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THE BRITISH ARCTIC AIR-ROUTE EXPEDITION 1930—31

LEADER: H. G. WATKINS

THE SCORESBY SOUND COMMITTEE'S 2ND EAST GREENLAND
EXPEDITION IN 1932 TO KING CHRISTIAN IX.s LAND

LEADER: EJNAR MIKKELSEN

GEOLOGICAL INVESTIGATIONS IN EAST GREENLAND

PART I

GENERAL GEOLOGY FROM ANGMAGSALIK TO KAP DALTON

BY

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WITH 7 FIGURES IN THE TEXT AND 12 PLATES

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CONTENTS

	Page
Preface	5
I. Introduction	7
II. The Metamorphic Complex.....	9
(a) The Grey Gneiss — Acid to Intermediate Orthogneiss.....	10
(b) Plagioclase Amphibolites.....	11
(c) Metamorphosed and Injected Sediments.....	12
(d) Ultrabasic Masses in the Grey Gneiss.....	13
(e) Hypersthene Granite-Gneiss of Charnockite Affinities.....	14
(f) Basic Rocks of Charnockite Affinities and certain Garniteferous Granite-Gneisses.....	15
(g) Pegmatites.....	16
(h) Transgressive Sheets of Plagioclase Amphibolite.....	17
(i) Tectonics	18
III. Angmagsalik Granites and related Basic Rocks	20
IV. Late Sediments.....	22
(a) Kap Gustav Holm Series.....	22
(b) Kangerdlugsuak Series.....	25
(c) Kap Dalton Series.....	27
V. Tertiary Igneous Rocks.....	28
(a) Basalts.....	29
(b) Tuffs and Volcanic Agglomerates.....	34
(c) The Plutonic Centres.....	35
(d) Dykes and Sills.....	40
(e) Tectonics.....	44
Bibliography.....	45
Plates	47

PREFACE

It was my privilege to act as geologist to the late H. G. WATKINS' British Arctic Air-Route Expedition to East Greenland in 1930—31. The geological work was mainly carried out during the boat journey from Angmagsalik to Kangerdlugsuak in the summer of 1930, during journeys in the neighbourhood of the mouth of Sermilik in the winter, during the Ice Cap journey to Mount Forel in the spring of 1931 and during a boat journey with the help of the East Greenlander CARL ANDREASSON in the Angmagsalik fjords in the following summer. General accounts of the expedition have been given by H. G. WATKINS [20]¹⁾ and F. S. CHAPMAN [16] and as appendices I have given a preliminary statement of the geological results [19]. In a later paper I have also discussed some of the physiographic results [24].

In the summer of 1932 the Scoresby Sound Committee's 2nd East Greenland Expedition visited the Blossville Coast and Kangerdlugsuak. Partly as a result of the kind offices of Dr. LAUGE KOCH, the leader, Captain EJNAR MIKKELSEN, invited me to accompany the expedition as geologist. I was thus enabled to continue geological work at Kangerdlugsuak which had been begun two years earlier and to extend the investigations northwards as far as Kap Dalton. Accounts of the expedition by Captain MIKKELSEN have already appeared [21 & 22].

It should have been my pleasant duty to thank Watkins for giving me an opportunity of carrying out geological work under him in East Greenland, but in 1932 he lost his life during a second expedition to the same district. This is not the place to express my admiration for WATKINS as a traveller and leader, but it is appropriate that I should mention his attitude towards scientific work. Watkins had a great gift for understanding in a general way the significance of the various scientific problems which he or others came up against, and this made him sympathetic towards anyone endeavouring to carry out scientific work.

¹⁾ Numerals in parenthesis refer to the bibliography.

I made frequent requests for special facilities, and these were always granted providing, of course, that they did not run counter to the plans of the expedition as a whole. The expedition was not primarily scientific — using that word in its narrower sense — yet I received from WATKINS nothing but genuine help and encouragement.

To Captain MIKKELSEN and the Scoresby Sound Committee I tender my thanks for the opportunity they gave me of continuing investigations in East Greenland. In particular I should like to thank Captain MIKKELSEN for his great personal kindness and friendship and for all the help given me in the field and since in connection with publication.

During the expedition I had as assistants Dr. JENS J. JENSEN and my brother, Dr. H. G. WAGER, who accompanied me on all mountaineering expeditions where it was unsafe for one man to go alone. They also gave me every possible assistance on the various subsidiary journeys by boat or sledge, and with them I discussed many of the geological problems. It is with pleasure that I thank them for their valuable help.

I also wish to thank the Council of Reading University for giving me leave of absence from my duties there, and the Royal Society, the Trustees of the Cambridge Worts Fund, and the Research Board of Reading University for grants of money for apparatus used in Greenland or required in the subsequent working out of the geological results.

Reading University, 1934.

L. R. WAGER.

I. INTRODUCTION

The Angmagsalik District was not reached by Europeans till 1883 [Holm (3) and A. E. Nordenskjöld (4)] and the coast between Angmagsalik and Scoresby Sound was not travelled along and mapped till 1900 [Amdrup (6)]. The geological results of these expeditions were scanty. A few rocks collected during the one day stay at Tasiusak by Nordenskjöld's expedition in 1883 were described by Tornebohm [2] and observations and collections made by H. Knutsen the mineralogist on Gustav Holm's Expedition of 1883—85 were described by H. Knutsen and P. Eberlin [5]. This early work showed that the prevailing rocks of the Angmagsalik District were Archean gneisses and schists cut by later basic dykes.

During the Amdrup-Hartz expedition, Otto Nordenskjöld examined geologically the coast between Scoresby Sound and Kap Dalton. All the rocks were found to be basalts except for an interesting series of marine sediments at Kap Dalton. [Ravn (8) and O. Nordenskjöld (9)]. A collection of rocks made by C. Kruuse, a botanist who wintered in the Angmagsalik District during Amdrup's expedition, were also described by O. Nordenskjöld [7]. No rocks were collected in 1900 during Amdrup's boat journey along the coast from Kap Dalton to Angmagsalik, but it was observed that the characteristic scenery of the basalts, which persisted from Scoresby Sound to Kangerdlugsuak, there gave place to scenery characteristic of the Archean rocks, and this continued till Angmagsalik was reached [6].

Before the British Arctic Air-Route Expedition of 1930—31 and the Scoresby Sound Committee's 2nd East Greenland Expedition in 1932, the coast between Kap Dalton and Angmagsalik was geologically the least known of the whole of Greenland. What little was known was not such as to attract geologists from the rich fields further north which, since William Scoresby's voyage to Greenland in 1822, had rightly been regarded as of particular geological interest.

Geological result from both the British Arctic Air-Route Expedition and the Scoresby Sound Committee's 2nd East Greenland Expedition

are incorporated in the present paper, and at this point will be given an indication of the expedition to which the various results are due.

During the British Arctic Air-Route Expedition a detailed examination of the rocks of the Metamorphic Complex, a group formerly called the Archaean, was begun. Of especial interest were the highly metamorphosed sedimentary rocks and the igneous gneisses which resemble the Charnockite suite of India. Certain acid to basic, massive, plutonic rocks of possibly Caledonian age were found which help to fill in the interval between the period of formation of the Metamorphic Complex and the late Mesozoic or Tertiary Sediments which were found on the mountain above Kap Gustav Holm. This thin series of sediments, protected by overlying basalt lavas, contains the most southerly fossils yet known from Greenland. Near Kap Gustav Holm there also occurs the first of a series of five centres of plutonic intrusion, the others being at Kialinek, Nualik, Igdlitarajik and Kangerdlugsuak; these centres were proved to be Tertiary in age. Among the rocks of the plutonic centres alkaline types occurred including large independent intrusions of syenites which had not been met with previously in the North Atlantic Tertiary Province.

During the Scoresby Sound Committee's 2nd East Greenland Expedition, the area of Tertiary fossiliferous sediments discovered by Nordenskjöld at Kap Dalton was mapped, and the sequence of the beds established. A high range of mountains which has been called the Lilloise Group was found to consist of Tertiary plutonic rocks, among which were alkaline types: otherwise the coast from Kap Dalton to Kangerdlugsuak proved to be Tertiary basalts and dykes. At Kangerdlugsuak a thin sedimentary series was found underlying the Plateau Basalts and the work of mapping and collecting from the complex Tertiary intrusions of Kangerdlugsuak was continued.

II. THE METAMORPHIC COMPLEX

The high mountain belt [Plate 1, fig. 1 and 2] which lies between Angmagsalik and Kangerdlugsuak is largely formed of gneisses and schists [see the maps, Plates 11 & 12]. There is little doubt that these rocks are Pre-Cambrian in age; their metamorphic grade is high and their strike is dominantly WNW. to ESE., that is at right angles to the strike of the Caledonian folding further north. The only definite fossil evidence of their age comes, however, from Kap Gustav Holm, where sediments which are either late Mesozoic or Tertiary rest unconformably on the gneisses. For the gneisses and schists called Archaean by Knutsen [5] and Nordenskjöld [9] it is here proposed to use the name Metamorphic Complex in order to avoid any definite implications as to their age, and at the same time to signify the varied rock types which make up the group.

In the field the prevailing unit in the Metamorphic Complex was given the name "grey gneiss", a term frequently used by Nordenskjöld in describing apparently similar rocks at Scoresby Sound. There is evidence, definite in some cases but in other cases open to doubt, which enables the age of certain of the other units building up the Metamorphic Complex to be determined relative to that of the grey gneiss. Thus the grey gneiss encloses masses of plagioclase amphibolite and ultra basic rock in a way that suggests that they are blocks of earlier rocks caught up in the grey gneiss. Intensely altered and injected sediments also occur floating as huge rafts in the grey gneiss, and these too must be earlier in age.

Another group of rocks with Charnockitic affinities is shown on the maps (Plates 11 & 12), but the age of these cannot at present be definitely determined relative to that of the grey gneiss. Some evidence, however, is given below for the view that they are intrusions of somewhat later age.

Certain transgressive pegmatites of the Angmagsalik District, and also certain transgressive plagioclase amphibolites which occur between Kangerdluguatsiak and Steenstrup's Braer are definitely later than the grey gneiss.

This attempt at a rough chronology is put forward with the full realization of the insecure foundation on which it is based. There are two main causes for doubt. In the first place the grey gneiss is to some extent variable in composition and it may also be of variable age. Secondly, there are occasional fragments of evidence which suggest that there was more than one period when the grey gneiss was capable of easy viscous flow separated by periods when fracture occurred. For instance, there is some indication that basic material was injected into the grey gneiss as extensive sheets during a period when the grey gneiss was capable of fracture and that the basic material became slightly injected by grey gneiss during a subsequent period of partial refusion of the latter. The usual reading of the field evidence in such a case points to the plagioclase amphibolite being earlier than the grey gneiss, while actually all that can legitimately be deduced is that the plagioclase amphibolite occupied its present position before the latest period of flow of the grey gneiss.

(a) The Grey Gneiss — Acid to Intermediate Orthogneiss.

In hand specimens of the grey gneiss quartz, feldspar, hornblende and biotite can usually be detected. The feldspar and quartz are present in about equal amounts, and the conspicuous banding of the rock is due to variation in the relative amount of the melanocratic constituents. In texture the grey gneiss is granitic; the individual mineral grains usually reach about 0.5 cm in diameter and they show but little tendency to elongated forms.

Under the microscope¹⁾ the feldspar is found to be mainly plagioclase. In the gneisses of intermediate composition, which are the most abundant, the plagioclase is andesine, hornblende is dominant over biotite and, although quartz makes up from one third to one half of the rock, orthoclase is practically absent. This type might be described as hornblende-quartz-plagioclase gneiss. The more acid gneiss, for example that forming the islet off Eric the Red Is. (Plate 2, fig. 1) has up to 30 per cent of orthoclase or microcline and myrmekite is also present; the plagioclase is oligoclase, and biotite rather than hornblende is the melanocratic constituent. This type may be distinguished as granite gneiss, but there are gradations between the two. Sphene, iron ore and apatite occur sporadically in all types. So far, garnet, hypersthene, epidote and primary muscovite have not been found.

On the maps (Plates 11 & 12) undifferentiated gneisses are shown

¹⁾ A certain number of rock sections were cut in Greenland during the winter to check field determinations and increase the value of the work during the succeeding spring and summer. Six hundred sections have, since been examined.

by the same symbol as the acid to intermediate gneisses. Although the area thus indicated is large and its examination has been but cursory yet I believe that the greater part of the area will prove, on detailed examination, to consist of acid to intermediate gneiss.

There is a general similarity between the Metamorphic Complex in the Angmagsalik District and the Lewisian of Scotland, but on the whole the grey gneiss constituent of the East Greenland Metamorphic Complex has less normal igneous character than the gneisses of the Lewisian of comparable composition.

(b) Plagioclase Amphibolites.

Various dark granular rocks consisting mainly of hornblende and plagioclase may be grouped under the name of plagioclase amphibolite. In hand specimens garnet is frequently conspicuous; in other examples biotite can be detected with the help of a lens. The plagioclase amphibolites occur in the grey gneiss in the form of large rafts (Plate 2, fig. 1) or as angular or lenticular blocks or as small wisps (Plate 3, fig 2). Certain garnet-rich plagioclase amphibolites were found injecting the metamorphosed sediments. The plagioclase amphibolites nowhere occur in sufficiently large masses to be indicated separately on the small scale geological maps, but the area indicated as acid to intermediate gneiss includes plagioclase amphibolites amounting to about a fifth of the total bulk. Regarded broadly the proportion of these two constituents is fairly constant.

The grey gneiss can often be seen to have incorporated materials from the disintegration of the plagioclase amphibolites, and indeed the more basic grey gneiss can sometimes be proved to have originated by this mixing process. Arrested stages in the disintegration of bands of plagioclase amphibolites immersed in the grey gneiss were not infrequently observed (Plate 3, fig. 1).

During periods of stress when the grey gneiss yielded by flow, it often happened that the enclosed plagioclase amphibolite sheets yielded to the same stress by fracture (fig. 1 and Plate 3, fig. 1). The reverse of this — that is the flow of the plagioclase amphibolite and fracturing of the grey gneiss — was never noted, but extensive flow of both has in many places given strongly banded gneisses, such as that shown in (Plate 2, fig. 2). In the shelter of the blunt ends of the plagioclase amphibolite after fracture quartz-rich segregation products accumulated (fig. 1). The relationships between the grey gneiss and the plagioclase amphibolite bands are clear indications of the protracted time during which the grey gneiss was capable of relatively easy plastic flow. Some of the plagioclase amphibolite sheets (Plate 2, fig. 1) are so extensive and yet so

thin that it may be that they represent sheet-like injections of basic material into the grey gneiss. As mentioned above the fact that the grey gneiss is always found injecting the amphibolite, apparently proving that the grey gneiss is the younger, may be due to a subsequent period of reheating and stress during which the grey gneiss became the more fluid and injected the plagioclase amphibolite.

Microscopic examination has shown that dark green hornblende and plagioclase of medium basicity make up ninety per cent. of the

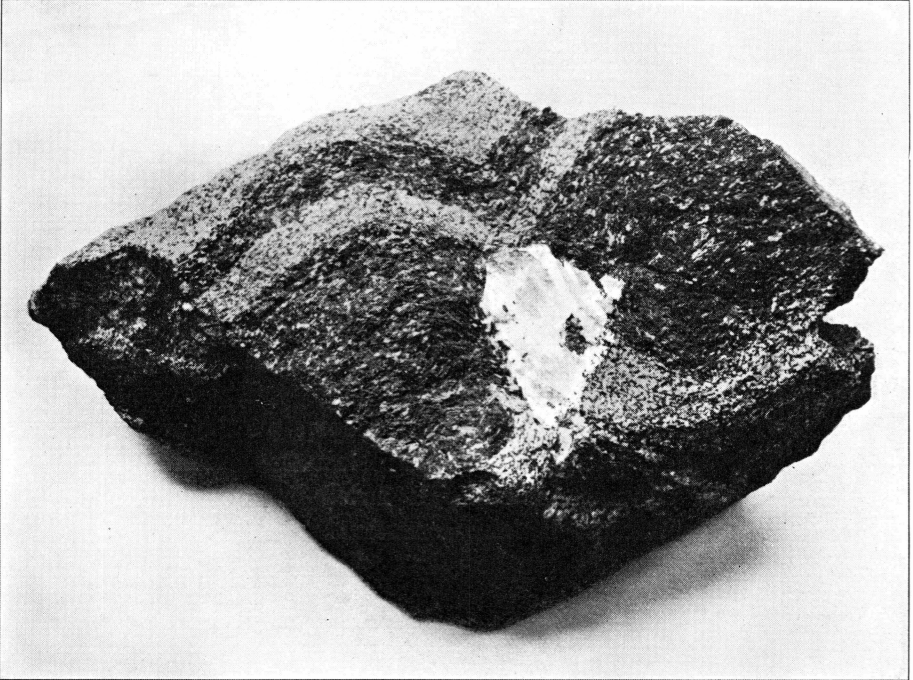


Fig. 1. Pegmatite between the ends of a broken amphibolite band, Isik Peninsula, Suportup Kangerdlua (Base Fj.), Specimen four inches high.

plagioclase amphibolites. Quartz is apparently always present but often only in small amounts, and sphene, iron ore and apatite are widely distributed as accessory minerals. In some of the plagioclase amphibolites, garnet, biotite, primary epidote and primary calcite have been found, but augite apparently does not occur. The structure of the rock is granulitic. No traces of any original igneous minerals or structures have been found.

(c) Metamorphosed and Injected Sediments.

Extensive zones of altered sediments have a wide distribution in the Metamorphic Complex. The principal localities have been indicated on

the map and are south of Kangerdlugsuatsiak, except for a small patch on Kraemers Ø in Kangerdlugsuak. In the field the sediments are conspicuous because the pelitic material usually weathers to a rusty brown colour, probably the result of the relatively rapid decomposition of widely disseminated iron pyrites. The stretch of coast from Kangerdlugsuatsiak to Kangerdlugsuak where sediments were not found is injected by an enormous number of Tertiary dykes. These, to a large extent, mask any differences there might be in the Metamorphic Complex, and it is possible that with further work sediments will be discovered in the region.

The dominant type of sediment seems to be pelitic, but this may be because it is more easily recognised from a distance. The pelitic material is now largely in the form of a muscovite-biotite-garnet schist sometimes with plagioclase porphyroblasts as at Kumiut, in Angmagsalik Fjord. Kyanite is frequently present in the Supertop-Kangerdlua and Kumiut regions. Fibrous sillimanite occurs at Kumiut and on Kujutilik. The non-fibrous type of sillimanite, probably the result of thermal metamorphism, occurs in the sedimentary material of Kraemers Ø at Kangerdlugsuak. These minerals indicate a high grade of metamorphism, a feature to be expected from the intimate association of the sediments with floods of grey gneiss.

Quartzites occur, but they are not conspicuous. Altered limestones were found at Supertop-Kangerdlua, and at the head of Kingorsuak, Angmagsalik Fjord.

The sediments are much injected by "lits" of the grey gneiss and its differentiates (Plate 4, fig. 1). In places they are also injected by garnet-bearing plagioclase amphibolites.

It is to be hoped that one day the distribution of the sediments may afford a clue to the processes of folding and igneous injection whereby the highly heterogeneous Metamorphic Complex has originated.

(d) Ultrabasic Masses in the Grey Gneiss.

Although occurring in only small amounts so that separate indication on the small scale maps is impossible, certain ultrabasic masses, which are found in the Angmagsalik District, are worthy of especial notice. They occur in the grey gneiss as irregular lenticles up to 300 yds. across or as a series of smaller masses strewn out along the strike of the gneiss. They stand up conspicuously as dark brown or dark green hummocks because they are resistant to ice erosion and the weather. From the boundary relationships, interpreted in the usual way, these ultrabasic rocks can be seen to be older than the grey gneiss in which they lie.

Large porphyroblastic enstatite crystals are frequently conspicuous

in hand specimens (fig. 2). In other types olivine and fibrous amphibole are most obvious. Intense metasomatic alteration for a foot or more along widely-spaced joints was found in all these rocks and is to be ascribed to solutions from the surrounding grey gneiss.

A microscopic examination of the homogeneous material away from the zones of particular alteration along the joints has shown that there are a number of minerals which, at the time of their formation, were

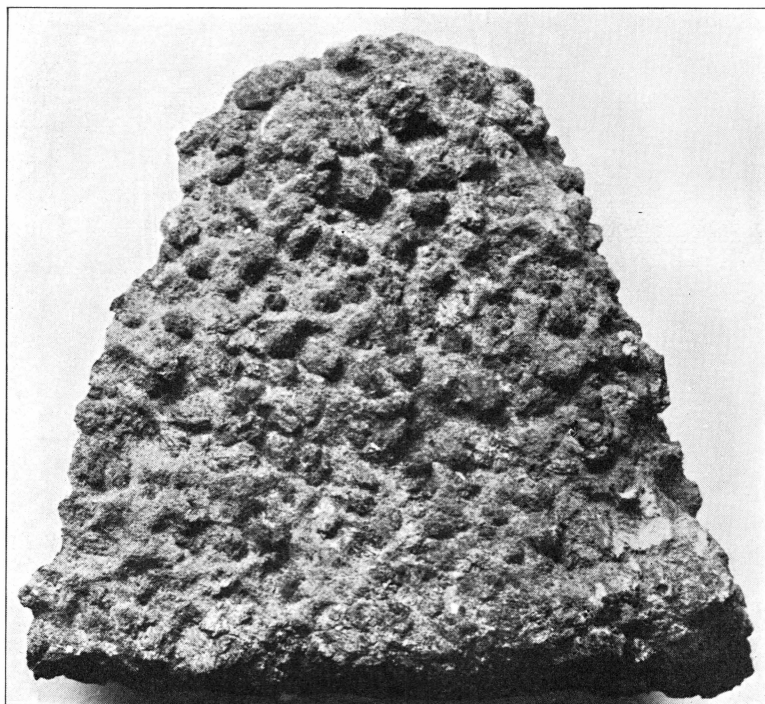


Fig. 2. Porphyritic enstatite crystals on weathered surface of ultrabasic rock, Navdlivit, Suportup Kangerdlua (Base Fj.), Specimen six inches high.

apparently in equilibrium with each other. A common type has, for instance, enstatite, hornblende, clinocllore, mica, calcite, iron ore and pyrites associated together, the mutual relationships apparently being due to the crystalloblastic properties of the minerals. In other specimens olivine is present in addition.

These rocks and their alteration products will be described in detail in a subsequent paper.

(e) Hypersthene Granite Gneisses of Charnockite Affinities.

In the Mount Forel area which lies north of Angmagsalik and seventy miles from the coast all the rocks were sufficiently dark in colour to be considered at first of basic composition. When fresh they were a

pinkish brown, and where weathered they were a darker chocolate brown. Examination with a lens shewed that the bulk of the rock consisted of pinkish brown felspar, bluish quartz and contrary to what was expected only 5—10 per cent. of ferromagnesian minerals. The rock was apparently a granulitised granite and recalled the well-known Charnockites of Peninsular India. Basic schlieren, usually only a few inches thick, were found abundantly and had an even distribution throughout the district examined. Streaks of coarser material consisting of large biotite crystals, pinkish brown felspar and bluish opalescent quartz were also frequent and are believed to represent partly crushed and granulitised pegmatites. The general strike of the basic schlieren and gneissic banding lies between W.S.W.—E.N.E. and N.W.—S.E.

As had been suspected, the Mount Forel rocks, under the microscope, prove to be hypersthene granites of Charnockite type. The quartz is full of minute acicular inclusions and the plagioclase has larger orthoclase inclusions with parallel orientation. Rarely there is a little interstitial orthoclase. The dark minerals are hypersthene, biotite, garnet, green hornblende, iron ore, and apatite. In the basic schlieren, augite also occurs. Reaction rims are a frequent feature. The general dark colour of the rock, as in the Charnockites of India, is to be ascribed mainly to the inclusions which crowd the quartz and plagioclase.

Hypersthene granites of similar type were also found in small amounts in Kangerdlugsuatsiak and a few miles south of Steenstrup Braeer.

(f) Basic Rocks of Charnockite Affinities and certain Garnetiferous Granite Gneisses.

Tornbolm in 1886 [2] described enstatite and hypersthene rocks from the Tasiusak district. The more acid hypersthene bearing rocks found at Tasiusak approach in composition the more basic members of the hypersthene granite gneiss of the Mount Forel area and they resemble them in colour and degree of granulitization. With the help of the microscope enstatite or hypersthene has been found to be characteristic of a large group. Within this group there is a considerable range in basicity, but quartz bearing types are not abundant except as contemporaneous pegmatite veins. There are also basic schlieren which are dark in colour because of an especial abundance of rhombic pyroxene, hornblende, and omphacite, and in some cases olivine.

In close association with the basic hypersthene bearing rocks are certain garnetiferous granite gneisses which pass into coarse garnet-biotite-quartz rocks. These rocks have not been shewn separately on the map because of their relatively small amount. They occur along

the southern border of the basic rocks of Charnockite affinities, and there is also a conspicuous band which runs between the large lake, north of Tasiusak and the summer settlement of Tasiusarsak. The garnetiferous granite gneiss was proved by the nature of the contacts to be later than the basic hypersthene rocks of Charnockite affinities. At first the garnetiferous granite gneiss was taken to be a variety of the grey gneiss and it was believed therefore that the grey gneiss was later than the Charnockite rocks. However, there seems to be no good reason for linking the garnetiferous granite gneiss with the grey gneiss. The Charnockitic rocks and the garnetiferous granite gneiss have both more definite igneous characters than the grey gneiss, and it is now tentatively suggested that they are intrusions into the grey gneiss and not, as formerly suggested [Wager (19) page 34] large blocks of earlier rocks caught up in the prevailing grey gneiss.

(g) Pegmatites.

In the Angmagsalik District there are abundant pegmatites cutting the grey gneiss and the included plagioclase amphibolites. The pegmatites are markedly transgressive and have suffered no crushing since their formation (Plate 2, fig. 2). They must be regarded as the last formed element of the Metamorphic Complex, except for certain transgressive plagioclase amphibolites to be described below.

Quartz-orthoclase-plagioclase-biotite pegmatites are the commonest and in them magnetite and garnet are frequent accessory minerals. Muscovite pegmatites occur only rarely. In marked contrast with the

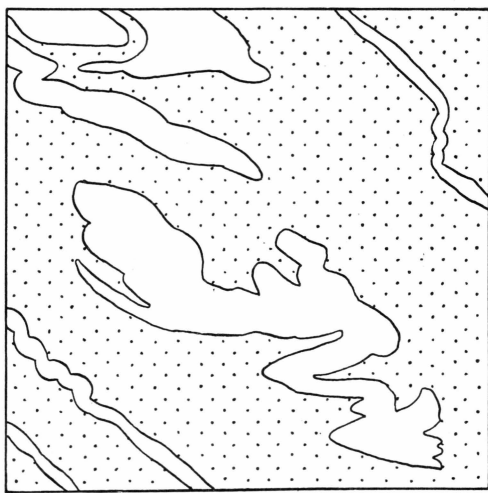


Fig. 3. Sketch showing pegmatite material (blank) in grey gneiss (dotted), near Navdlivit, Suportup Kangerdlua (Base Fj.). On surfaces at rightangles to that figured the pegmatites are strongly elongated lenticles or streaks. Area shown is nine square feet.

pegmatites of West Greenland, graphite was only found once in the pegmatites of the Angmagsalik District.

In the Kangerdlugsuatsiak region and to the north, conspicuous transgressive pegmatites are absent, but coarser streaks, welded into the gneiss, apparently represent crushed and granulitised pegmatites. A rock consisting of quartz and brick red orthoclase occurs frequently as a unit in the Metamorphic Complex at Kangerdlugsuak and this also seems to be pegmatite material which has suffered subsequent granulitization. In the hypersthene-granites of Mount Forel and in the basic hypersthene rocks of Angmagsalik Island, pegmatites, like those cutting the grey gneiss, were never found.

Several cases were noticed of early pegmatites in the grey gneiss which had suffered slight compression and folding (Plate 4, fig. 2). These are not to be confused with the late stage pegmatites just described but they are of interest because they help to prove the protracted time during which the gneisses were at a high temperature and undergoing alternating phases of compression and tension. It is suggested for instance that pegmatites, such as those shown in fig. 3, were formed from the liquid residuum of the grey gneiss in cracks opened up during a period of tension and that subsequently they were folded by further compression while the mass was still capable of slight flow.

(h) Transgressive Sheets of Plagioclase Amphibolite.

On Kap Japetus Steenstrup an almost horizontal sheet of plagioclase amphibolite, some 100 feet thick, cuts transgressively across the gneisses of the Metamorphic Complex (Plate 5, fig. 1). A similar sheet was visited half way between Wahls Fjord and Steenstrup Søndre Brae, and others were seen in the coastal cliffs. In mineral composition there seems to be no significant difference between the plagioclase amphibolites of the transgressive sheets and those intimately incorporated in the surrounding Metamorphic Complex.

The transgressive plagioclase amphibolites must be distinguished from the plagioclase amphibolites already described because they are clearly later than the grey gneiss or any period of flow of the grey gneiss. Where they occur the foliation and banding of the grey gneiss are almost vertical, while the transgressive sheets are almost horizontal (Plate 5, fig. 1) and have a foliation parallel to their extent. Yet the transgressive sheets consist of plagioclase amphibolite which like that of the Metamorphic Complex has no relics of igneous structures or of igneous minerals. It is clear that the transgressive plagioclase amphibolites were injected after the last yielding by horizontal compression of the rocks of the Metamorphic Complex, and in a period when a clear-cut fracture was

possible. As, however, the injection took place at such a time that then or afterwards a typical plagioclase amphibolite was produced they are regarded as forming a late stage in the building of the Metamorphic Complex.

(i) Tectonics.

In the Metamorphic Complex where the dips are high, the prevailing strike of the gneissic structures and banding is about W.N.W.—E.S.E. The fact that this is roughly the strike of the Lewisian Gneiss may perhaps mean that the Metamorphic Complex of the Angmagsalik District and the Lewisian Gneiss of Scotland originated at the same time.

A detailed study was made of the dips and strikes of the Metamorphic Complex in the neighbourhood of Supertop-Kangerdlua (Watkins' Base Fjord) where there is a considerable amount of sedimentary material to act as a datum line, but this led to no satisfactory understanding of the meaning of the structures.

In the Kangerdlugsuatsiak region there is a zone of intense granulitization. This zone has indefinite boundaries, but it is several miles at least in width, and it trends in a W.N.W. direction. Certain hypersthene granites in this zone have been reduced to fine-grained granulites, and bands in the gneiss which are believed to represent former pegmatites have also been granulitized. In the granulites from the plagioclase amphibolites, scapolite minerals are usual and they have not so far been found in the plagioclase amphibolites elsewhere. Granulitization must have taken place at high temperatures and pressures and the changes are therefore regarded as belonging to some stage in the formation of the Metamorphic Complex, although clearly a late one.

The Kangerdlugsuatsiak zone of granulitization is probably a line of considerable tectonic importance. To the south transgressive pegmatites are widespread, and the plagioclase amphibolites are often garnetiferous. Along the zone and to some extent to the north of it, the pegmatites are granulitized and only rarely are garnets found in the plagioclase amphibolites. It appears therefore that along this zone and to a less extent to the north, the Metamorphic Complex underwent a late stage shearing pressure which did not affect the Angmagsalik District. The formation of the transgressive amphibolite sheets may perhaps have occurred towards the end of this period of shearing stress.

Subsequent to the phenomena directly connected with the forging of the Metamorphic Complex — perhaps long subsequently, — certain master joints were produced along which epidote was deposited and the grey gneiss on both sides was reddened for many feet. The plagioclase amphibolites near these joints have been slightly epidotised and the biotite of the grey gneiss chloritised. This type of alteration was common

about Supertop-Kangerdlua, and was noted as far north as Depot Fjord. At first it was thought that the changes suffered by the grey gneiss along the joints was connected with vapours or solutions from the Tertiary Igneous rocks, but the effect dies out as the Tertiary dyke swarm and plutonic centres are approached. The change in the gneisses as the result of the dyke swarm seems to be a different type of retrograde metamorphism which results in the grey gneiss becoming dull white due to a micaceous decomposition of the feldspars. This type of change was only noticed in the region of the Steenstrup's Braer and northwards.

III. ANGMAGSALIK GRANITES AND RELATED BASIC ROCKS

On both sides of Angmagsalik Fjord, on a small island east of Erkilikartek, on Angmagsalik Island near the centre, and in Hunde Bay, a branch of Sermilik, igneous rocks were found which are regarded as later in age than the Metamorphic Complex. These rocks have boundaries which are markedly transgressive towards the gneisses of the Metamorphic Complex and they are quite unfoliated.

Granites, gabbros, norites and some hypabyssal rocks are included among this suite of rocks, granites being the most abundant. At Kernatorsuit, on the east side of Angmagsalik Island, the granite is relatively coarsegrained. A specimen which seemed to be typical is a biotite granite with a little muscovite and microcline dominant over plagioclase. The small exposure at the centre of Angmagsalik Island is finer grained with muscovite, green biotite and about equal amounts of orthoclase and plagioclase. The granite of Hunde Bay is a potash-rich muscovite granite in which nine-tenths of the felspar is microcline. In this rock there is a good deal of interstitial primary epidote.

The patch of basic rock on the west side of Angmagsalik Fjord is, in part, a quartz norite. Besides enstatite there is a good deal of green hornblende and biotite. The plagioclase is dusty with inclusions, some of which are acicular and have special orientations, features which suggest reheating after crystallization. Certain transgressive sills of basic material which occur just to the north consist of thermally metamorphosed dolerite. Their texture is that of a hornfels in which there has been complete recrystallization of the felspar, augite, hornblende and biotite. The plagioclase is not twinned and is dusty with inclusions.

The area of basic rock on the west side of Kingorsuak, the most northerly branch of Angmagsalik Fjord, is rather different. Some of it is a quartz gabbro in which the augite is partly converted to hornblende, but the felspars are not dusty from thermal metamorphism. Basic rocks which are more finegrained and sometimes porphyritic also occur here.

At first it was thought that all these rocks might be Tertiary in age and thus belong to the same cycle of igneous activity as that occurring extensively to the north, but petrological considerations seem to be opposed to this view. The Tertiary granites are usually drusy and free from pegmatites; the Angmagsalik granites are not drusy and always have pegmatites associated with them. These distinctions are probably a function of the depth of solidification, but in this case they probably also indicate differences in age, because there seems to be no reason why erosion should have exposed deep-seated granites of Tertiary age in the Angmagsalik District and only drusy Tertiary granites, cooled in the upper part of the crust, in the region to the north. In the Angmagsalik District the common associates of the East Greenland Tertiary granites, such as the syenites, are wanting, while muscovite, which is a frequent mineral in the Angmagsalik granite, is not found in the definitely Tertiary granite. Petrologically, therefore, the Angmagsalik granites differ significantly from the Tertiary granites and they almost certainly belong to an earlier cycle of igneous activity.

Whether or not the Angmagsalik granites and basic rocks are closely connected in origin with the formation of the Metamorphic Complex is not clear. The norite, briefly described above, seems to have some affinity with the basic rocks of Charnockite type in the Metamorphic Complex. On the other hand the partly uralitised gabbros in Kingorsuak are very different from the rocks of Charnockite affinities. If the rocks of the Angmagsalik region had suffered the same late stage granulitization as the rocks at Kangerdlugsuatsiak there would have been another line of attack on the problem of their age, but no trace of such a granulitization occurs so far south. At present, therefore, it cannot be definitely decided whether the Angmagsalik granites and basic rocks are intrusions associated with the last phases of the igneous activity which produced the Metamorphic Complex or belong to a later episode. Since there is Caledonian tectonic and igneous activity on a large scale in the country to the north of Scoresby Sound it may be that the Angmagsalik granites and basic rocks are Caledonian in age.

IV. LATE SEDIMENTS

In 1930 marine fossiliferous sediments were found on Kap Gustav Holm. They were resting on a peneplained surface of the Metamorphic Complex and were overlain by basalt lavas. In the same year on an islet west of Skaergaards Halvøen in Kangerdlugsuak, traces of sediments were also found resting on the Metamorphic Complex, but the relationships were complicated by a later gabbro intrusion. Better exposures of the Kangerdlugsuak sediments were found in 1932 in Mikis Fjord which lies just east of Kangerdlugsuak. These sediments, like those at Kap Gustav Holm, are marine and shallow water in origin and immediately underly the Plateau Basalts.

At Kap Dalton, in the midst of the extensive basalt area between Kangerdlugsuak and Scoresby Sound, sediments were found in 1900, by O. Nordenskjöld, a member of the Amdrup-Hartz Expedition [9]. Marine fossils and plant remains were collected which indicated a Lower Eocene age. In 1932 these sediments were re-examined and the sequence and relationship to the Plateau Basalts determined.

(a) Kap Gustav Holm Series.

The sediments and overlying basalts on Peak Gustav Holm (Plate 5, Fig. 2) were found during an ascent and descent of the Peak, c. 3,000 ft. which occupied only $4\frac{1}{2}$ hrs. It was hoped to re-examine the district during the return journey from Kangerdlugsuak in the fall, but pack ice and the limited time at our disposal prevented this. In 1933, Dr. Richard Bøgvad, during the course of the 7th Thule Expedition led by the late Knud Rasmussen, had an opportunity of investigating the neighbourhood of Kap Gustav Holm in some detail and from him, in the near future, we may hope for a map and more information about the sequence.

The relationships of the sediments is complicated by a swarm of Tertiary dykes along which some movement has taken place (fig. 4). On the S.W. side of Peak Gustav Holm, which was the side ascended,

the dip of the sediments seemed to be about 50° to the E.N.E. The actual plane of unconformity was not seen but the gneisses of the Metamorphic Complex, 20 ft. below the lowest occurrence of the sediments were not noticeably weathered. The lowest sediment is a hardened impure grit about 50 ft. thick. The coarser bands contain pebbles up to 5 mm in diameter, consisting of rounded fragments of quartz and acid gneiss. Above the grit are metamorphosed shales and fine grained pelitic and calcareous sandstones. The light-coloured rock with the marine fossils described as metamorphosed, impure limestone [Wager (19), p. 35] proves on further examination to be only slightly calcareous. In associa-

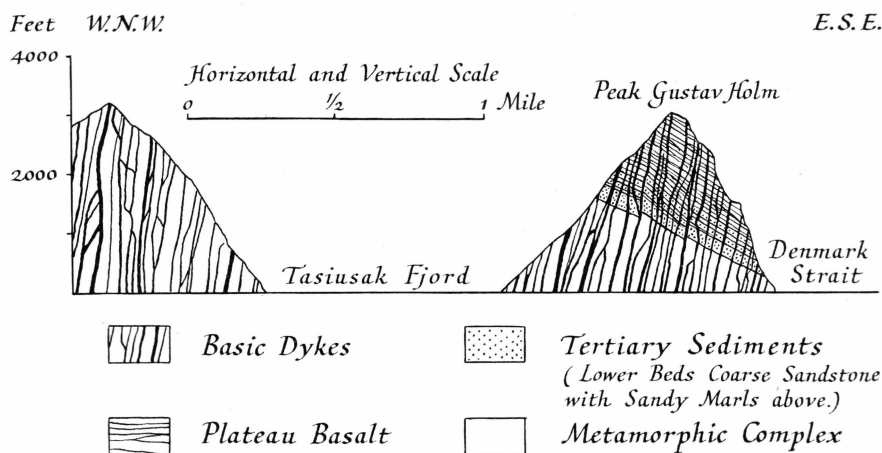


Fig. 4. Cross-section showing Peak Gustav Holm and the mountain to the west, both rising to the general level of the former peneplain, with Tasiusak Fjord cut along the former line of junction between the sediments and the Metamorphic Complex. The thickness of the sediments and the individual lava flows is exaggerated. (Reproduced by permission from the Geographical Journal).

tion with the 30 feet or so of sediments above the lower grit, there are two lava flows about 10 feet thick, which were clearly poured out in a shallow sea. The lavas above form a pile about 1,000 ft. thick which is apparently free from sediment. Among the lavas autobrecciation is common, and red partings were not noticed, so that perhaps the main lava series, like the two lowest flows, was submarine in origin.

The fossiliferous rocks occur in the shale and sandstone horizon. It is unfortunate that the sediments are here so metamorphosed that specific determination of the fossils is impossible. Professor H. L. Hawkins, however, examined them and considered that one specimen was an undoubted *Glycimeris*, and he suggested that some of the others might be *Cyrena gravesii*, Deshayes [see Wager (19), p. 35], a form which had previously been described by Prof. Ravn [8] from the Kap Dalton Series.

The comparison with *Cyrena gravesii* was made before Captain Mikkelsen's Expedition and therefore before the relationship of the Kap Dalton Series to the Plateau Basalts was established. From the work done on the latter expedition it is now known that a basalt pile, many thousands of feet thick, occurs below the Lower Eocene Kap Dalton Series, and therefore exact contemporaneity of the Kap Gustav Holm Series lying below the Plateau Basalts and the Kap Dalton Series is unlikely. The only fossil among the material collected from Kap Gustav Holm which helps to date the beds is the *Glycimeris*. The presence of *Glycimeris* suggests a late Cretaceous or Tertiary age for the beds and it precludes the possibility of these sediments being much older than the Tertiary, as has been suggested by Professor Ravn [23]. It is not justifiable to assume exact contemporaneity of the lavas at Kap Gustav Holm and those further north, but it is at any rate likely that the Kap Gustav Holm Series of sediments lying below the lavas is earlier than the Lower Eocene beds at Kap Dalton which are several thousand feet above the base of the lavas. Till further evidence is forthcoming, the Kap Gustav Holm Series will be regarded as late Cretaceous in age.

Both the sediments and lavas on Peak Gustav Holm have suffered considerable metamorphism, which is probably to be ascribed to the Tertiary plutonic rocks immediately to the N.E. rather than to the dyke swarm actually cutting through them. The detailed petrological examination of the sediments can better be left to Dr. Bøgvad, who has a large collection of specimens, but certain general observations may be recorded here. The grit is a tough rock due to the metamorphism, and biotite has developed in some of the pelitic material which occurs between the grains. The fossiliferous sediment, as Professor Bøggild has stated [see Ravn (23) p. 9] is not a limestone, nor is it, in my opinion, appropriately named a tuff, although it may possibly contain some material from the lavas with which it is associated. Professor Bøggild has kindly sent me the slice which he examined, and I have another of a slightly different part of the rock. The second specimen consists of two materials — one a dark greyish green in colour and the other a light yellow; the latter occurs as an auriole around enclosed shell fragments. In the greyish green material there are slightly corroded detrital quartz and plagioclase crystals in about equal amount and forming two-thirds of the total. The remaining material between the grains is recrystallised albite with acicular hornblende crystals or, in places, bunches of hornblende grains. In the light grey material forming the auriole round the shell fragments pyroxene grains are present to the extent of one quarter of the rock; here no hornblende is found and the amount of detrital quartz is less. Like the grit which is developing biotite, this rock has clearly suffered considerable thermal metamorphism. Where shell fragments were present, providing a source of lime, augite

has been produced by the interaction of silica with the materials which, away from the source of lime, have given hornblende grains and needles. The rock is surprisingly rich in plagioclase, but I consider that it is more likely that this material was derived with the quartz from the break up of the gneisses of the Metamorphic Complex than from contemporaneous lavas or ashes. The augite grains noted by Professor Bøggild in the rock which he has described as a tuff are, I believe, the product of the thermal metamorphism of a calcareous sandstone. The fairly high degree of metamorphism suffered by the rocks on Peak Gustav Holm, besides being shown by the newly formed biotite of the grit, is also indicated by the present state of the basalt lavas. These now consist mainly of plagioclase and hornblende; augite was found still preserved only at the centre of a former, porphyritic augite crystal.

(b) Kangerdlugsuak Series.

In the valley running north from the elbow of Mikis Fjord, the development of the Kangerdlugsuak Series is as follows:

Plateau Basalts.		
Kangerdlugsuak Series	{ Conglomerate	50 ft.
	{ Sandstone with sandy shales	100 -
	{ Sandstone, often calcareous and with calcareous sandstone balls	100 -
(Unconformity)		
Metamorphic Complex.		

The conglomerate consists of well-rounded pebbles up to 20 cm in length, and mainly derived from the Metamorphic Complex. Occasionally dark pebbles were noted which proved to be altered shale but the constituents of the conglomerate have not been submitted to any detailed examination. Layers of false bedded sandstone and grit are interleaved with the layers of conglomerate and similar fine-grained material formed the cement of the conglomerate. On the east side of the valley the first lava rests on the conglomerate; on the west side, overlying the conglomerate, there are six feet of sandstone and five feet of baked sandy shale with fragments of plants now composed of graphite. The shale is overlain by the same thick lava flow as occurs on the east side of the valley. The field relations left no doubt that the overlying basaltic material is a lava flow and not a sill. The top beds of the Kangerdlugsuak Series are exceedingly variable, and clearly were mainly beach deposits. The sandstones below the conglomerate contain grains of quartz and felspar up to 5 mm in length, and the cement especially in the lower series is usually calcite. The estimates of thickness given above are only approximate.

The sequence in the valley running N.W. from the end of Mikis Fjord at a point which is only four miles east of the locality just described seems to be of somewhat deeper water origin and is:

	Plateau Basalts.	
Kangerdlugsuak Series	{ Fine grained sandstone.....	100 ft.
	{ Baked sandy shale.....	?40 -
	{ Baked Calcareous shale.....	?20 -
[Base not seen.]		



Fig. 5. The top surface of a lava, showing flow structures, north coast, at end of Mikis Fj. The lava was poured out under water. Area shown about six square feet.
(Photo J. J. JENSEN).

This occurrence is close to an extensive gabbro intrusion which has metamorphosed the beds and complicated the field relation.

A more westerly occurrence of sediments was found on the islet to the west of Skaergaards Halvøen in Kangerdlugsuak. Here the series consists only of a basal conglomerate one foot thick with about two feet of a highly metamorphosed calcareous sediment above. Although the top beds of the series have been removed by erosion, the whole deposit was probably thin. A little further west on Amdrup's Point only a trace of sediment occurs mixed with volcanic ash. This series is only a few feet thick and lies between the gneisses of the Metamorphic Complex and the overlying basalts. The character and thickness of the

Kangerdlugsuak Sediments, indicate that at the time of their deposition, land lay to the west of the present Kangerdlugsuak. The sediments themselves were clearly deposited in a shallow sea deepening to the east. As additional evidence for this it was found that the surface flow structures of the lower Plateau Basalts, observed at three widely separated places, showed unambiguously that the lava had flowed towards the east (fig. 5).

Except for the plant remains, now films of graphite, which occur in the shales, fossils were not found in position. However, a party of the biologists of the 1932 expedition found a loose block of metamorphosed sandstone showing the impression of a large Pecten-like shell. There is little doubt that this specimen was derived from the Kangerdlugsuak Series and perhaps search further to the N.E. along the strike would yield sufficient fossils to prove the age of the series. For the present all that can be said is that the Kangerdlugsuak Series was deposited immediately before the outpouring of the Plateau Basalts of the region, and is therefore presumably slightly older than the Eocene rocks of Kap Dalton. The Kangerdlugsuak series is probably to be correlated with the Kap Gustav Holm Series.

(c) Kap Dalton Series.

In 1900 the short time available to Nordenskjöld and Hartz at Kap Dalton was largely spent in making a collection of the organic remains. These have been described by Ravn [8], Mathiesen [17] and Henriksen [11] and Professor Ravn was able to decide from the marine fossils that the age of the beds is approximately Lower Eocene.

In 1932, an attempt was made to find additional fossiliferous material which might yield more definite evidence for the age of the deposits. Professor Ravn has again undertaken the examination of the marine fossils which were collected and Professor Mathiesen that of the plant remains. The fossils have already been described by Professor Ravn [23] but the collection, as was suspected in the field, contains little that is new. It is still the opinion of Professor Ravn that the series is Lower or Middle Eocene in age and that a Lower Eocene age is the more likely.

Professor Ravn has also given in his paper [22] certain information about the sequence and geological relations of the Cape Dalton Series which was contained in two letters written by me immediately after returning from East Greenland. From the detailed mapping in 1932 it is clear that the preservation of the sediments is due to down-faulting and it is likely that the sediments are later than the basalts which are now exposed between Kap Dalton and Kangerdlugsuak. In a subsequent paper I will amplify, with a map, the information given by Prof. Ravn and also describe certain alkaline basalts, etc. which occur as pebbles in the basal conglomerate of the Kap Dalton Series.

V. TERTIARY IGNEOUS ROCKS

Between Angmagsalik and Scoresby Sound, Tertiary igneous phenomena are displayed on at least the same scale and with at least the same variety as in the British Isles. The broad peninsula between the southern branches of Scoresby Sound and Kangerdlugsuak, which is about 16,000 sq. miles in area, is composed of a thick series of basalt lavas. To the south only small patches of basalts are now preserved, but they indicate that the basalt area was once much more extensive. Along the present coast several Tertiary plutonic centres are arranged at about the same intervals as in the Hebrides. In one of these centres, namely, that at Kangerdlugsuak, the area of Tertiary plutonic rocks considerably exceeds the area at present exposed in any of the British centres. Many of the East Greenland rock types are comparable with those of the British area and, to some extent, the tectonic conditions seem to have been the same. However, two of the East Greenland plutonic centres, include a considerable development of syenites and nepheline syenites which are not known from the British Tertiary Province. Nepheline-leucite basalts also occur, but they have not yet been found in situ. These alkaline igneous rocks were not mentioned in the preliminary account of the work of Watkins' expedition, owing to the possibility of their being associated with minerals of economic importance.

The Tertiary igneous phenomena fall naturally into three phases: (a) the volcanic phase — mainly extrusion of basalt but also with minor explosive activity, (b) the phase of plutonic intrusion and (c) the phase of dyke intrusion. This appears to be roughly the chronological order since the plutonic rocks and dykes are usually found intruded into the basalts.

The age of the igneous activity is indicated by the occurrence and fortunate preservation of the Lower Eocene sediments at Kap Dalton. As has been mentioned above in the discussion of the Kap Dalton Series, the lavas which occur between Kap Dalton and Kangerdlugsuak are probably earlier than the Kap Dalton Series which is Lower Eocene in age. From statements made by Nordenskjöld [(9), p. 220], it is possible

that certain lavas occurring between Kap Dalton and Scoresby Sound are slightly younger than the Kap Dalton Series.

The laboratory investigation of the Tertiary igneous rocks collected is by no means completed and more work in the field is much to be desired, especially in connection with the plutonic intrusions.

(a) The Basalts.

In 1822 William Scoresby discovered the Fjord which is named after him and described the basalt mountains with basic dykes which form its southern side [1]. This basalt region as far south as Kap Dalton was later especially studied by Nordenskjöld [9] and zeolites from the basalts collected by him have been described by Prof. Böggild [10]. Tertiary basalts also occur to the north of Scoresby Sound, but in less abundance and lava flows have not always been distinguished from

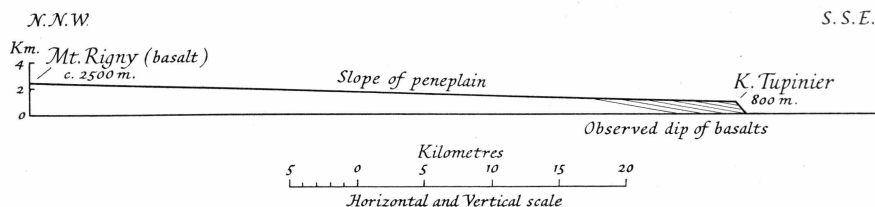


Fig. 6. Diagram to show the observed dip of the basalts at the coast near Kap Tupinier, compared with the true slope of the peneplain from which the mountains inland have been cut.

sills. Recent descriptions of the basalts from the northern district have been given by Koch [10], Tyrrell [18] and Backlund and Malmqvist [15].

The coastal mountains from Kap Dalton to Kangerdlugsuak are built up entirely of basalt lavas and basic dykes. Admiral Amdrup considered this to be the case from general observations made during his boat journey in 1900 [6]. Views from the summit of the mountains climbed during the coastal journey in 1932 showed that the basalt country extended far inland. Examination of the moraines of several of the big glaciers (e. g. Stor Brae and the glacier coming down to the east of the Lilleoise Group) failed to show the presence of any rocks of the Metamorphic Complex. Apparently the Metamorphic Complex is not exposed within the drainage area of these glaciers, which extends for more than fifty miles from the coast. Moreover, in the moraines of the glaciers along this stretch of coast plutonic rocks were found only in those of the Lilleoise Group.

Mountains 7,000 ft. high are composed entirely of the gently dipping basalts and the total thickness of the lavas is undoubtedly great. The mountains inland from Stor Brae could be seen to be cut out

of a raised peneplain which transgresses the lava sequence. Thus near the coast in this region the lavas dip at about 10° to the S.E. and the peneplain from which the mountains have been cut rises steadily, but less steeply than the lavas, towards the group which presumably includes Blossville's Mt. Rigny. From the summit of a coastal mountain this group could be seen to consist of basalts. The section from Mt. Rigny to Kap Tupinier (fig. 6) illustrates what is at present known of these relationships, but unfortunately it does not give any absolutely definite information about the thickness of the lava pile, because the present dip of the lavas may be partly due to a south-easterly slope at the time of their extrusion, and also because it is not yet known how far inland the dip of 10° persists. The section does, however, suggest that the thickness of the lava series is great — perhaps as much as fifteen or twenty thousand feet.

The south-easterly dip of the lavas is a feature of the whole coast examined except at Kap Dalton, where the dip is to the N.W. This reversal is connected with the faulting, which is also responsible for the preservation of the Kap Dalton Series. No trace of marine sediments were found interbedded with the lavas to the S.W. of Kap Dalton and for this reason the sediments are believed to belong to a higher horizon which has been removed by erosion from the region to the S.W. where the dips remain constantly seawards. Both the dip of the lavas and the dip of the peneplain from which the mountains have been cut must be ascribed to tilting of the crust causing uplift inland ie, to the N.W. and sinking in the region of the Denmark Strait ie, to the S.E.

The lavas are usually thin; on Kap Vedel fortysix flows were counted in a cliff about 2,000 ft. high. On the other hand flows between 50 and 100 feet thick were sometimes observed. Only rarely has a flow been seen to thin out and end and sometimes a single flow in the coastal cliffs could be followed by eye for three miles. The basalts were apparently extruded on an even surface very different from that on which the Icelandic lavas of the present day are being poured out.

The tops of the basalt flows are scoriaceous and a layer composed of fragments of reddish, decomposing, scoriaceous lava on the top of the flows usually passes upwards into a definite red earth. On Kap Ravn unidentifiable plant impressions were found in the red earth. The red partings prove that the basalts were poured out on a land surface. At the S.W. point of Kap Barclay a portion of the upper ropy surface of a lava flow was noticed but usually sub-aerial weathering in the interval between successive flows has obliterated such features.

During the journey from Kap Dalton southwards no sills were noticed until Mikis Fjord was reached although there was ample opportunity for detecting them in the towering cliffs of the outer coast. At

Mikis Fjord, because perhaps it is near the plutonic centre of Kangerdlugsuak, thick dolerite sills have been injected (see p. 41).

In the neighbourhood of Kap Johnstrup a slight change in the coastal profile and in the form of the mountains was noticed. To the north, step-like cliffs have been produced by denudation of the lava pile. This is the result of the soft red partings and the soft scoriaceous tops of the lava flows alternating with more resistant massive centres (Plate 6, fig. 1). The change at Kap Johnstrup, which becomes more marked towards Kangerdlugsuak, is due to the hardening of the red partings and scoriaceous parts of the flows so that the whole series behaves more like a massive rock (Plate 6, fig. 2). The red zones also become less conspicuous because the scoriaceous upper part of the lavas which to the north are stained red, here become greenish in colour and only the thin band of fine grained earthy material remains red. These changes are particularly obvious in the neighbourhood of the Lilleoise Group where they are clearly due to local thermal metamorphism by the plutonic intrusion. I am inclined to ascribe the less definite change, sometimes not to be detected in hard specimens but only showing up in the coastal profile, to thermal metamorphism on a regional scale due, partly at any rate, to deep burial.

In Mikis Fjord the lower basalts of the series are found resting directly on the thin marine sediments of the Kangerdlugsuak Series. Some of the basalts were poured out in shallow water but between others red partings occur indicating subaerial weathering in the time interval between successive lava flows. The basalts are probably slightly different in composition from those further north but the differences are masked by thermal metamorphism due to the proximity of the plutonic intrusions of the Kangerdlugsuak Centre.

So far only the features of the main basalt outcrop have been given but to the south small patches of altered basalt lava were also found on Amdrup Point, Keglen, Kap Edward Holm, Igdlitarajik and Kap Gustav Holm while blocks believed to be basalt are enclosed in the gabbros of the Nualik Plutonic Centre. All these rocks have suffered considerable metamorphism, and the original augite has largely been replaced by hornblende. These remnants of basalt lavas indicate, however, a once much more extended basalt area. They also help to define the age of the plutonic intrusions, and one day they may help to throw light on their form.

Taken broadly, all the lavas from Kap Dalton to Kangerdlugsuak may be classified as basalts. They are all vesicular and 99 per cent of the vesicles are completely filled. This is in striking contrast with the recent basalts of Iceland, and we must suppose that the infilling of the

vesicles was due to migrating, heated waters which acted at considerable depths during the slow cooling of the lava field. Hot springs still occur along the Blossville coast and some are known in the Scoresby Sound region [Koch (14) p. 200—201 and Pedersen (13)]. The hot springs in the fjord between Kap Ewart and Kap Barclay had a temperature too hot for a hand to bear, the one on Kap Koster had a temperature of about 105° F. and the one in the bay to the N. of Kap Tupinier had a temperature of 101° F. Perhaps the igneous activity of East Greenland has ceased more recently than the Tertiary igneous activity of the British Isles.

TABLE I:
ANALYSES OF BASALTS

	I	II	III	IV
SiO ₂	48.89	47.26	47.81	53.00
Al ₂ O ₃	13.60	14.17	13.64	22.70
Fe ₂ O ₃	4.72	4.68	4.50	2.43
FeO.....	9.65	8.32	8.84	1.49
MgO.....	4.54	6.65	6.51	.12
CaO.....	10.09	10.64	11.29	1.00
Na ₂ O.....	2.74	2.30	2.54	10.20
K ₂ O.....	.30	.81	.35	2.35
H ₂ O+.....	1.38	1.45	.76	5.90
H ₂ O—.....	1.14	.90	1.26	.35
CO ₂	.02	.04	none	none
TiO ₂	2.64	2.69	2.51	.15
P ₂ O ₅	.39	.23	0.24	none
Cl ₂	trace	.01	trace	
S.....	.02	.01	0.01	none
MnO.....	.24	.19	0.22	.15
SrO.....	trace	none	none	
BaO.....	trace	none	none	
Li ₂ O.....	trace	trace	trace	
	100.36	100.35	100.48	99.84
Spec. Grav.....	2.90	2.97	2.95	

- I. Tholeitic Basalt (E. G. 1057) Kap Dalton, East Greenland. Hill west of anchorage and 100 ft. below lowest sediments. Anal. H. F. HARWOOD.
- II. Olivine Basalt (E. G. 1093) north side of Barclay Bugt, East Greenland. On Coast about one mile W.N.W. of Host's Havn. Anal. H. F. HARWOOD.
- III. Olivine Basalt (E. G. 1112) Kap Daussey, East Greenland. Anal. H. F. HARWOOD.
- IV. Erratic (E. G. 1289) Probably altered nepheline basalt. Narrow valley east of Notch Mountain on the West side of Kangerdlugsuak, East Greenland. Anal. W. H. HERDSMAN.

TABLE II:
NORMS OF BASALTS

	I	II	III	IV
Quartz.....	4.5	.7	.8	
Orthoclase.....	1.78	4.8	2.2	13.6
Albite.....	23.37	19.4	21.5	51.0
Anorthite.....	23.66	25.9	24.5	5.0
Nepheline.....	—	—	—	20.8
Corundum.....	—	—	—	1.6
Diopside.....	21.7	21.7	25.5	
Hypersthene.....	10.5	13.4	13.3	
Olivine.....	—	—	—	.8
Magnetite.....	6.7	6.9	6.5	3.5
Ilmenite.....	5.1	5.2	4.7	.2
Apatite.....	—	.5	.7	
Calcite.....	—	.1		

At Kap Dalton porphyritic basalts were not found. In the bay inside Kap Ewart basalts, with porphyritic feldspars, form about half the scree below the basalt cliffs. This may include some porphyritic dyke material, but all except one of the dykes observed here were non-porphyrific. Towards the head of Barclay Bugt three quarters of the basalts contain conspicuous porphyritic feldspars, and, on one mountain lying inland from D'Aunay Bugt climbed on 15th July, all the lavas have porphyritic feldspars which are up to 1½ inches in length, of tabular form and sometimes occur in glomeroporphyritic groups. The N.W. part of Kap Daussy consists of lavas which are mainly porphyritic, but the higher flows to the S.E. are mainly non-porphyrific. On Kap Ravn and near the Lilleoise mountains the basalts are mainly porphyritic. The lower lavas found in Mikis Fjord are mainly non-porphyrific. Nordenskjöld [(9), p. 220] states that between Kap Dalton and Scoresby Sound porphyritic lavas "seem to play only a small part among the sheet-like basalts".

The variation in the character of the basalts as determined in the field and given above may be partly due to a definite time sequence of the types. Kap Ewart and Kap Barclay are not far removed from Kap Dalton and evidence from the sediments suggests that S.W. of Kap Dalton only lower horizons occur. Therefore it seems that in this neighbourhood there is an early, mainly porphyritic series and a later non-porphyrific series. The basalts on Kap Gustav Holm, on Amdrup Point in Kangerdlugsuak and in Mikis Fjord are, in each case, the earliest basalt for the particular region and, in each case, are non-porphyrific.

The microscopic and chemical examination of the basalts has

been begun. Tholeitic types occur at Kap Dalton [Table I, Analysis I]. In them small olivine crystals, largely replaced by serpentine, occur sparingly. Two non-porphyrific types which must be classified as olivine basalts as before alteration they contained a considerable amount of olivine, have also been analysed by Dr. Harwood, and the results, with calculations of the norm, are set out above. (Table I, Analyses II & III and Table II). The analyses are given at the present stage of the investigation to show that the lavas conform to types already well known from the Tertiary basalt areas of the North Atlantic. The tholeitic basalt (Analysis I) corresponds to the Non-Porphyrific Central Magma Type of the Hebrides. The other two basalts, while being similar to each other, are about a mean between the averages for the Non-Porphyrific Central Type and the Plateau Type as defined by the authors of the Mull Memoir. Analyses of more extreme types of East Greenland basalts are given by Holmes [12], Backlund and Malmqvist [15] and Tyrrell [18].

Pebbles of leucite nephelinite and other alkaline types occur in the basal conglomerate of the Kap Dalton Sedimentary Series and a highly alkaline glacial erratic, which is probably a lava and not a dyke, was found in Kangerdlugsuak (Analysis IV). The alkaline lavas have not yet been found in situ.

(b) Tuffs and Volcanic Agglomerates.

The extrusion of the basalts of the main area, except near the northern and southern limits, was free from explosive volcanic activity; in the middle section, if tuffs had occurred, it is unlikely that they would have escaped notice in the magnificent cliff sections. At the northern limit of the main basalt area, on Kap Brewster, Nordenskjöld [(9), p. 220] found true tuffs interbedded with sandstone and basalt. At the southern limit, that is in the neighbourhood of the Kangerdlugsuak Plutonic Centre, tuffs and volcanic agglomerates were found at several localities although only in small amount. These will now be briefly described.

The coarsest volcanic agglomerate of the district occurs immediately west of the elbow of Mikis Fjord. It consists of basalt fragments, usually fine grained, or fine grained except for conspicuous porphyritic augite crystals. The fragments average two to three inches in diameter, but some were seen which were as much as three feet across. The deposit lies near the base of the basalt series and, where it is coarsest, it is 300 ft. thick. Two miles northwards and also a few hundred feet above the base of the lavas, there is a fine grained agglomerate, only 100 ft. thick, which is presumably the same bed. Again, four miles E.N.E. and at apparently the same horizon, an agglomerate occurs which is still finer in grain and thinner.

In 1930, on the point between Kap Hammer and Skaergaards

Halvøen, a series of tuffs were found (Plate 8). They were about 200 ft. thick and dipping at 45° to the S.S.E.¹⁾ On the whole these tuffs are extremely fine grained and flinty in fracture, the largest fragments noticed being only half an inch across. Stone implements made of this tuff were found in the ruined Eskimo houses of Skaergaards Halvøen. Under the microscope the fragments can be seen to consist of glass or fine grained basalt. From field evidence these tuffs were clearly laid down in water. The position within the basalt series is approximately the same as that of the agglomerate of Mikis Fjord.

On the same cape and about half a mile S.E. of the tuffs there are thin larva flows, sometimes variolitic and sometimes with rude pillow structures. Between the flows fragmentary deposits, including basic glass, were found. It is probable that these deposits are not true tuffs but the auto-brecciated fragments of the upper surface of the lava flow which was poured out in water.

An attenuated basaltic tuff series, now much metamorphosed, was found resting on the Metamorphic Complex and underlying the basalts at Amdrup Point. A little east of Kap Edward Holm there also occurs a thin deposit which is either a metamorphosed tuff or a metamorphosed red parting.

The only other occurrence of tuffs so far found is on Keglen, an island which lies south of the entrance to Kangerdlugsuak. At the west end of this small island there is a bed of flinty crystal tuff and fine-grained agglomerate fifty feet thick, which is injected by quartz syenite veins. Above are two or three basalt flows and then another crystal tuff and agglomerate horizon about 12 ft. thick. This is overlaid by a succession of lavas which continues to the west end of the island. The tuffs of Keglen are distinct from the others described as they consist largely of crystals of perthitic felspar and fragments of trachyte. There is at present no definite indication of the position of these tuffs in the basalt sequence, but they prove that sometime during the period of basalt extrusion there must have been explosive volcanic activity from an already differentiated syenite magma.

(c) The Plutonic Centres.

The Tertiary plutonic rocks occur in distinct centres now separated by tracts of Metamorphic Complex or basalt. In each of the six centres there is a range in rock type from gabbro to granite or quartz syenite. In two centres nepheline syenites occur, and in one thoroughly ultra-basic rocks were found. The excellence of the exposures in a country

¹⁾ The dip arrow on the maps marks the position and dip of the tuffs but the area is too small for a distinctive colour and is shown like the surrounding gabbro.

such as Greenland and the favourable stage to which denudation has at present reached are two factors making the Tertiary plutonic rocks of East Greenland particularly worthy of detailed study. In the present paper, however, only a general statement of the main types and their distribution will be given. The centres will be treated in order from north to south.

The Lilloise Plutonic Centre is the most northerly, definitely tertiary, plutonic centre so far known, yet I suspect that work carried out during Dr. Koch's recent expeditions may ultimately prove that Tertiary plutonic rocks exist north of Scoresby Sound. Wordie and Tyrrell have stated that a Tertiary age for the Cape Parry rocks seems not unlikely [see Tyrrell (18)]. Although the 1932 expedition was kept for several days in the vicinity of the Lilloise mountains by adverse ice conditions, the plutonic rocks were not actually reached. During this enforced stay a short excursion with Captain Mikkelsen was made to a high col on Kap Ravn, and in addition to the usual dolerite dykes various picrite and lamprophyre dykes were found which suggested a special focus of differentiation. Some way inland a high mountain group was visible which we named the Lilloise Group (Plate 7), and this seemed to consist of light-coloured rocks intruded into the basalts. An attempt was made to reach this range; dragging a sledge with food and camping equipment, a successful crossing was made of the eastern and central distributory glaciers of a large unnamed glacier coming from far inland, but no way could be forced through the tremendously crevassed and quickly moving western distributory by the route to which we were committed. Camp was pitched at the inland point of the mountain mass forming Kap Stephensen. The rocks proved to be hardened basalts metamorphosed by the plutonic intrusion of the Lilloise mountains. Over the cliffs above the camp erratics were scattered which had been left by the glacier when more extensive than at present. The bulk of these erratics consist of syenites among which are types rich in nepheline and sodalite. From the light colour of the rocks forming the Lilloise Group and from the evidence of the erratics, the group may be assumed to be mainly composed of syenites and nepheline syenites, and it has been so indicated on the map.

Between Kap Rink and Kap Irminger the coast was only obscurely seen from a distance, but no rocks other than basalts and dykes were made out. The next plutonic centre so far known is, therefore, that at Kangerdlugsuak. On the west side of Kangerdlugsuak and stretching also some way south, the Tertiary plutonic intrusions exceed 300 square miles in area. On the east side is a relatively small complex consisting dominantly of basic rock.

The intrusion on the east side of Kangerdlugsuak which may be

called the Skaergaards Halvøen Complex (Plate 8), will be described first. In form the intrusion seems to be comparable with that of the Cuillin Hills of Skye. Thus the west and north-west margin is either vertical or dipping steeply in an easterly direction, and the north and east margins also dip steeply towards the centre of the intrusion. The south-east side has not yet been examined, and the south side is cut away by the sea. Flow banding is conspicuous in many of the types forming the complex, and the banding dips towards the south-easterly part of the intrusion, but not with the same regularity as in Skye. Part of a covering of the Metamorphic Complex was found at a height of 2,500 feet near the south-east boundary of the intrusion and this material must have been raised three or four thousand feet by the act of intrusion. A patch of sediments, raised one thousand feet above its proper position, was found on the north-east margin.

Along the boundary on Skaergaards Halvøen¹⁾ and on Kraemers Ø there is a troctolite margin 300 yds. in average breadth. This rock has been considerably modified by the incorporation of acid gneiss from the Metamorphic Complex. Excluding the marginal types the westerly and lower part of the complex consists of a banded gabbro of peculiar composition. The feldspar is dominantly andesine and iron ore is as abundant as augite. In some specimens iron-olivine crystals occur in the same rock as a mesostasis of quartz and orthoclase. The most easterly and higher parts of the intrusion consist of quartz gabbros, some of which are relatively rich in orthoclase. Plagioclase, more basic than andesine, has not so far been noted in these rocks if the troctolite is excluded. The various types occur in gently dipping, sheet forms, and over a certain range the quartz gabbro is interleaved with the easterly type of gabbro.

The elongated patch of basic rock towards the west of Kraemers Ø consists of troctolite and olivine gabbro and here also there has been much assimilation of the surrounding acid part of the Metamorphic Complex. The southern part of the westerly peninsula of Kraemers Ø is an augite syenite. This intrusion is remarkable for the huge rafts of basalt enclosed in the syenite. Lavas, now completely removed by denudation, must have overlain the syenite at the time of its intrusion (Plate 9, fig. 1). The basalt inclusions give a definite proof of the Tertiary age of the syenites.

Forming the point between Amdrup Fjord and Kangerdlugsuak proper there is a quartz syenite similar to that on Kraemers Ø, although here with only one or two per cent of quartz. For ten miles to the north the coast of Kangerdlugsuak consists of the Metamorphic Complex, but at an

¹⁾ The intrusion is here in contact with basalt but the latter forms too small an area to be indicated on the map.

average distance of half-a-mile from the coast there is a large complex consisting mainly of quartz syenite, syenite, and nepheline syenite. The marginal type is usually a quartz syenite, then comes a zone of syenite, and the nepheline syenite has so far only been found some six miles within the complex. From the top of the coastal mountains massive, light-coloured plutonic rocks were seen to extend inland for fifteen miles from the western shores of Kangerdlugsuak. The syenite forming Notch Mountain, one mile inland from the point where the west coast of Kangerdlugsuak turns north-west, has a lower and outer rim of a gabbroic rock and the small patches of basic rock shown along the part of the coast which has an E.—W. trend are peridotite and dunite. The southerly moraine of the Kangerdlugsuak Glacier contains an abundance of a quartz syenite close to the Nordmarkite type. The source of this material could be seen in the distance, and has been roughly indicated on the map. So far, no highly alkaline types such as those in S.W. Greenland have been found, and except for traces of galena and fluor-spar mineralization has not been noted. The analysis (Table III, Analysis V) is of a nepheline-sodalite syenite from the head of Syenite Glacier, five miles from the coast of Kangerdlugsuak and four miles north of the head of Amdrup Fjord.

Only the outer part of Amdrup Fjord has so far been visited; on every occasion when a party was in a position to go up the fjord there has been heavy pack ice blocking the way. Half of the southern shore consists of the Metamorphic Complex, but underlying it are patches of quartz syenite resembling that on Kraemers Ø and that on the point between Amdrup Fjord and Kangerdlugsuak. About half way along the fjord a biotite-bearing alkali granite occurs in association with various gabbros, peridotites and hybrid rocks.

Between Amdrup Point and Kap Edward Holm is another intrusion complex bordered on both the north and south by metamorphosed basalts which rest on the Metamorphic Complex. The bulk of this large area consists of gabbros of various types. In the gabbros there is a marked banding; in the north the dip of the banding is south-west or south at 30—50°; in the south, on Kap Edward Holm, the dip of the banding is about 50° to the north-east, while in the middle stretch of the coast the dip is in an easterly direction. Like the Skaergaards Halvøen complex, the form of this intrusion seems to be comparable with that of the Cuillins of Skye. Cutting through the gabbros, however, there are two masses of quartz syenite, one forming Kap Deichmann (Plate 10) and the other, the promontories west and north-west of Keglen. These masses have contacts with the gabbros which are vertical or dipping steeply outwards. They would seem, therefore, to be comparable in form to the ring dyke type of intrusion described first from the British Tertiary Province. Between the syenite intrusions and the gabbro there is, in

TABLE III.
ANALYSIS AND NORM OF NEPHELINE-
SODALITE SYENITE

	V	
S ₁ O ₂	61.70	
Al ₂ O ₃	18.35	
Fe ₂ O ₃	1.63	
FeO	1.62	Orthoclase 32.8
MgO	.61	Albite 51.8
CaO	.95	Anorthite6
Na ₂ O	7.50	Nepheline 4.7
K ₂ O	5.53	Sodalite5
H ₂ O+	.73	Nosean6
H ₂ O—	.04	Diopside 2.4
CO ₂	.07	Olivine 3.2
Z ₁ O ₂	.02	Magnetite 2.3
TiO ₂	.80	Ilmenite 1.5
P ₂ O ₅	.08	Apatite3
Cl ₂	.04	Calcite2
SO ₃	.09	
MnO	.32	
SrO	none	
BaO	trace	
Li ₂ O	trace	
	100.08	
Spec. Grav.	2.63.	

V Nepheline-Sodalite Syenite (E.G. 1300), Col at head of North Syenite Glacier, West side of Kangerdlugsuak.

places, a zone, several hundred yards wide, consisting of shattered gabbro injected by syenite.

In composition the basic rocks of this complex are olivine gabbros and eucrites with patches of bytownite rock, etc. They are thus very different rocks from those of the Skaergaards Halvøen Complex. The quartz syenite of Kap Deichmann consists of two or three types, but the dominant one is rather basic with aegerine, arfvedsonite, fayalite, perthitic feldspar and a little quartz. The quartz syenite forming the promontories west and north west of Keglen is a coarser and more normal rock consisting of perthitic feldspar with small amounts of quartz, aegerine and arfvedsonite.

The Igdlitarajik Centre to the south of Kangerdlugsuak is now only a cluster of small islands, composed mainly of flow-foliated gabbro. On the most westerly island of the group metamorphosed basalts occur

and near the junction of the basalt and gabbro there has been injection of acid material. Deceiving Island, further to the west, was found to consist of the Metamorphic Complex cut through by such a large number of dolerite dykes that only about a quarter of the island consists of the gneisses the rest being dyke material.

The next centre to the south may be called the Nualik Centre, after a former Eskimo settlement. The islet north of Søndre Aputitek forming part of this centre consists of fine grained gabbro with rather acid plagioclase and augite now largely converted to hornblende. On the main island a light pinkish intrusion, probably granite, could be seen injecting gabbro, but owing to ice, the island could not be reached.

The peninsula of Nualik itself shows a complicated contact between a quartz diorite intrusion and the Metamorphic Complex. On the point, the quartz diorite is crowded with inclusions of basalt. A little further west, occasional blocks of metamorphosed pelitic sandstone occur among the abundant, basalt inclusions. Then comes a zone, one or two hundred yards wide, in which blocks of gneiss are the commonest inclusion. Sometimes chilled basic material is in contact with gneiss. As the invading diorite is not chilled against the inclusions the blocks, consisting of gneiss and chilled basalt, are interpreted as inclusions of the gneiss and dolerite dyke complex which, further west, towers above the lower part of the peninsula. Apparently at Nualik the quartz diorite invaded (1) basalts with which were associated some Mesozoic or Tertiary sediments and (2) the gneisses of the Metamorphic Complex which were already injected by dolerite dykes. Immediately north of Nualik peninsula is another promontory which, from a distance, seemed to consist of basalts with lighter zones of sediments but when visited the lighter, gently-dipping bands were found to be sills of microgranite injecting gabbro.

The Kialinik Centre, the next to the south, is of considerable extent but has only been cursorily examined. A quartz syenite, with somewhat alkaline hornblende and aegerine, forms the bulk of the island S.W. of Long Island. The north end of Kialinik consists of a minutely drusy, even-grained granite injecting a hybrid rock of acid and basic material (Plate 9, fig. 2). The conical hill in the foreground of the photograph consists of blocks of gabbro, in all stages of digestion, set in a base of microgranite and the light streaks in the hill behind are sill-like masses of microgranite injecting the basic rock. The whole of the small island called Lille Ø, north of the north end of Kialinik is also microgranite crowded with basic inclusions and the island to the E.N.E. of this (1100 ft. on Amdrup's Map) consists of pink granite with small druses containing

epidote, fluorspar, chalcopyrite, etc. Other areas of plutonic rocks could be seen from the deck of the ship but were not visited.

The most southerly of the plutonic centres, that of Kap Gustav Holm, includes foliated gabbros and biotite diorites. Along the western edge of the basic plutonic rocks and to the north of the basalts, is a mass of quartz syenite too small to be indicated on the map, which is 200 yds. wide and dips steeply east parallel to the foliation in the basic rocks. We may hope that Dr. Bøgvad, when he describes the sedimentary beds of Kap Gustav Holm, will also give an account of the Tertiary Igneous rocks.

(d) Dykes and Sills.

Tertiary dolerite dykes were found along the whole stretch of coast with which this account is concerned, but they were not observed in the neighbourhood of Mount Forel, which is sixty miles inland. There is a noticeable falling off in the number of dykes between Kap Dan, where there are approximately eight per mile and the head of Angmagsalik Fjord where there are only two or three per mile. There are also less dykes at the head of Kangerdlugsuatsiak than on Kap Japetus Steenstrup. The same distribution was noted in Kangerdlugsuak, but here there are irregular variations in direction and distribution due to the Tertiary plutonic centre.

Dolerite sills are of extremely limited distribution, having so far been found only in the Mikis Fjord region. Here the greatest development is at the end of the fjord on the south side, where dolerite sills, totalling three or four hundred feet in thickness, are to be seen.

The Tertiary dykes between Kangerdlugsuatsiak and Kangerdlugsuak strike between N.E. and N.N.E. that is, parallel to the general trend of the coast (Plate 5, fig. 1). In the Angmagsalik District the general direction of the coast changes, but one of the dominant directions of the fjords and valleys is N.E.—S.W., which is that of the dykes and of certain of the master joints. The strike of the dykes in the main basalt area varies from N.E.—S.W. in the Barclay Bugt region to E.N.E.—W.S.W. as Kangerdlugsuak is approached. Again the dyke direction is parallel to the general trend of the coast. About the plutonic centres, especially the Lilleoise and Kangerdlugsuak centres, dykes are found in various other directions.

Certain generalizations can also be made about the dip of the dykes. In the main basalt area the dykes are approximately at right angles to the bedding of the lavas. Thus they generally dip steeply in a north westerly direction except at Kap Dalton, where the dip of the dykes and the lavas is locally reversed. Along the outer coast about

Mikis Fjord there is an abnormal dyke swarm which has not the regional strike but runs E.N.E.—W.S.W. Here too the dip is relatively low, averaging only 60° .

Turning now to the southern part of the area, the dykes of the Angmagsalik District are found to be approximately vertical, but north of Kangerdlugsuatsiak the dip is between 70 and 80° to the N.W. For the

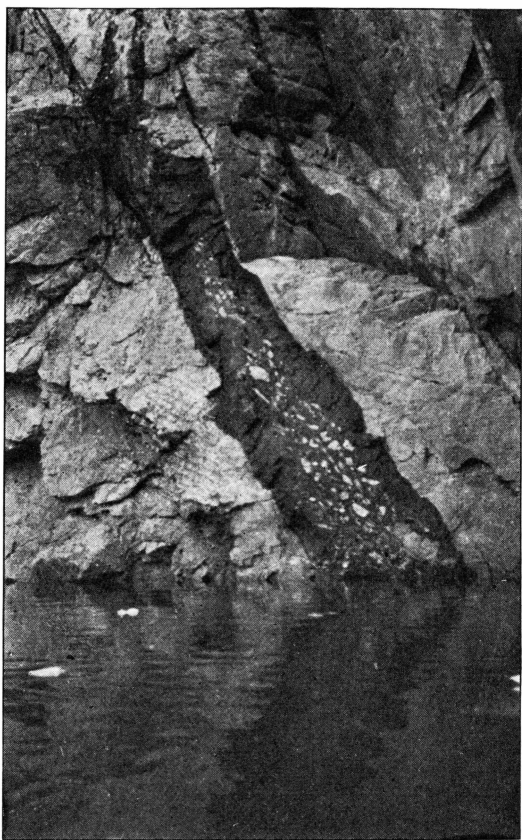


Fig. 7. The top of a Tertiary dolerite dyke cutting the Metamorphic Complex on the north coast of a small island three miles W.S.W. of Kap Gustav Holm. The fragments of angular grey gneiss occupy the central part of the dyke only.

long stretch of coast between Kap Gustav Holm and Kangerdlugsuak an average amount of dip of 80° is indicated on the map. There are exceptions; thus on Deceiving Island the dip is about 70° . On the whole, however, the constancy in direction of the dip over this 120 miles of coast is remarkable.

It is reasonable to assume that faulting at Kap Dalton, causing a reversal in the dip of the lavas and dykes, was subsequent to the period

of dyke injection, but it is not at present clear whether elsewhere the dykes were approximately vertical at the time of intrusion and owe their present dip to a subsequent tilting of the crust or whether dyke injection and tilting of the crust were simultaneous and genetically related phenomena.

The number of dykes in the Angmagsalik district away from the plutonic centres is relatively small and all examined have proved to be olivine dolerites of a type poor in olivine. At Kangerdlugsuatsiak the numbers of dykes begins to increase, and beside the olivine bearing types which weather a rich chocolate brown colour, there are quartz dolerites weathering greyish brown. At Kap Gustav Holm the amount of dyke material exceeds the amount of the Metamorphic Complex and there is greater variety in composition. The dykes are still basic, but types with porphyritic feldspar, augite, or hornblende occur. Some olivine-rich rocks and one lamprophyre were also collected. Between Kap Gustav Holm and Kangerdlugsuak, the dykes so far examined are all dolerites of various types with the single exception of a quartz porphyry cutting the gabbro on the islet north of Søndre Aputitek. This is probably merely an apophysis of the granite which could be seen on the main island. About Langöen and Aggas Ø the dykes were particularly observed and collected, and in amount they almost equalled the amount of the Metamorphic Complex. On Deceiving Island, as on Kap Gustav Holm, the dyke material considerably exceeds the amount of the gneisses.

Where the dykes become frequent, multiple dykes are perhaps as common or commoner than single dykes. Here, too, there are frequent composite dykes where a second injection of magma has followed the first while that was still hot. Out of the several hundred dykes which must have been seen closely, only four contained conspicuous inclusions of the gneisses of the Metamorphic Complex. In three of these cases it was clear that the part of the dyke containing the inclusions was near the original top of the dyke (fig. 7). In the fourth case, a dyke which cuts the lavas on Kap Gustav Holm, the gneiss inclusions are several hundred feet above the plain of unconformity between the Metamorphic Complex and the sediments. Further it was found that the quickly-cooled marginal parts of these four dykes were free from the gneiss inclusion (see fig. 7), which proves that the presence of gneiss fragments is not due to peculiar shattering of the rock near the top of the dyke. It is fair, therefore, to deduce that, at the temperature of the basalt magma, the solid, acid to intermediate gneiss was sufficiently lighter than the basalt magma to allow of its effective flotation.

At Kangerdlugsuak, although the dominant dykes are still dolerite, a small number of other dykes having a range in composition of the same order as that of the plutonic rocks were found. The number of

dykes cutting the Skaergaards Halvøen Complex is less than the number cutting the lavas about Mikis Fjord and the number cutting the other plutonic masses of Kangerdlugsuak is still less. Considerable variety in composition of the dykes also occurs round the Lilloise plutonic centre.

Between Kap Daussy and Kap Dalton only dolerites were found. Although porphyritic basalt lavas are here abundant, porphyritic dolerite dykes are very rare. Tholeiitic dolerites are about as common as olivine or quartz dolerites, and it is worthy of note that tholeiites were not found injecting the Metamorphic Complex south of Kangerdlugsuak. In no case was it proved that a dolerite dyke had acted as a feeder for a lava flow.

Several dykes between Kap Tupinier and Kap Ryder were seen to be shattered and veined by light-coloured material. Where close examination was possible the light veining material was found to be a zeolite which to some extent invades the immediately surrounding basalt. In one striking case the zeolite is as abundant as the somewhat altered dyke material. Dr. F. A. Banister, at the British Museum, has kindly examined the zeolite and tells me that it is mainly laumontite. Only one specimen of the zeolites collected by Nordenskjöld and examined by Prof. Böggild [10, pp. 128 & 129] proved to be laumontite and this occurred in a similar situation. These shattered and zeolitised dykes were no doubt once the feeders of hot springs or geysers. The present-day hot springs which we found along this coast have already been mentioned (p. 32.).

(e) Tectonics.

Since the formation of the Metamorphic Complex the tectonics of this part of East Greenland seem to have been of the simplest. The high grade of the metamorphic rocks now exposed indicates a protracted period of crustal upwarping with concomitant denudation. Plateau basalt eruptions are usually taken to indicate tension in the crust, and the dyke swarms prove definitely that during a considerable part of the period of Tertiary igneous activity in Greenland there was continuous tension in a WNW.—ESE. direction which led to repeated fracturing. The local tectonic conditions at the various plutonic centres is a matter for future investigation, but, as has been briefly indicated above, the tectonic conditions, in some cases, have given rise to intrusions resembling that of the Cuillin Hills of Skye and in other cases to intrusions of ring dyke form.

Both the seaward dip of the lavas and the normal faulting at Kap Dalton indicate a gentle down-warping of the crust where the Denmark Strait now lies and upwarping inland. The slope of the peneplain from which the present mountains have been cut is apparently a continuation of this movement.

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PLATES

Plate 1.

Fig. 1: Kangerdlugsuatsiak and Ingolfs Fjeld from Eskimo Ø.

Ingolfs Fjeld, 7,300 ft. is a conspicuous mountain on the north side of Kangerdlugsuatsiak (a a₁). In this region the mountains, have been cut out of the Metamorphic Complex. They are of spiky form and show no evidence of having been covered by the extended ice cap.

Fig. 2: The south-west corner of Angmagsalik Island. (Air photograph by H. G. Watkins from 10,000 ft.) In the foreground is Sermilik; in the background Denmark Strait. The mountains, except perhaps a a₁, have been completely submerged in the extended ice cap. The isolated mountain b b₁, which has been shaped by the ice, is cut out of the grey gneiss of the Metamorphic Complex. The dark mountains about a a₁ are composed of basic rocks of Charnockite affinities.



Fig. 1.



Fig. 2.

Plate 2.

- Fig. 1: Plagioclase amphibolite in the grey gneiss, the most easterly islet of Eric den Rødes Ø. Small blocks of the conspicuous plagioclase amphibolite band have been broken off and are now enclosed in the grey gneiss. Pegmatites derived from the grey gneiss can be seen cutting the plagioclase amphibolite. The islet is 880 ft. high.
- Fig 2: Pegmatite cutting mixed gneiss, in the gulley leading to the ice tongue which formed the route from Watkins' Base on to the Ice Cap, Supertup Kangerdlua. (Base Fj.). The gneiss has been formed by intense flow of a mixed rock made from the grey gneiss and plagioclase amphibolite. The later transgressive pegmatite is about four feet wide (the Everest carrier on the snow gives the scale).

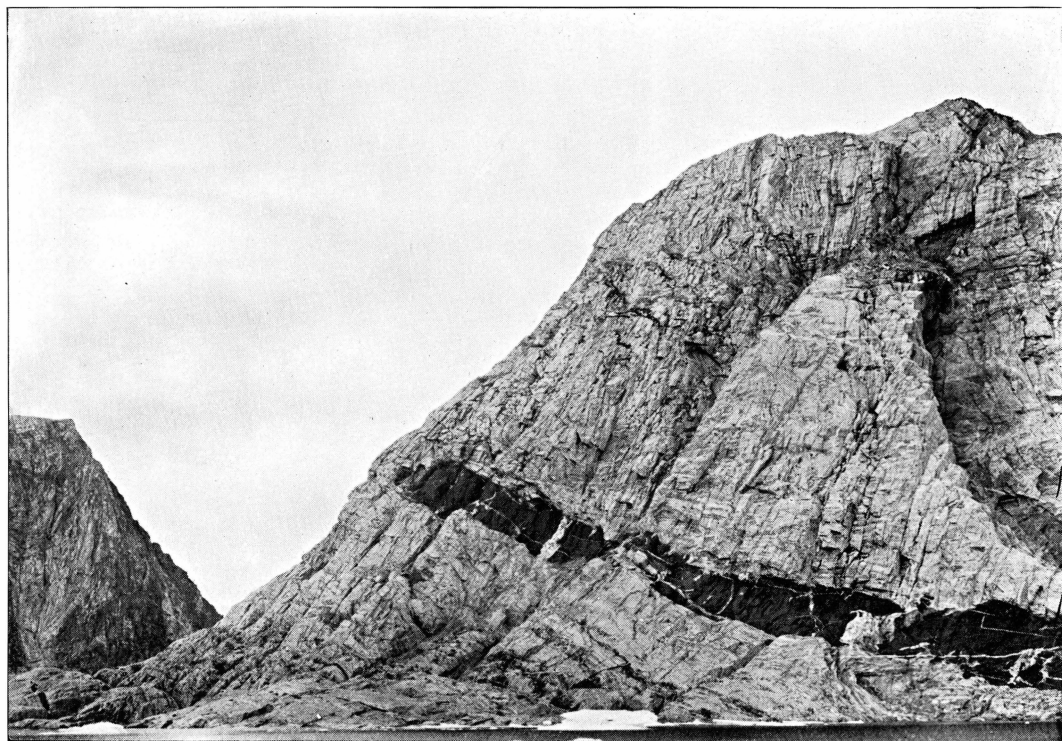


Fig. 1.

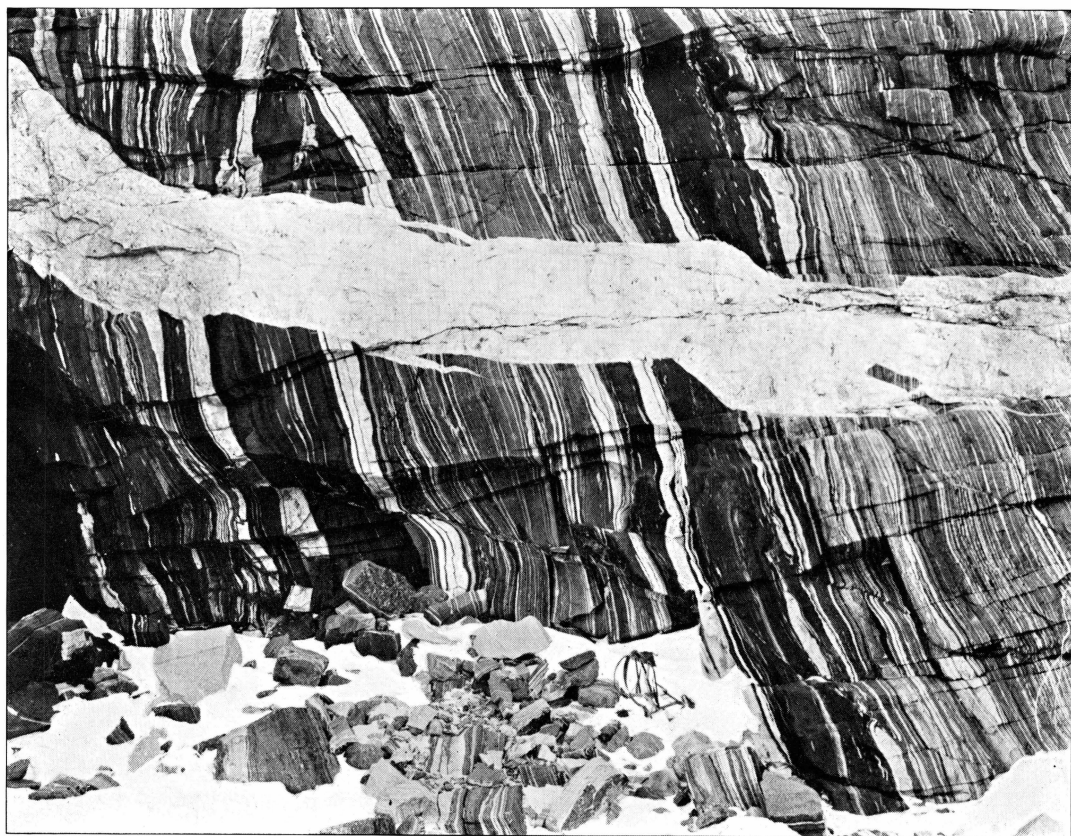


Fig. 2.

Plate 3.

Fig. 1: Fractured plagioclase amphibolite band. Shore at Watkins' Base, Supertup Kangerdlua (Base Fj.). The amphibolite band, about 10 inches wide, was apparently broken across during a period of flow of the grey gneiss. A coarse rock consisting of quartz, plagioclase, and amphibole without gneissic structure formed in the shelter of the ends of the amphibolite. Folia of the amphibolite, separated from the main mass, have become partly disintegrated in the grey gneiss giving a composite rock.

Fig. 2: Disintegrating plagioclase amphibolite in grey gneiss, east side of Tugtilik (Lake Fj.). The area of the rock surface shown is about twenty square feet. The disintegration was here unaccompanied by shearing processes.

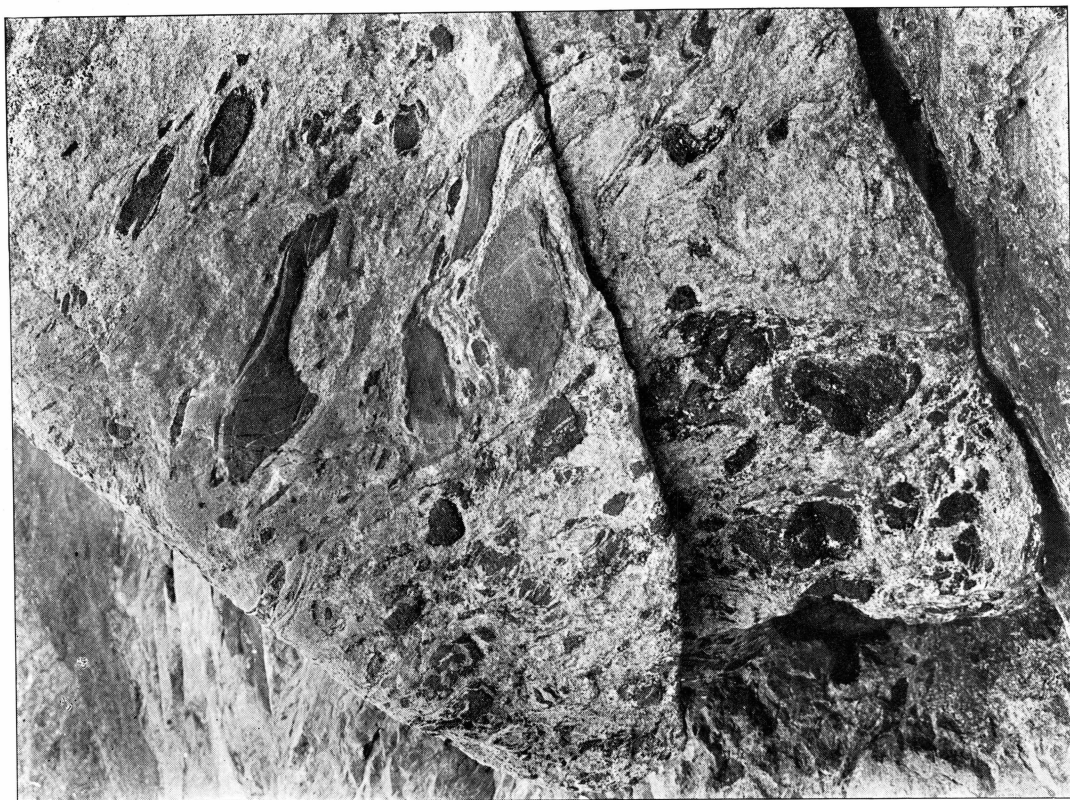


Fig. 2.



Fig. 1.

Plate 4.

Fig. 1: Kyanite schist injected by acid gneiss. Photograph taken about 700 ft. up on a yellow rib of rock half a mile north of Watkins' Base, Suportup Kangerdlua (Base Fj.). The area of rock shown is about 20 square feet. The black margins of the "lits" are due to the development of abundant biotite, a feature frequently observed.

Fig. 2: Pegmatites formed before complete cessation of flow of the mixed gneiss, the shore at Watkins' Base, Suportup Kangerdlua (Base Fj.). The mixed gneiss is the same as that shown in Plate 3, fig. 1. The match box gives the scale.



Fig. 1.



Fig. 2.

Plate 5.

- Fig. 1: A plagioclase amphibolite sheet in the Metamorphic Complex, and Tertiary dykes. (Air photograph by H. G. WATKINS from 10,000 ft.). The view includes Kap Japetus Steenstrup and the coast to the N.E. The transgressive plagioclase amphibolite can be seen a little above sea level on Kap Japetus Steenstrup (a a₁). The coast is trending NE. parallel to the dykes. Kap Gustav Holm (b b₁), and the entrance to Tugtilik (Lake Fj.) (c c₁) can be seen.
- Fig. 2: Peak Gustav Holm about 3,000 ft. high. (Air photograph by H. G. WATKINS from 10,000 ft.). The mountain (a a₁) has been well rounded during the period of maximum extension of the ice cap. Behind the peak is Tasiusak with a larger glacier coming in to it. The Cape Gustav Holm Series of sediments occurs on the SW. flank of the mountain about half way up. (cf. fig. 4).



Fig. 1.



Fig. 2

Plate 6.

Fig. 1: Basalt mountains showing step-like form, near the head of d'Aunay Bugt. The mountains are between 3,000 and 4,000 ft. high.

Fig. 2: Mountains of slightly metamorphosed basalt weathering as a massive rock, the coast between Kap Irringer and Mikis Fj.

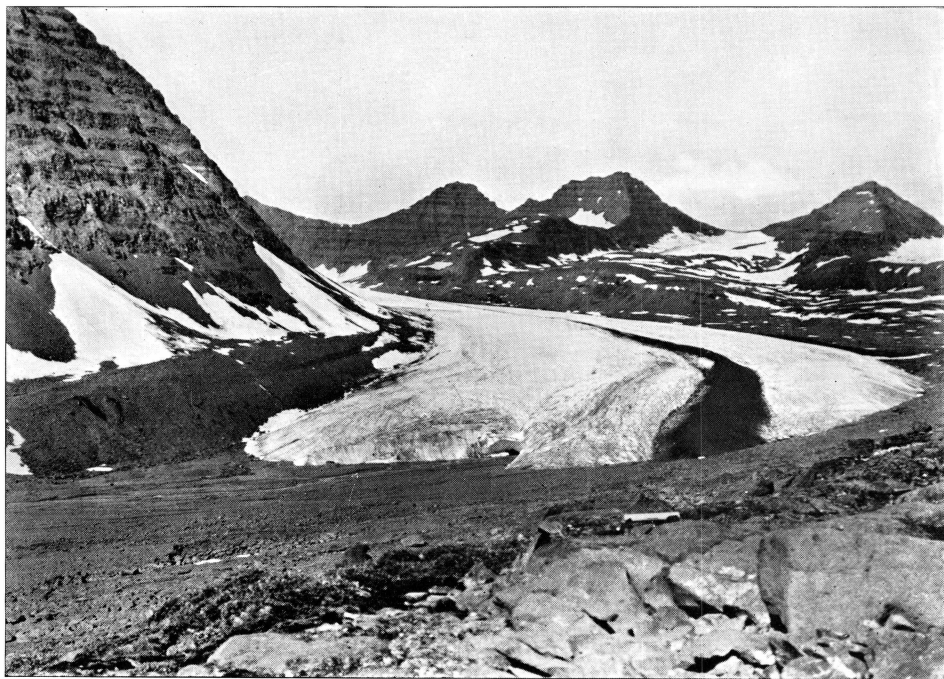


Fig. 1.

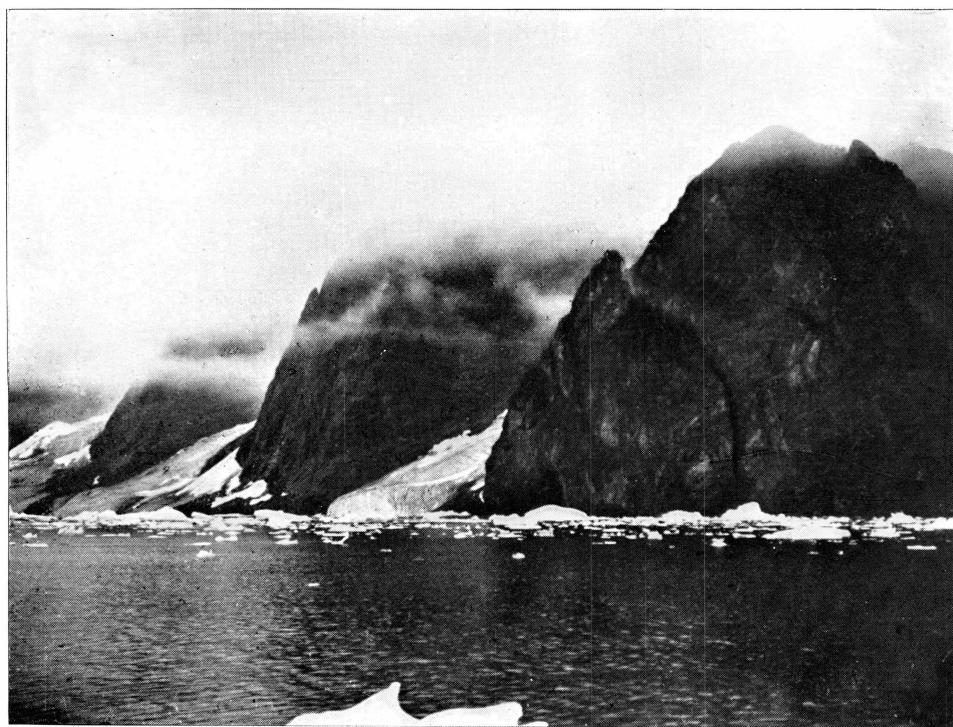


Fig. 2.

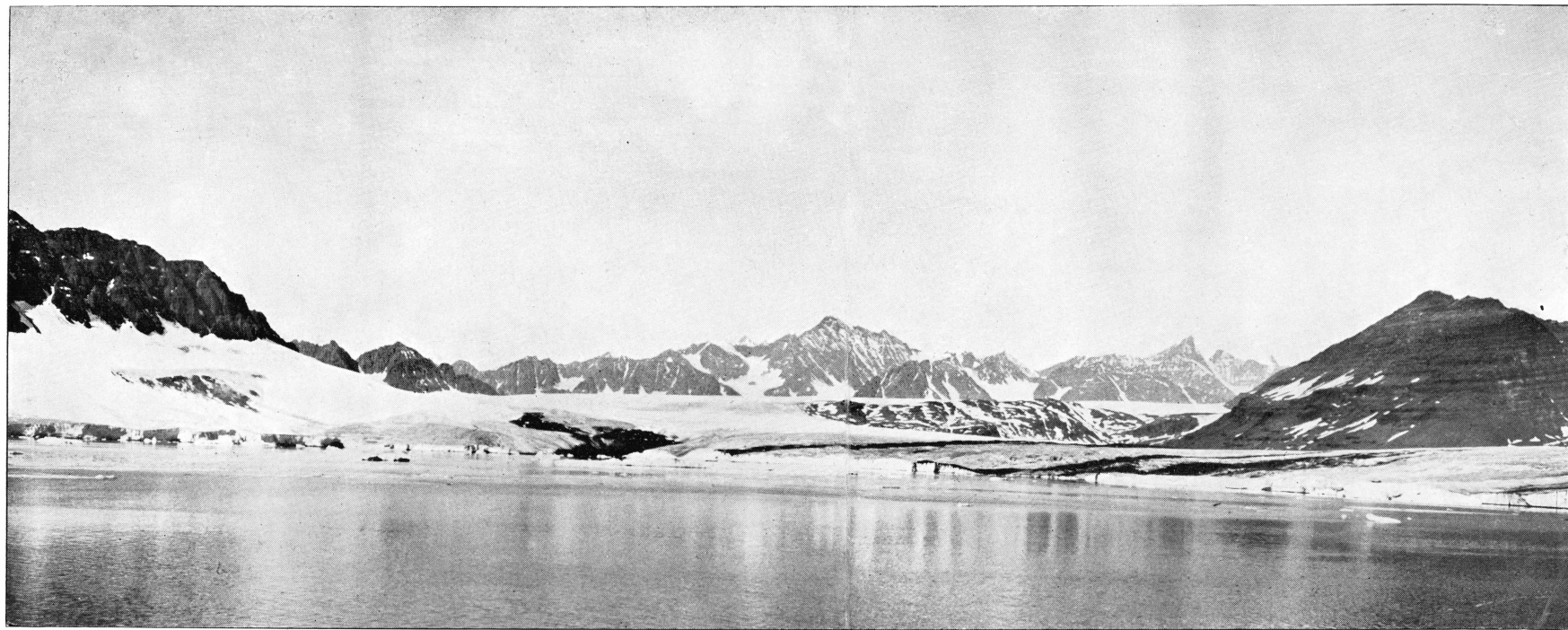
Plate 7.

Lilloise Bjaerge from the head of Wiedemann's Fj. The near mountains on the right and left sides of the photograph are of basalt. Peak 2106 m and Peak 2473 m are of light-coloured plutonic rocks, presumably syenite. a a₁ is the inland point of Kap Stephensen. Between the fjord and the high mountains is a particularly large glacier which passes out to the coast between the mountains on the left of the photograph.

a

Peak 2106 m

Peak 2473 m



a₁

Plate 8.

East side of Kangerdlugsuak from Kraemer's Ø southwards showing the Skaergaards Halvøen intrusion. (Photo by M. SPENDER and CHR. LARSEN). The panorama is taken from the coast between Kap Deichman and Amdrup Point (a a₁), which can be seen on the left. The mountains of Kraemer's Ø (Pk 1125 m and Peak 813 m) consist of the banded gneisses of the Metamorphic Complex. The mountain group round Peak 1277 m overlooks Uttental Sound and consists of the banded gabbros of the Skaergaards Halvøen intrusion complex. Peak 897 m and Peak 1120 m consist of the upper quartz gabbros of the complex. The mountains between Pk 1036 m and Kap Hammer consist of metamorphosed basalt. b b¹ marks the point where the tuffs occur.

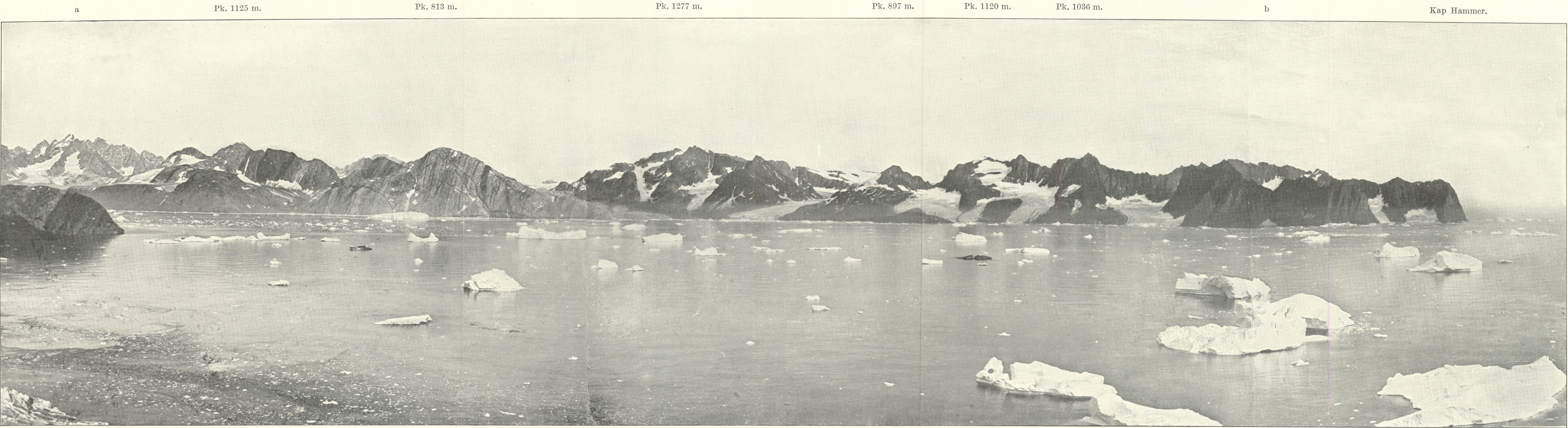


Plate 9.

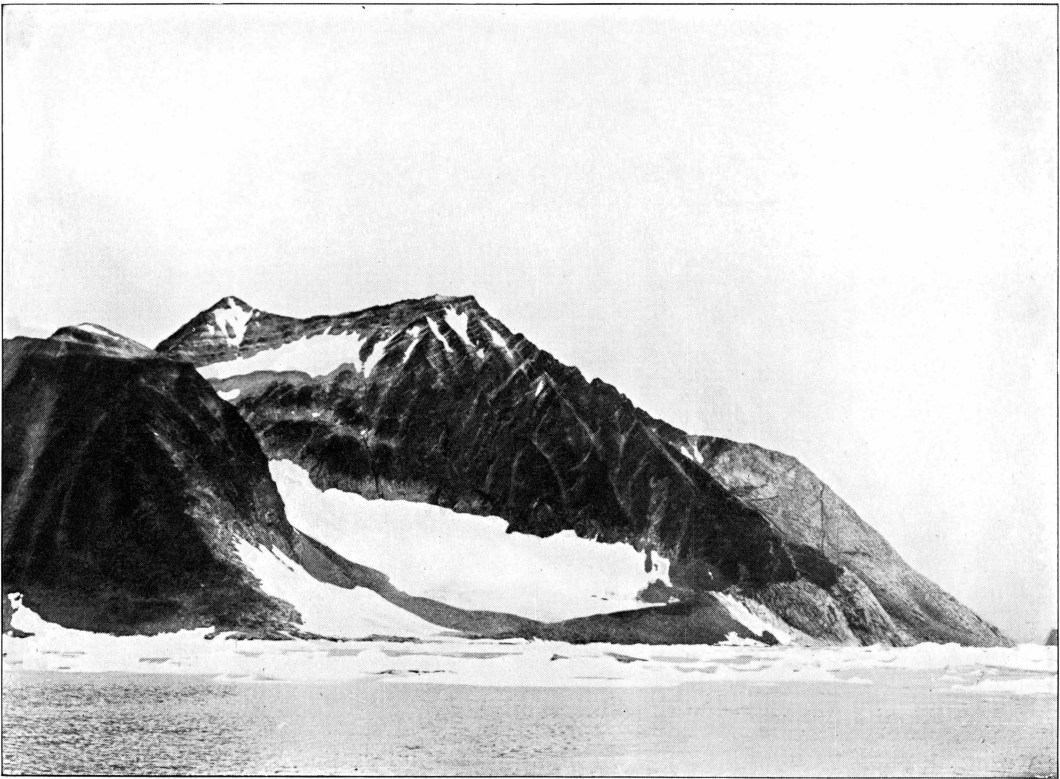
Fig. 1: Basalt blocks in syenite, the southerly point of the westerly peninsula of Kraemer's Ø. The rock surface seen is approximately 500 ft. high.

Fig. 2: Tertiary granite and gabbro on Kialinek. The photograph shows the north end of the island. The buttress, a a_1 , consists of blocks of basic rock in more acid, the mountains, b b_1 and c c_1 , consist of basic material with sheets of more acid material and the light rock on the right hand side is a drusy granite.



Fig. 1.

a b c



b₁ c₁
a₁

Fig. 2.

Plate 10.

Kap Deichman, Amdrup Fj. and the mountains behind. (Air photograph by H. G. WATKINS from 10,000 ft.) Kap Deichman (b b₁), about 2200 ft., high consists of a melanocratic quartz syenite. The mass a a₁ and the small masses on the coast north of Kap Deichmann are of Tertiary grabbro; c c is Amdrup Fj. and on the top right-hand corner the ice cap and the Kangerdlugsuak Glaciers can just be seen.



Plate 11.

Geological Map of East Greenland from Angmagsalik to Kangerdlugsuak.

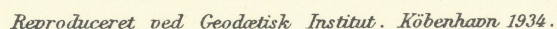


Plate 12.

Geological Map of East Greenland from Kangerdlugsuak to Kap Dalton.

Geological Map of East Greenland from Kangerdluġsuak to Cape Dalton.

Topography compiled from Maps of Amdrup's, Watkins', Mikkelsen's and Rasmussen's Expeditions

Geology by L.R.Wager

ca. 1: 650 000

0 10 20 30 40 50 60 70 km (in Lat. 68°30' N.)

