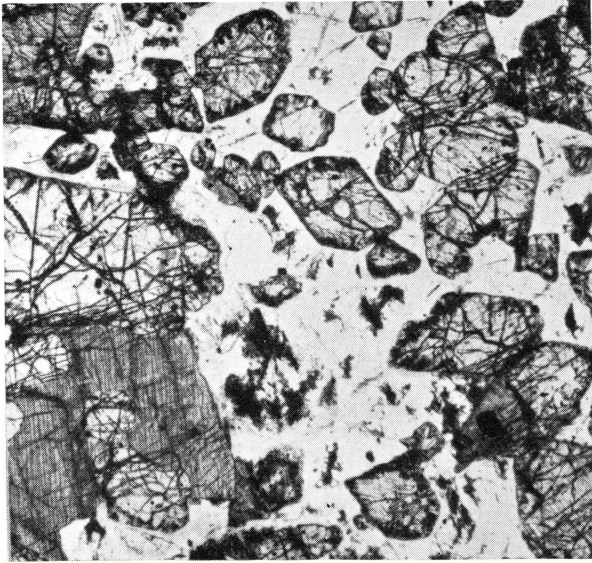
Idiomorphic olivines occur in rounded equidimensional crystals about 1 mm in size. A primary euhedral black spinel is found included in the olivine which also contains magnetite dust along cracks in the crystal and also round the crystal margins.

The two pyroxenes have a granular subidiomorphic habit, modified occasionally in the case of the augite to a subpoikilitic texture towards olivine crystals.

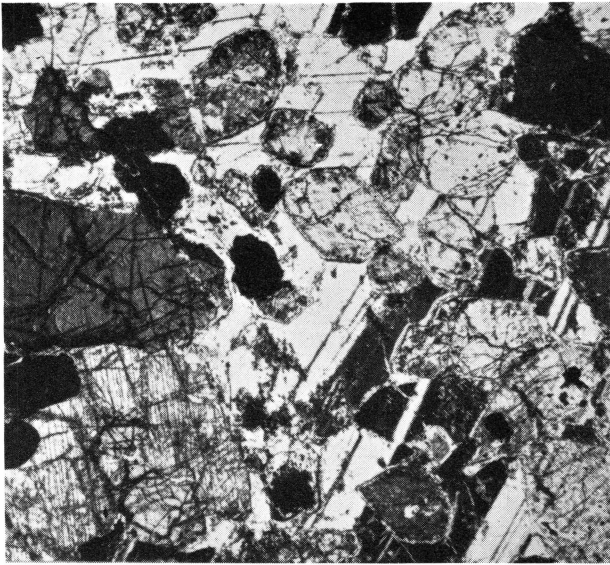
The augites average about 1 mm in length. In common with all other augitic pyroxenes in the sill, they exhibit striae parallel to (001), giving the characteristic herring-bone appearance in (010) sections of (100) twins.

Orthopyroxene occurs in large idiomorphic prismatic crystals averaging 2 mm in length. It contains narrow lamellae of uncertain

¹ Numbers refer to the collection of East Greenland rocks housed in the Department of Geology and Mineralogy, Oxford.



A



B

Fig. 4. Picrite. 1754. Basisgletscher. (Magnification X 19). A. The olivine accumulate. Some olivines contain chrome-spinellids of early crystallization. Poikilitic augite in lower left-hand corner. B. The same, under crossed nicols, showing the poikilitic habit of the plagioclase.

extinction parallel to *c*; these are believed to be due to exsolution. The crystals are traversed by irregular veins of serpentine, the first stage in the alteration to bastite which is commonly complete in the sill rocks.

Plagioclase, reduced in amount compared with E.G. 1754 remains poikilitic in habit towards the other major constituents.

This rock contains more late stage minerals. Biotite, strongly pleochroic from straw-yellow to deep tan, with 2V about 15°, an anisotropic opaque ore mineral—probably ilmenite, chlorite and a few crystals of apatite were the last minerals to crystallize.

b) Hypersthene-gabbros.

These rocks are found at a higher horizon in the sill where orthopyroxene, now largely altered to bastite, and augite are the only primary ferromagnesian minerals.

3062 (Fig. 5) is considered to be an average rock, containing three idiomorphic minerals: plagioclase and two pyroxenes.

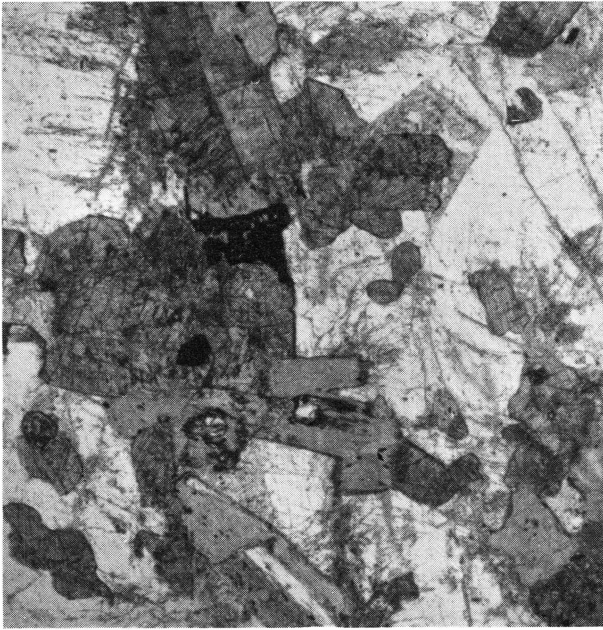
The plagioclase, up to 3 mm in size, exhibits strong normal zoning at the margins of crystals so that the rims are optically continuous with the alkali feldspar of micropegmatite which is present interstitially in small amount.

Fresh augite occurs in idiomorphic crystals up to 2 mm in size; crystal outlines are modified at contact with plagioclase crystals. Simple twinning on (100) is present in practically every augite crystal in the rock.

Rather less abundant are the bastite pseudomorphs replacing prismatic orthopyroxene crystals and enclosing small anhedral granules of ore and leucoxene.

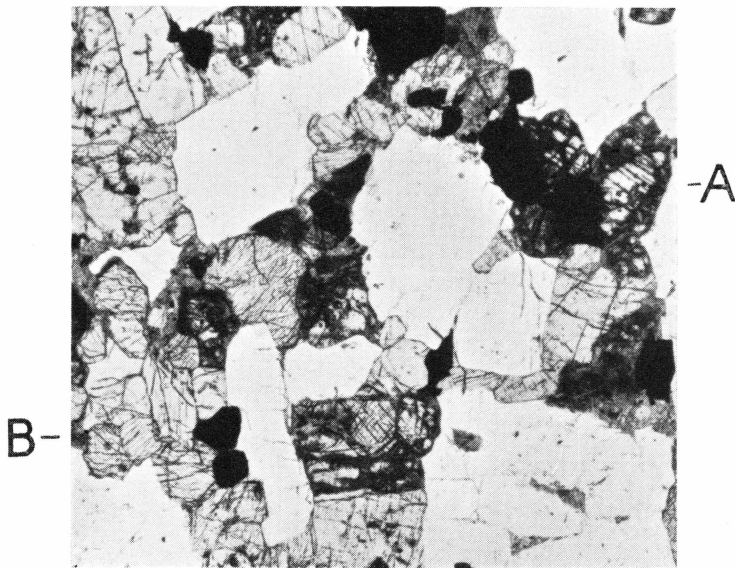
Some titaniferous iron ore occurs sparingly in scattered areas of the thin section, often associated with a late-stage chlorite and a few crystals of apatite. Early spinel is absent. A microscopic examination of a polished specimen of the rock shows that the ore mineral is largely magnetite with thin ilmenite exsolution lamellae; the magnetite also contains discrete corroded ilmenite crystals, possibly the first ore mineral to crystallize.

3063 is from a similar horizon to the above. Although of a finer grain size, it exhibits the same mineral assemblage and texture, the latter modified by a marked igneous lamination of the tabular plagioclases and the prismatic augites. There is a narrow band, parallel to the lamination, consisting of large orthopyroxene crystals up to 3 mm in size, in which small euhedral plagioclase crystals are embedded. The centres of the large orthopyroxenes have escaped the common alteration to bastite and were used to obtain measurements of 2V and hence the composition (En 72 %) of the orthopyroxene at this height in the sill.



A

Fig. 5. Hypersthene-Gabbro. 3062. Skillenunatak. (Magnification X16). A core of unaltered orthopyroxene in bastite is seen at A.



B

Fig. 6. Pigeonite-Gabbro. 4474. Kobbernunatak. (Magnification X20). Pigeonite can be seen altering to chlorite at A and BB.

c) Pigeonite-gabbros.

These rocks form approximately the top half of the sill. A pigeonite-gabbro 4474 (Fig. 6), from about the middle of the sill, contains four primary phases of simultaneous crystallization: plagioclase, augite, pigeonite and iron-ore.

The plagioclase occurs in equidimensional crystals up to 2 mm in size and is normally zoned, strongly at the margins, where it is optically continuous with alkali felspar present in a little interstitial micropegmatite.

The augite is found in fresh crystals of the same size as the plagioclase. Sometimes it is idiomorphic towards the latter but more commonly it has its crystal outlines determined by the shape of the plagioclase.

The pigeonite is now largely replaced by a highly birefringent chlorite which sometimes preserves the simple (100) twinning and (001) parting of a clinopyroxene. The crystals are rounded, up to 1 mm in size and often enclosed in the augite. (Unaltered cores have a $2V\gamma$ about 11° , with the optic plane perpendicular to (010).

Titaniferous iron ore occurs in rounded grains up to 1 mm in size.

A little late stage chlorite, pleochroic from yellow-green to blue-green and with low birefringence, occurs in patches and as veins in the plagioclase.

A rock from a higher horizon in the pigeonite-gabbros, 5176, contains the same primary minerals and possesses a similar texture. The maximum size of the strongly zoned plagioclase is again about 2 mm, the pyroxenes being somewhat smaller. Pigeonite, completely pseudomorphed by a chlorite is present in greater amount than the augite and sometimes encloses crystals of the latter, thus reversing the textural relationship of 4474. Microscopic examination of the polished surface of the rock reveals discrete separate crystals of ilmenite and magnetite, the latter containing exsolution lamellae of ilmenite.

In this rock hydrothermal quartz is found interstitially in large grains in addition to micropegmatite of earlier crystallization.

The mineralogy of a rock from the highest preserved part of the sill, 5177, suggests that it may represent an horizon near to the original top of the sill. The same minerals as those in 5576 are again present. In addition apatite and micropegmatite are present in abundance.

3) Skærgaard ferrogabbro overlying Raft sill.

A rock, E.G. 5178, collected immediately above 5177 on the Skille-nunatak traverse is considered to belong to the Skærgaard complex on the following grounds:—

1. The rock contains a yellow iron-rich olivine.
2. The composition of its clinopyroxene has been estimated optically and shows it to be very rich in Fe (see Table and Figure 7).
3. There is a greater quantity of ore. In these respects it is similar to the Skærgaard rocks at this level.
4. The rate of cryptic variation (see below) in the primary phases of the sill would have to be much increased to result in a rock of this nature at this level.
5. There are some hundreds of feet of rock of similar and more acid types overlying the sill on Kobbernunatak; they would appear to be too thick to have been produced by fractionation within the sill alone, and must owe their existence to the extreme fractionation in the larger Skærgaard gabbro complex.

4) The Raft Pegmatites.

Several sheets of pegmatite, averaging six or eight feet in thickness are exposed to view on the nearly vertical west face of Kobbernunatak in the upper third of the sill. They form parallel schlieren dipping parallel to the mapped boundaries of the sill. A prominent pegmatite about ten feet in thickness is exposed on the nunatak about 50 feet above the glacier; it is composite in character, the upper eight feet having rusty weathering. Collections from fallen blocks were made of the average rock, the lower non-rusty weathering pegmatite and the upper rusty pegmatite.

The following is a discussion of the petrography and probable origin of the specimens of pegmatite collected, which is believed to be representative of the several that are visible in the rock face. Accurate modes have not been determined due to the coarse nature of the rocks. The average rock in contact with the lower half of the pegmatite is similar in mineralogy to the sill rocks of this horizon, though containing less chlorite after pigeonite. It differs also in being variable in grain size. The contact with the pegmatite is not sharp, large plagioclase crystals of the pegmatite being continuous with those of the normal sill rock at their junction.

In the field a gradational contact was observed between this lower variety of pegmatite (4493), and the rusty-weathering pegmatite above (4494). Both contain large augites and normally zoned plagioclase crystals up to 3 cm in size. The upper rusty pegmatite has more modal iron-ore, apatite, quartz and micropegmatite; in both varieties the latter contains rod-like crystals of quartz possibly paramorphing tridymite. There is a variation in the properties of the augite of the above rocks (see Figure 7). The data are compatible with a ten per cent enrichment in iron of the

augite of the upper rusty pegmatite relative to the lower part of the pegmatite, or a smaller enrichment in titanium (SEGNIT, 1953).

The mineralogy and coarse texture of the pegmatite suggest that it crystallized late from a volatile-rich fraction of the sill magma, the upper rusty part of more extreme composition being the last to crystallize.

No crystals of olivine, orthopyroxene, pigeonite or identifiable pseudomorphs after these materials are present in the pegmatites and quartz and iron ore are present in increased amount relative to the average rock of this horizon.

5) Petrology and cooling history of the Basistoppen Raft Sill.

The olivine of the picrite (1754) has a composition of Fa_{17} ; the spinellid is opaque and strongly magnetic, but gives a strong chromium reaction in the borax bead test. The composition of the olivine is comparable to that of early crystallized olivine in the Stillwater complex (Fa_{14}) (PEOPLES, 1936), the Rhum ultrabasic complex (Fa_{14}) (BROWN, 1954) and the Shiant Isle sill (Fa_{17}) (JOHNSTON, 1953). The spinel appears similar to that found in the Rhum ultrabasics. These two primary minerals are enclosed by poikilitic plagioclase and augite, which have not the extreme composition of bytownite and diopside occurring as primary phases in ultrabasic rocks. The texture and mode of this rock is compatible with an accumulation of early crystallized olivine and spinel crystals. This rock is the lowest preserved horizon of the sill.

The higher of the two basal picrites (4141) is remarkable for containing idiomorphic crystals of four minerals, spinel, olivine, orthopyroxene (En_{75}) and augite. The olivine crystals are not obviously resorbed, although their edges are rimmed with magnetite grains of late magmatic origin. The texture indicates that primary crystals of the two pyroxenes and olivine were accumulating together. Plagioclase, biotite, ilmenite and apatite are of later crystallization.

At a higher horizon in the sill (3062—3) olivine has ceased to crystallize from the magma. The texture of the average rock indicates simultaneous crystallization of plagioclase, augite and orthopyroxene and rather later ore, which has taken the place of the chrome-magnetite.

The three silicate phases exhibit slight differences in composition from the lower rocks (see Table 1), such as would be expected from some degree of crystal fractionation.

In one rock from this horizon (3063), which contains the same primary minerals of compositions identical with those in 3062, there is a pronounced igneous lamination: a narrow band parallel to the lamination contains large orthopyroxenes enclosing small crystals of plagioclase.

These composite grains may have fallen or been carried by local currents through the magma above; the accompanying igneous lamination favours the latter hypothesis.

Above this horizon there is no textural evidence of gravity settling of the dark minerals, whose modal proportions remain remarkably constant from this horizon to one near the top of the sill. Also there is no evidence for the existence of convection currents above this level as the overlying rocks are unlayered and homogeneous apart from pegmatitic schlieren.

This being so, the systematic compositional variation upwards found in rocks above this horizon, i.e. roughly the upper two thirds of the sill, can most easily be explained in terms of upwards migration of interstitial liquid when lower rocks were nearly crystallized. The pegmatites are believed to represent levels at which these late stage volatile rich liquids have been partially trapped, causing crystallization to proceed at lower temperatures so explaining the different composition of minerals found in the pegmatites.

The upward cryptic variation is displayed by all the primary silicate phases. The plagioclases have less calcic cores, the higher they occur in the sill.

Primary orthopyroxene gives way to primary pigeonite without exsolution lamellae at an horizon roughly half way up the sill and at a composition of about En_{72} . This is in good agreement with Hess's value of En_{73} at which composition he states the change to a primary monoclinic form occurs in basic rocks (HESS and PHILLIPS, 1940). On slow cooling or thermal metamorphism the monoclinic form may itself invert to orthopyroxene with lamellae of more calcic clinopyroxene. That the pigeonite has not inverted in the sill may be due firstly to relatively quick cooling in a sill estimated as about 800 feet thick, and secondly to the fact that the mineral is found fresh only in the centre of the sill (4474) where the degree of thermal metamorphism consequent on immersion in the Skærgaard gabbro may not have been intense.

The pigeonite of 4474 for which optics have been determined, has a $2V\gamma$ of 11° with the optic axial plane perpendicular to (010), indicating 8 to 10 atomic per cent Ca.

With increasing heights in the sill there is also continuous variation in the values of $2V$ and β of the augites. Too much reliance should not be placed on the quoted compositions based on Hess's curves (HESS, 1949) and later modified by MUIR in the hedenbergite range (MUIR, 1951), as recent work by SEGNET (1953) has shown that small amounts of titanium, aluminium and ferric iron affect the values of $2V$ and β markedly. However, an hypothesis of continuous enrichment in ferrous

iron in the upwards sequence of the sill rocks would explain the optical variation (see Fig. 7).

The highest sill rock collected shows a marked increase in the modal amount of quartz and micropegmatite, as well as representing the extreme of cryptic variation apart from the pegmatites. It has probably crystallized from a magma considerably enriched in acid interstitial liquid which migrated upwards.

No chilled margins to the Raft sill are preserved, so that the composition of the parental magma is not known. However, the course of

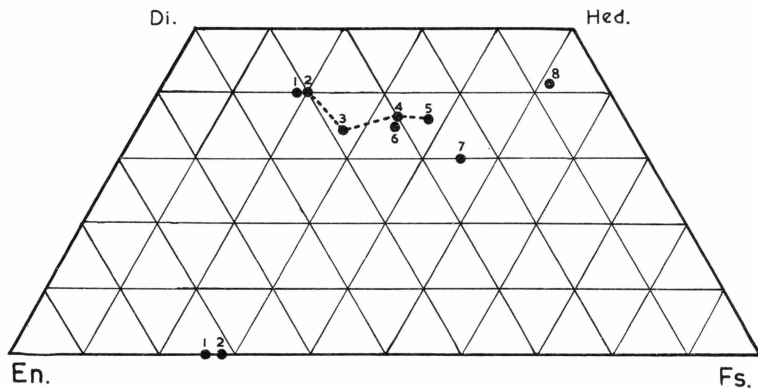


Fig. 7. Pyroxene compositions of Basistoppen Sill rocks, based on optical data. 1. Orthopyroxene and augite of Picrite (4141). 2. Orthopyroxene and augite of Hypersthene gabbro (3062). 3, 4, 5. Augitic clinopyroxenes of Pigeonite-Gabbros, respectively (4474, 5176, 5177). 6. Augite from lower part of pegmatite, at approximately same horizon in sill as 5176 (4493). 7. Augite from upper rusty weathering part of same pegmatite (4494). 8. Ferroaugite of Skærgeard ferrogabbro overlying sill (5178).

The dashed line defines the trend in composition of the augites of the normal sill rocks, taken in order of ascending height in the sill.

crystallization parallels closely that of the Palisades sill, the parental magma of which was a slightly undersaturated basalt, and which contains a small percentage of olivine phenocrysts in its chilled margin.

The Raft sill, like the Palisades Sill, defines a course of crystallization in which effective removal of a limited amount of olivine by gravity settling from the magma is followed by the crystallization of two pyroxenes and the production of a silica-rich but not alkaline residual liquid.

Similar olivine-bearing, pigeonite dolerite sills are mentioned as occurring in the Svartenhuk peninsula, West Greenland (ROSENKRANTZ et al., 1942).

6) Comparison with Palisades Sill.

Both in field characters and in mineral constituents there is a remarkably close analogy between the Basistoppen Raft sill and the Palisades Sill described by WALKER (1940), from whose account this comparison is made, supplemented by the author's microscopic examination of several thin sections of rocks from the Palisades Sill.

The thickness of the two sills is roughly the same; the Palisades has a thickness of about 1000 feet, whereas the Raft has a thickness of at least 800 feet. Both sills possess a gravity accumulated olivine layer near their base, and a prominent feature of the upper parts of both sills in the field is the presence of numerous pegmatitic schlieren.

The mineralogical resemblances are no less striking. Olivine in both sills is not found above the olivine layer except that in the Palisades Sill it is found sparingly as phenocrysts in the lower and upper chilled margins, which are not preserved in any of the Raft inclusions. Idiomorphic crystals of olivine in the olivine layer of the Palisades Sill show marked resorption and occur in two generations of which the larger crystals have approximately the same composition (Fa_{20}) as those of the Raft, Fa_{17} . In the Raft there is no obvious resorption and there are crystals of one generation only. In the Hængefjældet sill (see below) the habit of the olivine is identical with that in the Palisades Sill, and the variation is possibly due to different rates of accumulation of the olivine layer.

The compositional range of the plagioclase, apart from that occurring in pegmatites, is from An_{70} to An_{48} in the Palisades Sill and from An_{76} to An_{52} in the Raft, measured in both cases on the cores of zoned crystals.

Augite is present at all horizons in both sills. No data on the range of variation in the clinopyroxenes of the Palisades Sill are given by WALKER. However, the optical properties of an augite from an horizon just above the olivine layer of the former ($\beta = 1.699$, $2V = 47^\circ$) compare very closely with those of augites from a similar horizon in the Raft, while there is systematic normal variation in the composition of the augite throughout the sill (see Fig. 7).

Orthopyroxene has a similar distribution in both sills, being confined approximately to the lower third in each. Values for $2V\alpha$ from 69° to 71° are quoted for the orthopyroxenes of the Palisades Sill. Using the latest curves (HESS and PHILLIPS, 1940) this would indicate a composition of En_{75-76} . The former figure compares closely with a compositional range of En_{75} to En_{72} found in the orthopyroxenes of the Raft sill.

In the rocks of both sills hypersthene gives place upwards to primary pigeonite, at a composition close to En_{73} , the figure quoted by

Hess (1940) for this change in the primary ferromagnesian pyroxenes. The pigeonite in the Raft has suffered widespread alteration to chlorite, making a detailed study of any cryptic variation impossible. WALKER records much variation in the optical properties of the pigeonite of the Palisades sill, but does not record any systematic variation.

The ore minerals of the Palisades Sill consist of a euhedral spinel of early crystallization found in the chilled margins and the olivine layer and a titaniferous iron ore occupying higher horizons. This is closely paralleled in the Raft.

Apatite is ubiquitous in both sills, but in the Palisades Sill it never reaches the maximum of 4% found in the highest preserved rock of the Raft.

Micropegmatite is widespread in both sills, increasing in amount upwards in each case.

Deuteric activity (using that term in its wide sense to include late stage magmatic crystallization and subsequent hydrothermal alteration) is present to about the same degree in both sills. The Hængerfjældet and Hammersdal sills exhibit a much greater degree of alteration (see below).

III. SILLS CUTTING THE COUNTRY ROCKS

1) Hængefjeldet Sill.

This sill, which was not visited by the 1953 expedition, has a thickness of about 600 feet and is intrusive into Tertiary lavas. It occurs in the steep limb of the later crustal flexure, so that the sill now has a dip of 50° seawards, (WAGER and DEER, 1939).

The lowest rocks collected are picrites passing upwards through olivine gabbros into hypersthene gabbros.

Pegmatitic material is found, some occurring low down in the sill; the latter may have been formed by hybridisation with inclusions rather than from segregations of late-stage volatile rich magma as is believed to be the case with the pegmatites of the Raft.

An inclusion of andesine-amphibole granulite, containing areas of quartz probably originating from gneiss, was collected about one third of the way up the sill. It is not known whether this inclusion gave rise to any hybrid material.

The rocks of the Hængefjeldet sill exhibit more extensive late stage alteration than the Raft; this is described below.

A short mineralogical description of the sill follows.

In this sill olivine occurs in the basal picrite and also in an olivine gabbro higher up. The olivine in the picrite (2133) occurs in crystals of two generations. The larger, up to 3 mm in size, composition Fa_{18} and unzoned, are often skeletal in habit, while others which are idiomorphic in character have irregular margins. The smaller crystals, about 0.1 mm in size, are frequently embedded in the clinopyroxene of the rock; their small size makes determination of 2V impossible. Some grains of olivine of a size intermediate between the above also have a composition of Fa_{18} . The picrite 2133, contains a total of 41% by volume of olivine. Olivine persists in rocks above the basal accumulate, for example in 2131, which has undergone considerable alteration but in which tremolite pseudomorphs after olivine can be recognised.

Plagioclase occurs as an idiomorphic mineral in all the sill rocks, in contrast to the Raft where it is poikilitic in habit in the picrites. Normal zoning can be seen wherever there are fresh crystals of plagioclase, the cores of which are rather calcic in composition. For example,

the plagioclase of the picrite 2133 has a compositional range of An_{86} to An_{60} , and the plagioclase of 2128 from the top of the sill, An_{80} to An_{45} . Another plagioclase from an intermediate position in the sill (2122) has cores of composition An_{86} . The composition of the plagioclase is close to that of the most calcic plagioclase found in the ultrabasic rocks of Rhum and the Stillwater complex.

Augite is also present throughout the sill, and exhibits very little change in optical properties with height in the sill. The augite of the picrite has $2V\gamma = 51^\circ$ and $\beta = 1.693$, whereas the augite of the uppermost rock 2128, has $2V\gamma = 48^\circ$ and $\beta = 1.696$. The former figures indicate a composition of around $Ca_{40}Mg_{42}Fe_{18}$, and the latter figures are compatible with a 4% enrichment in iron, using Hess's curves for the two variables.

Olivine is replaced upwards in the sequence by orthopyroxene which is never seen fresh in the Hængefjældet sill, but is identified by bastite pseudomorphs, which are subordinate in amount to the augite. The mode of 2122, a relatively fresh rock from the upper part of the sill is:—

Plagioclase	67 %	by volume
Augite	24 %	„ „
Orthopyroxene	6 %	„ „
Ore	3 %	„ „

The ore mineral of the Hængefjældet sill, which is more common in the upper part, is largely titaniferous, altering partly to leucoxene.

Apatite is a rather rare accessory also more common in the upper horizons.

It is apparent from the above that the amount of cryptic variation in the sill is very small, far less than that obtaining in the Raft sill. The only major mineralogical variation is the change upwards from olivine to orthopyroxene, which appears to be a delicately balanced change, taking place early in the crystallization of both sills.

2) Hammersdal Sill.

This sill, again not visited in 1953, is similar in thickness and field characters to the Hængefjældet Sill, described above. It is similarly involved in the steep limb of the crustal flexure and dips seaward at about 50° .

At the base of this sill there is a picrite, largely serpentised where it is in contact with the Skærgaard gabbro; the subsequent course of crystallization is similar to that of the Hængefjældet sill.

This sill has also suffered a considerable amount of alteration, secondary calcite and epidote veins being common near the top.

IV. LATE STAGE PHENOMENA

The minerals of late formation indicate two phases in the final cooling history of the sills.

The first is late magmatic crystallization from a volatile rich silicate melt, resulting typically in the formation of patchy but ubiquitous micropegmatite and uralite. These add on to, rather than replace, primary plagioclase and augite. Two other minerals of late magmatic crystallization, which are, however, restricted to the picrites, are biotite and ilmenite, present in the same rock as the primary chrome-magnetite.

Hydrothermal processes are characteristic of the second group of late stage phenomena. In the upper part of the sill there are large crystals of quartz in interstitial relationship to micropegmatite fringing plagioclase crystals. The crystallization of quartz alone from a silicate melt after the latter has precipitated a quartz and alkali felspar eutectic is unlikely. This quartz with associated chlorite is believed to have been precipitated from hydrothermal solutions succeeding the magmatic stage. Hydrous decomposition products of the primary minerals were also formed during this hydrothermal phase. Olivine, plagioclase, orthopyroxene and pigeonite alter respectively to talc plus ore, sericite, bastite containing granules of ore and leucoxene, and a highly birefringent chlorite sometimes preserving simple twinning on (100) and a (001) parting, of the original pigeonite.

Alteration is more extensive in parts of the Hængefjældet and Hammersdal sills. These two sills, intruded into the Tertiary lava series, were involved in the steep limb of the East Greenland crustal flexure, which was later intruded by the dense dyke swarm (WAGER and DEER, 1938) and (WAGER, 1947). The operation of stress in this area coupled with heat due to prolonged minor igneous activity may be invoked to explain the extensive alteration, amounting to a regressive metamorphism. In the lower olivine bearing rocks, olivine and plagioclase are now commonly replaced by tremolite and chlorite respectively. This

involves the reciprocal transfer of calcium and magnesium or iron; the chlorite forms at the expense of the plagioclase only, no doubt because the trivalent aluminium is not so free to migrate. Nests of small crystals of tremolite show the former presence of olivine in rocks where the texture has been obliterated. In the upper olivine-free rocks, plagioclase has sometimes altered to epidote and oligoclase, again obliterating the original texture. Even in the most altered rocks, the areas of augite have remained fresh, giving a characteristic spotted appearance.

V. RELATIONSHIPS OF SILLS TO THE SKÆRGAARD INTRUSION

The large size of the major mass of the Raft sill and the absence of any original country rock of the sill is surprising, but evidence of the earlier age of the sill is provided by the thermal metamorphism of the margin of the inclusion on Nunatak I and injection of the sill by Skærgaard material on Basistoppen.

The lowest preserved sill rock on Nunatak I is an olivine-free hypersthene-gabbro. At the contact with the Skærgaard ferrogabbro, the sill rock is a granulite of about 0.05 mm average grain size, with the same mineral assemblage as the normal sill rock.

On Basistoppen the lowest picrites of the sill are veined by andesinite, a Skærgaard rock type from the upper part of the unlayered layered series, and detached blocks of picrite are found in the andesinite.

At the head of Basisgletscher similar andesinite veins inject higher horizons of the sill, and slight granulitisation of the hypersthene-gabbro of the sill occurs adjacent to the andesinite.

Where Skærgaard gabbro is in contact with the basal picrite of the Hammersdal sill the olivine of the sill has altered to a pale serpentine rather than to tremolite or talc, which are the more usual products of hydrothermal alteration in this sill.

The Raft is clearly an inclusion in the Skærgaard complex. Against its being a cognate inclusion, e.g. a foundered block of Upper Border Group material, there is the negative evidence of a non-plutonic mineralogy such as the presence of pigeonite, the very small extent of exsolution in the orthopyroxene and augite and a relatively small grain-size.

For its being an accidental inclusion of part of a sill, there is the detailed similarity in mineralogy, texture and composition to other known basic sills of the same dimensions as well as a general similarity in appearance to the two undoubted sills intruding the neighbouring basalts. These similarities coupled with the field evidence at the contacts detailed above make it impossible to ascribe any other origin to the

Basistoppen Raft material than that of a sill included in the Skærgaard complex.

An earlier age than the Skærgaard intrusion is indicated for the Hammersdal sill and is also likely for the Hængefjældet sill. The three sills belong to a phase of Tertiary igneous activity in the area, post-dating the lavas and antedating both the Skærgaard intrusion, and the later period of dyke formation and crustal flexure.

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