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THE SCORESBY SOUND COMMITTEE'S SECOND EAST GREENLAND EXPEDITION IN 1932 TO KING CHRISTIAN IX.S LAND
LEADER: EJNAR MIKKELSEN

THE BRITISH EAST GREENLAND EXPEDITION 1935–36
LEADER: L. R. WAGER

GEOLOGICAL INVESTIGATIONS IN EAST GREENLAND

PART IV

THE STRATIGRAPHY AND TECTONICS OF KNUD RASMUSSENS LAND AND THE KANGERDLUGSSUAQ REGION

BY

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WITH 12 FIGURES IN THE TEXT AND 6 PLATES

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I. INTRODUCTION AND ACKNOWLEDGEMENTS

The British Arctic Air Route Expedition 1930—31 [WATKINS, 1932][1]) provided an opportunity of making a preliminary geological investigation of parts of Kangerdlugssuaq and the coast to the South. This work was continued during the Scoresby Sound Committee's second East Greenland Expedition in 1932 [MIKKELSEN, 1933, A & B] and the coast to the north-east of Kangerdlugssuaq was also examined. Prior to these expeditions our knowledge of the geology of these areas was scanty [see WAGER, 1934, p. 7] but the results of the 1930 and 1932 expeditions allowed a general account of the coastal geology to be produced [WAGER, 1934]. Much remained to be done especially in the mountainous region away from the coast and this was attempted during the British East Greenland Expedition 1935—36, which spent fourteen months in Greenland in the neighbourhood of Kangerdlugssuaq. During the summer of 1935, in collaboration with Mr. AUGUSTINE COURTAULD, a journey was made to the Watkins Bjærge and the highest point was ascended. The following year, during long spring and summer journeys the broad belt of coastal mountains was crossed at various points and the Ice Cap reached. Many shorter journeys by sledge and boat were also made around Kangerdlugssuaq. Descriptions of these journeys and of the general activities of the expedition have been given in the Geographical Journal [COURTAULD, 1936, WAGER, 1937].

The main geological work of the British East Greenland Expedition 1935—36 was the detailed study of the Tertiary igneous intrusions near Kangerdlugssuaq. A paper describing one of these, the Skærgaard Intrusion, has already appeared [WAGER and DEER, 1939] and other petrological work on the rocks collected is still being carried out. The present paper gives an account of the stratigraphical observations made during 1935—36 in the Kangerdlugssuaq region and Knud Rasmussens Land and then attempts a synthesis of the late Cretaceous and early

[1]) Dates in square brackets refer to books and papers cited in the list of references at the end of this paper.

Tertiary tectonics of the middle part of East Greenland, based on these observations and others from the 1930 and 1932 expeditions.

In 1935—36 we were fortunate in having copies of a fine map on the scale of 1:250.000 and with 100 m contours which the Danish Geodetic Institute had constructed from the air photographs taken during Knud Rasmussen's last expedition, the 7th Thule Expedition. Not only was the map of great value as a basis for the geological mapping but it was also an aid to travel through the inland country which had, until then, only been seen from the air. The contrast between the difficulties of doing accurate geological work on the earlier expeditions compared with the ease and precision of the work that could be done on the British East Greenland Expedition when the new map was available, was very great, and the latter expedition is much indebted to Professor P. NØRLUND, Director of the Danish Geodetic Institute, for an advance copy of the map and for copies of the air photographs on which it was based.

During the 1935—36 expedition Dr. W. A. DEER, the second geologist, who was mainly concerned with the petrological work, never-the-less contributed much to the geological mapping; in particular he made a long and useful journey round the head of Kangerdlugssuaq and returned through the coastal mountains on the west side. I have incorporated his observations in this paper. I also wish to express my thanks to him for reading this paper when in manuscript and for making many helpful suggestions.

Since the present account makes use of results of the earlier expeditions, I wish again to record my gratitude for the facilities for geological work which were provided by the leaders of these expeditions, Captain EJNAR MIKKELSEN and the late H. G. WATKINS. I also wish to thank Mr. AUGUSTINE COURTAULD and his party for the pleasant and profitable collaboration with them during the summer of 1935, and I wish to thank the members of the wintering party, Mr. P. B. CHAMBERS, Dr. W. A. DEER, the late Dr. E. C. FOUNTAINE, Dr. H. G. WAGER, Mrs. H. G. WAGER and my wife, together with fourteen Eskimos, the families of ENOCH and HANSIE of Angmagssalik, for their effective and enthusiastic contributions to the expedition as a whole which alone made possible the collection of data on which the greater part of this paper is based.

I have expressed my thanks in a previous paper to the many individuals without whose assistance I could not have organised this last expedition [WAGER, 1937, pp. 414—415]. Generous grants were made towards the cost of the expedition by the Royal Society, the Royal Geographical Society, the Trustees of the Percy Sladen Fund and the Research Board of Reading University. The work of the expedition was

further assisted by the Trustees of the Leverhulme Fellowships who awarded me a Leverhulme Fellowship for 1935—36.

Since my return to England the few marine fossils which were collected have been described by Prof. H. H. SWINNERTON, and the fossil plants by the late Prof. Sir ALBERT SEWARD. In presenting the account of the stratigraphy it is of great value to have their expert opinion on the age of the horizons from whence the fossils came.

L. R. WAGER.
Durham Colleges in the University of Durham, 1945.

II. STRATIGRAPHY

The main rock groups of Knud Rasmussens Land and the Kangerdlugssuaq region are:

1. The basement complex of metamorphic rocks.
2. The Kangerdlugssuaq Sedimentary Series resting on the metamorphic complex.
3. The thick series of Plateau Basalts, resting sometimes on the sediments and sometimes directly on the metamorphic complex.
4. The Tertiary igneous intrusions.

In the coastal region these four groups were distinguished and partly mapped during the two earlier expeditions. [See map, 1934, Pl. 12][1]). During the later expedition the mapping was improved and also extended to include the inland region. The combined stratigraphical results are summarised in the map, covering an area of 30.000 sq. km, which accompanies this paper (Plate 6).

That so large an area could be mapped in so short a time was due on the one hand to the fact that the ice cap and many of the glaciers proved to be but little crevassed, thus providing a high-road for travel, and on the other hand to the distinctness between the different rock groups mapped, and to the simplicity of the geological structures. A further contributory cause is the nature of the country which is either steep and bare, giving much information at a glance, or ice-covered, when there is no chance of rock exposures and time is not used looking for them. In the basalt country any interruption of the parallel trap featuring is conspicuous from great distances and such regions were picked out for detailed work. In the gneiss country, massive Tertiary intrusions could usually also be detected from a distance by the weathering and structural features of the rock. It is the writer's

[1]) When no author is cited in the references, the paper referred to is either by WAGER, or WAGER and DEER.

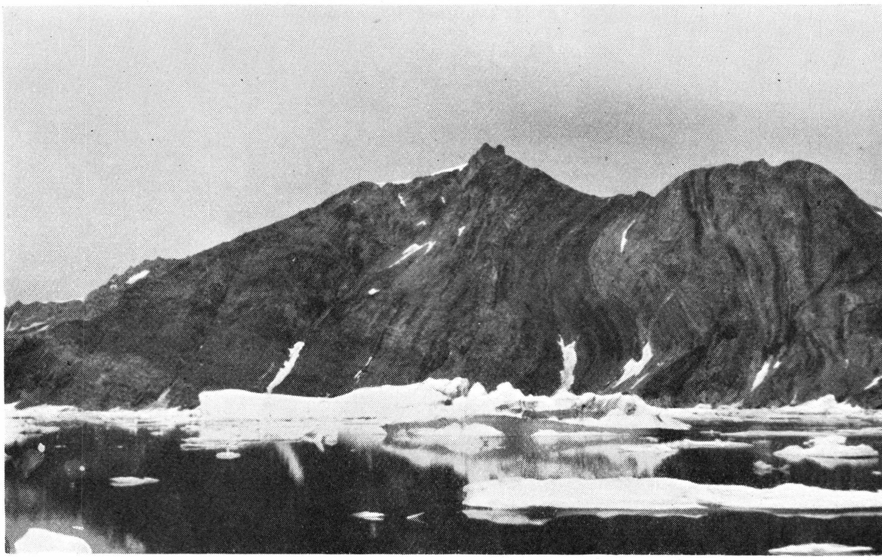

Fig. 1. Sedimentary material in the metamorphic complex of the Angmagssalik District, between Depotfjord and Bjørnebugt. The dark, folded band running from $a\,a_1$ to $b\,b_1$, is rusty weathering, garnetiferous mica schist of sedimentary origin. The rest is grey gneiss with amphibolite bands, seen well on the right hand side of the figure. The cliffs are about 400 m high.

view that, within the area of the geological map, no major intrusions or structures are likely to have escaped notice.

a. The Basement of Metamorphic Rocks.

A brief mention of the metamorphic complex around Kangerdlugssuaq is included in the general account of the geology from Angmagssalik to Cape Dalton [1934, pp. 9—19], and a petrological description of the dominant rock type, the "grey gneiss", has been given in a later paper on the Skærgaard intrusion [1939, pp. 9—12]. The investigation of the metamorphic complex of East Greenland, like that of other basement complexes, is likely to prove long and arduous. All that will be attempted here is to indicate, in general terms, its character and age. Part of the account will be a summary of previous findings.

By far the greater part of the metamorphic complex in the Kangerdlugssuaq region consists of somewhat granulitised acid gneiss in which soda felspars are dominant over potash, and in which hornblende and biotite are the usual ferromagnesian minerals. Irregular pink schlieren are found which are richer in potash felspar and represent pegmatites partly granulitised by later compression. Amphibolites form about a tenth of the whole and are not usually garnet bearing as they often are in the Angmagssalik area. A conspicuous and unusually broad band of amphibolite crosses the centre of Kraemers Ø [1934, Pl. 8], and another occurs just south of the glacier which enters the sea a kilometre south of the Kangerdlugssuaq Glacier. A band of garnet- and sillimanite-bearing gneiss on Kraemers Ø is undoubtedly of sedimentary origin [see map, Pl. 12, 1934]. Porphyroblast schists, probably partly derived from sedimentary material, also occur on Uttentals Plateau but such sedimentary remnants are rarer in the Kangerdlugssuaq region than in the Angmagssalik district. Likewise early ultrabasic masses, which are common about Angmagssalik, are rare at Kangerdlugssuaq. A remarkable magnetite-tremolite rock containing well-shaped magnetite crystals up to 7 cm across was found by Deer in the metamorphic complex of Gardiners Plateau; this is a rock type not so far found elsewhere in the region. The general appearance of the metamorphic complex of Kraemers Ø at the mouth of Kangerdlugssuaq is well shown in a photograph already reproduced [1934, Pl. 8].

The dip of the banding in the metamorphic complex at selected localities round Kangerdlugssuaq is shown in figure 9. Some of the values given were obtained by combining data from the Danish Geodetic Institute maps and from the air-photographs of the 7th Thule Expedition which were examined in a simple stereoscope. The dips given apply to a wide area around the position of the dip arrow, and such generalised values are better obtained from the photographs than in the field. Although there are not sufficient observations to show the real structure of the area it is clear that the prevailing strike is east-north-east. The same general strike was also found in the inlier of the metamorphic complex north of Nansens Fjord. In the Angmagssalik district the commonest direction of strike is east-south-east, and the metamorphic complex of the coastal mountains between Angmagssalik and Kangerdlugssuaq has a dominant easterly strike varying between these two.

In the region to the north of Scoresby Sound a Caledonian orogeny has impressed a general north-south strike on lower Palaezoic and late Pre-Cambrian sediments. Since the dominant strike of the metamorphic complex from Angmagssalik to Kangerdlugssuaq is not far removed from east-west, there is a high probability that the orogeny responsible for the strike shown by the metamorphic complex of this region is not Caledonian. A date later than Caledonian for this orogeny cannot be accepted on general grounds, and therefore the foliation of the metamorphic complex of Kangerdlugssuaq must have been produced by a Pre-Cambrian orogeny. Rocks with an east-west strike are also found in Suess Land. They have been briefly described under the name of the Silva-Maria Group by WEGMANN [1935] and from his preliminary descriptions and photographs, these rocks have apparently many similarities with the metamorphic complex of the Kangerdlugssuaq and Angmagssalik districts. The east-west strike of the Silva-Maria group, which is at right angles to the Caledonian direction, must clearly have been impressed in Pre-Cambrian times, and the rocks themselves must be Pre-Cambrian in age.

While it seems certain that no part of the metamorphic complex from Angmagssalik to Kangerdlugssuaq is later than the late Pre-Cambrian, it is probable that more than one period of Pre-Cambrian tectonic and magmatic activity is recorded in the rocks. From Kangerdlugssuaq southwards to Kangerdlugssuatsiaq the metamorphic complex seems to be of a relatively constant type but the transgressive amphibolite sheets, previously described [1934, pp. 17 and 18] provide evidence for two periods of metamorphism. At Kangerdlugssuatsiaq there is a zone of intense granulitization, and to the south of this the metamorphic complex differs in the following ways from that to the north:

1. Sediments are far more abundant
2. Certain amphibolites, which must have been sheets injected into the metamorphic complex, were subsequently themselves injected by the acid part of the metamorphic complex [1934, pp. 11 and 12]
3. Transgressive unsheared pegmatites are abundant [1934, p. 16]
4. Rocks having charnockite affinities occur in three widely separated localities [1934, p. 15]
5. There are late transgressive and unfoliated granites and gabbros which are different from the Tertiary plutonic rocks further north, and are ascribed to an earlier period of igneous activity [1934, pp. 20—21].

The metamorphic and igneous history of the Angmagssalik and Kangerdlugssuaq districts was clearly long and complicated. By a detailed study, it may one day be possible to correlate the complex of metamorphic rocks forged during Pre-Cambrian times with that of other parts of Greenland, but at present all that can be done is to point out that the Angmagssalik-Kangerdlugssuaq metamorphic complex is apparently similar to WEGMANN's Silva-Maria Group. No rocks of the Angmagssalik-Kangerdlugssuaq district so far found can be correlated with the Peterman or Gregory Valley Series of late Pre-Cambrian age [WORDIE & WHITTARD, 1930; PARKINSON & WHITTARD, 1931; ODELL, 1939].

KOCH [1935, p. 51 and 1936, p. 16] has postulated that the north-south Caledonian orogeny, so well seen in Franz Joseph Fjord, passes through the Kangerdlugssuaq region and then down the east coast to join up with the contemporaneous Appalachian folding. In an earlier paper [1929, p. 318] he gave another interpretation postulating that the Caledonian folding passed out to sea between Scoresby Sound and Kangerdlugssuaq, and thus is hidden beneath the waters of the Atlantic. As Caledonian folding occurs in the sediments to the east and west of the Silva-Maria Group of Franz Joseph Fjord, it is likely that the Silva-Maria Group itself was involved to some extent in the Caledonian orogenic movements, as Wegmann has suggested [1935]. From this evidence it is possible to argue that the metamorphic complex of the Kangerdlugssuaq and Angmagssalik districts has been involved in the Caledonian orogeny which, however, was not sufficiently powerful to obliterate the pre-existing east-north-east strike of the rocks. No observations which might be held to support this view have been made in the Kangerdlugssuaq region and it is of interest to note that Wegmann believes that the Caledonian orogeny did not affect the region studied by him in south-west Greenland [1938, p. 132]. It seems reasonably certain that the Caledonian orogenic belt of North East Greenland did not pass southwards through the Kangerdlugssuaq-Angmagssalik region and that, therefore, it must either have ended surprisingly abruptly in the neighbourhood of Scoresby Sound or, must lie down-sunken beneath the Denmark Strait, or, if the hypothesis of continental drift be correct, it must be continued in the rocks on the opposite shores of the North Atlantic.

b. The Kangerdlugssuaq Sedimentary Series.

This name was originally given to a thin series of shallow water sediments without recognisable fossils, lying unconformably on the metamorphic complex and conformably beneath the plateau basalts in Mikis Fjord [1934, p. 25]. The age of the series was presumed to be somewhat earlier than the fossiliferous Eocene sediments of Kap Dalton. Sedimentary rocks occypying the same stratigraphical position, and often of greater thickness, have now been found over a wide area. At one locality marine fossils have been found in them and fossil plants at others. The term Kangerdlugssuaq Sedimentary Series is now extended to cover all the sedimentary rocks lying between the metamorphic complex and the Plateau Basalts found in the area. From a broad stratigraphic point of view the whole of these sedimentary rocks form a single unit; their systematic subdivision could no doubt be accomplished but must be left for the future.

1. Description of the principal Localities.

Re-examination of Vandfaldsdalen, the name since given to the original locality for the Kangerdlugssuaq Sedimentary Series in Mikis

Fig. 2. The Kangerdlugssuaq Sedimentary Series underlying the Main Tuffs on the north side of Rybergs Fjord near the head. The conspicuous light horizon (c) is a sandstone at the top of the sedimentary series which has been displaced by the injection of a dolerite sill. Below are shales (d), and above, tuffs (b) with some sills such as the one forming the skyline on the left of the photograph (a). The cliffs are about 300 m high.

Fjord, has led to a better lithological subdivision and to a more exact estimate of their thickness in that locality. The revised sequence, taken immediately south of the macrodyke which cuts across the head of the valley, has already been given in the paper on the nearby Skærgaard intrusion [1939, pp. 12—14] and the outcrop has been shown on a map of the scale 1:40.000. For the sake of completeness the sequence is repeated here.

Plateau Basalts.

Kangerdlugssuaq Sedimentary Series	Conglomerate	20—50 ft.
	Sandstones and sandy shales	250 ft.
	False bedded sandstone often calcareous	100 ft.
	Ferruginous sandstone................	200 ft.

(Base not seen but probably not far below).

Even within Vandfaldsdalen the series is variable; thus on the west side of the valley the conglomerate is overlain by 2 m of shale while on the east side the lowest lava rests directly on the conglomerate.

On Mellemø in the Skærgaard which is 10 km west of Mikis Fjord, only two metres of sediment are found resting on the gneisses [1934,

p. 26, and map in 1939]. These have been preserved by their proximity to the Skærgaard intrusion, and an unknown amount has been removed by erosion. Traced still further west the sediments become thinner and disappear. Thus on Amdrups Pynt, between the gneisses and the overlying lavas, there are only a few feet of sediment mixed with volcanic ash, and the whole is much metamorphosed. North-east of Kap Edvard Holm where the ridge ends against the south-east distributary of Hutchinsons Gl. no sediments were found, the lavas resting directly on the metamorphic complex. A kilometre north of this locality, however, there is again a little sediment below the first lava, and as on Amdrups Pynt, this is mixed with volcanic material. The sediments mentioned in this paragraph have not been indicated on the map (Pl. 6) because of their thinness.

Traced north-eastwards from Mikis Fjord the sediments increase in thickness. They form a highly variable series, which is badly exposed because more easily eroded than the dolerite sills injecting it and the basalt lavas overlying it. Mapping of subdivisions of the sedimentary series has not been attempted, and estimates of thickness are only approximate, having been made with difficulty owing to the dolerite sills. The map (Pl. 6) shows the general distribution of the sediments, and observations of the sequence at selected localities will be given here.

At the head of Rybergs Fjord, on the north-east side, a white sandstone, about 20 m thick, immediately underlies a thick series of tuffs (Fig. 2). Below the sandstone there are 200 metres or more of silty shales, and during a hurried examination no fossils were found. The base of the series was not seen.

At the head of Nansens Fjord, on the north-east side, an unexpected mass of gneiss occurs which, when seen from the fjord, seemed to stretch far inland. Probably basalt lavas rest directly on the gneisses but scree covered the junction at the place examined and the occurrence of a few feet of sediments was not entirely precluded. No rocks below the plateau basalts have been seen along the coast to the north-east of this point until Scoresby Sound is reached, and none are likely to be exposed inland as neither gneisses nor sediments have been found in the moraines of the glaciers descending from the coastal mountains.

In the inland region, to the north of J. C. Jacobsens Fjord and south of Sortekap, the sediments consist of silty shales and sandstones, extensively injected by dolerite sills. In passing along the ridge which trends south-east from Sortekappasset to Pyramiden, the first sediments are silty carbonaceous shales with septarian nodules. The next type found on the further side of the first saddle in the ridge is a light grey micaceous shale which is less silty and less carbonaceous than the usual shales of the Kangerdlugssuaq Sedimentary Series; in this a few belemnites were found which are so far the only marine fossils found in position. These are mentioned again below as they provide evidence for the age of the series. Further along the ridge the more carbonaceous type of sediment begins again, consisting of silts and sandy shales with bands of sandstone up to 30 cm thick. Nodules were found, some of clay-ironstone, some calcareous, and some phosphatic, but in a hurried search no fossils other than worm casts were seen. Pyramiden was not reached but could be seen to consist of sediments injected by sills. Solifluxion makes it difficult to determine the lie of the beds but the shales with belemnites were apparently low in the sequence. Sortekap, the peak which dominates the sedimentary ridge at its northern end, was named from the small capping of dark and approximately horizontal sediments with included sills which rest unconformably on the gneisses and form its summit (Pl. 3, fig. 2). The position of the sediments on the summit of Sortekap and at its southern base shows that a fault with a throw of several hundred metres passes through Sortekappasset. The upper part of Narren, the peak to the north of Sortekap which was not visited, is also apparently made of sediments with a capping of basalt. A further 15 km north of Narren, metamorphosed sediments with ill preserved plant remains were found by Deer on Trillingerne. They owe their preservation to their association with a small volcanic neck.

The mountains separating Sorgenfri Gl. and Christian den IV's Gl. and stretching from the head of Rybergs Fjord to Isfaldgletscher, a distance of 60 km, are mainly composed of sediments and sills with only here and there a capping of the basalt-tuff series. At the north end of this stretch is Kulhøje where fragments of Tertiary coal were found. The south-east point of Kulhøje consists of sandstones, shales, thin coals and conglomerates. In the conglomerates are abundant well-rounded pebbles of basalt indicating that somewhere in the neighbourhood the Tertiary igneous activity had already begun. A kilometre to the north a section was examined consisting of about 250 m of sandstones and shales, some of which were highly carbonaceous. In the sandstones leaf impressions and fossil fruits were found in a state of rather poor preservation. This is the material which has been described by Seward & Edwards [1941]. The sediments were also examined further south about Dumpen and Vejrgabet. A kilometre north-east of Dumpen, 200 m of silty sandstones and shales were ascended but no recognisable fossils obtained. At the top of Vejrgabet sandstones with poor plant remains were found, and also a conglomerate, mainly of quartz and gneiss fragments. The sandstones and conglomerate were considered to overlie the shales examined north of Dumpen. Sandstones with poorly preserved plants were again encountered at the south-west foot of the pass. These seem to be the same as the ones at the top of the pass 100 m above, and their position may be due to downthrow by the Sortekappasset fault which may extend to about this point. On the east side of Christian den IV's Gl. sediments were not actually collected but from a distance were believed to form the southern part of Skærmen.

On the south-west side of Urbjærget, 20 km north of the head of Kangerdlugssuaq, the basalts were observed to rest directly on the metamorphic complex which is weathered to a depth of 10 m. The surface on which the basalts were poured out is irregular in detail; where examined it declined 15 m in a horizontal distance of 100 m, and a coarse arkose made its appearance between the gneiss and the lowest lava. In this region there is no thick and constant series of sediments between the metamorphic complex and the basalts. The same is probably true for the region between Trekantnunatakker and Hutchinsons Plateau as Deer found no sediments there during his summer journey through the region.

2. Conditions of Formation, Age, and Comparisons with other Areas.

The Kangerdlugssuaq Sedimentary Series rests on a fairly even surface of the metamorphic complex having an unaccentuated relief. During the deposition of the sediments, parts of the surface, for instance around Kap Edvard Holm, around Urbjærget in the inland region, and around the head of Nansens Fjord, stood a little above the general level and never became covered by sediments; or, if they were covered by sediments, slight uplift and erosion caused their removal before the lavas were poured out. It cannot be assumed that the sediments began to be deposited simultaneously in all the areas in which they occur. The sediments containing belemnites on the ridge south-east of Sortekap are marine, and sufficient fragments of organisms were found in some of the sediments between J. C. Jacobsens and Rybergs Fjords to prove that they also are marine. This marine transgression took place early in the period of formation of the Kangerdlugssuaq Sedimentary Series, and it apparently only extended over the lower part of the basin of deposition which included the region between Rybergs Fjord and Sortekappasset.

The Kangerdlugssuaq sediments appear to have been shallow water and estuarine in origin. On the whole the series consists of silty shales but, at the top in widely separated areas, a sandstone and conglomerate facies occurs which seems to indicate the complete silting up of the shallow basin of deposition. The upper limit of the sediments, like the lower, does not mark a constant time horizon. The basalt pebbles in the conglomerate at Kulhøje show that igneous activity had already begun in some neighbouring region. A widespread tuff formation described below, is regarded as marking a constant horizon, and using this as a datum, it appears that a thick series of lavas in Mikis Fjord lying below the main tuff horizon was formed approximately contemporaneously with the sediments which immediately underlie the tuffs in the area to the north-east and east. The extrusion of basalts in a shallow basin would be expected to prevent the further accumulation of sediments because the basalts would quickly rise above the level of deposition of the sediments, and this seems to have happened in the Mikis Fjord area.

The age of the Kangerdlugssuaq Sedimentary Series, formerly estimated as slightly older than the middle Eocene rocks of Kap Dalton, [1934, p. 27] can be more firmly established by means of the fossils since found in them. The few belemites from the sedimentary ridge south east of Sortekap have been described by Prof. H. H. SWINNERTON [1943] as *Actinocamax* cf. *blackmorei Crick*, *Actinocamax* cf. *plenus* (Blainville) and *Actinocamax* sp. He considers that they suggest a Senonian age for the marine horizon from which they come. The fossil plants collected at Kulhøje on the west side of Christian den IV's Gl. have been described by the late Professor Sir. ALBERT SEWARD and Mr. W. N. EDWARDS [1941]. They list the following: *Sequoia langsdorfi* (Brongn.), *Elatocladus* sp. cf. *Eungeri* (Heer), *Platanus* sp., *Cercidiphyllum richardsoni* (Heer), Fruits of *Cercidiphyllum*, *Palaeanthus* sp., and they point out that these few specimens may be closely matched among the more extensive flora of West Greenland which they regard as of very early Eocene age. The field evidence suggests that the plant bearing beds followed the marine shales containing belemnites with but a short time interval between. It appears likely, therefore, that the Kangerdlugssuaq Sedimentary Series is Senonian to lowest Eocene in age.

The sequence of events during the deposition of the Kangerdlugssuaq Sedimentary Series may be summarised as follows:

1. A Senonian transgression reaching the lower parts of an approximately peneplained surface of the metamorphic complex. The marine deposits, now shales, probably formed in a narrow arm of sea limited by land to the west and east.

2. The deposition of estuarine sediments in a rather more extensive basin, the western margin of which lay in about the position of Kangerdlugssuaq and the eastern margin about Nansens Fjord. The upper part of these sediments tends to be coarse sandstones or conglomerates, suggesting the complete silting up of the basin of deposition.

3. While sediments were still forming in the inland region, accumulation of basalts and volcanic ash began about Mikis and J. C. Jacobsens Fjords.

Other sedimentary rocks approximately contemporaneous with the Kangerdlugssuaq Sedimentary Series are known from Greenland. Thus from Disco and neighbouring regions on the west coast Ravn [1918] has described a marine horizon belonging to the Senonian, and beds containing a rich fossil flora are associated with it [Seward, 1926]. The whole sedimentary series is usually now accepted as Cretaceous to Eocene. The region is being re-examined by Prof. A. Rosenkrantz and others, and further comparison may best await the completion of their work[1]). In North-East Greenland (see Fig. 10) a series of sediments occur at Cape Hold-with-Hope. These are 100 m or more thick and contain a few fossils, mostly *Pteria* and *Inoceramus*, which indicate according to Freebold [see Koch, 1935] about a Middle Senonian (Upper Emschian) age for the rocks. Still further north plant remains were collected long ago on Sabine Ø in an estuarine series [cf. Mathiesen, 1932], and similar deposits are now known from several neighbouring localities. From the published descriptions it is clear that these estuarine deposits are like the upper part of the Kangerdlugssuaq Sedimentary Series of the Christian den IV's Gl. region, and they are usually considered of similar Lower Eocene age. At Kap Gustav Holm, 200 km south of Kangerdlugssuaq, metamorphosed sediments have been found containing poorly preserved fossils, some of which certainly belong to the genus *Glycimeris* [1934, pp. 22—25]. These sediments underlie the lava series and indicate a definite marine transgression, which may well have been approximately contemporaneous with the Senonian transgression in Knud Rasmussens Land. The only other Greenland locality of Tertiary sediments so far found is Kap Dalton where marine fossils were collected by Nordenskiold and Hartz in 1900. According to Ravn [1904 and 1933] the deposits are Lower or possibly Middle Eocene. Later work by Sorgenfrei [1940] suggests that they may be somewhat younger. The Kap Dalton sediments have been shown to occur near the top of the Tertiary lava series [1935, pp. 13 and 26].

The palaeo-geography of the Greenland region in the late Cretaceous and Lower Eocene is an elusive problem. Marine transgression of Senonian age has been proved in the Disco Bay region, in Knud Rasmussens Land, in the Hold-with-Hope region, and probably also on Kap Gustav Holm, and it may be asked whether this implies that there was an extensive marine transgression over much of the Greenland Shield resulting in a connection between the east and west coast Senonian provinces, or whether the transgression covered only the present coastal areas. The evidence from Disco Bay indicates that the

[1]) Since writing this a valuable preliminary account has become available [Rosenkrantz 1942].

basin of deposition of both the estuarine and marine sediments was limited eastwards; Koch suggests that the limit was abrupt, perhaps a coastal cliff [1929, pp. 300—304][1]). In Knud Rasmussens Land the sediments become thinner and disappear when traced westwards. Thus the meagre field evidence at present available suggests that there was no connection between the west and east coast basins of deposition. This point might be further investigated if a larger collection of marine fossils could be collected from the east and west coast Senonian deposits, as it might then be clear from the assemblages whether there was at that time a sea connection across Greenland or not. Ravn [1918] considered that the Senonian fossils of West Greenland were more closely related to those of Montana than to those of the east coast of America [see Koch, 1929, pp. 260—261][2]). A larger collection from the East Greenland Senonian deposits would be of interest in relation to this observation. In East Greenland a reasonably extensive fauna might well be found if a detailed search were made in the mountains between the Sorgenfri Gl. and Christian den IV's Gl. At the same time a larger collection of fossil plants could undoubtedly be obtained there.

c. The Plateau Basalt Series.

The thick series of basalts in the Kangerdlugssuaq region and Knud Rasmussens Land forms a wide-spread stratigraphical unit of value in determining the structure of the region, and only the stratigraphical aspect will be considered in this paper. Steep mountain sides or coastal cliffs of the typical plateau basalts show the flows to be sensibly parallel to each other over wide areas; the pile of lavas seems to have been built up as shown by Noe-Nygaard [1942, Fig. 25]. By comparison with the slope of lava flows of comparable composition in Iceland or Hawaii, it seems likely that the flows of a basalt plateau such as that of Knud Rasmussens Land would be within 1° of the horizontal, a value of the same order as that for the original slope of sheets of ordinary marine sediments. Thus the dips of the plateau basalts recorded on the geological map [Pl. 6] are regarded as having the same value for the purposes of elucidating the structure or determining thicknesses as the dips of an ordinary sedimentary formation.

A general account of the basalts from the coastal parts of Rasmussens Land and the Kangerdlugssuaq region has been given in a previous paper [1934, pp. 29—34]. Since then, as a result of the various journeys of the British East Greenland Expedition in 1935—36, and

[1]) The Idea of a coastal cliff is not supported by Rosenkrantz [1942, p. 69].
[2]) See also Rosenkrantz [1942, p. 39—41].

of Lindsay's journey in 1934 [see Wilson, 1935], a large inland area has been shown to consist of basalts. Over much of the region a fair sampling of the basalts has been made. Except for certain special areas to be mentioned below, the general description given previously for the coastal sections holds for the whole basalt region south of Kap Dalton and probably also for the Scoresby Sound region, judging by Nordenskiold's description [1909].

Used in a stratigraphical sense the term Plateau Basalt Series will be taken to mean the whole pile of basalts with interbedded tuffs, which are found in the region. Not all are typical plateau basalts. Thus the upper basalts in the Prinsen af Wales Bjærge are of varied types which do not form parallel sheets, and these have been put into a special sub-division. Furthermore, the lower basalts between Kangerdlugssuaq and J. C. Jacobsen's Fjord show evidence of having been extruded under water and are associated with abundant tuffs, which are scarce or absent in the normal plateau basalt pile. They are shown to be earlier than the main plateau basalts and are classified as the Lower Basalts and Tuffs. The broad variation at different localities can be illustrated by vertical sections (Fig. 3). In the following account of typical localities the coastal region west of Kangerdlugssuaq is considered first, then the coastal region east of Kangerdlugssuaq and finally the inland region.

1. Sequence at Typical Localities.

Within the region covered by the map only small areas of basalt are preserved to the south west of Kangerdlugssuaq and these are only in the proximity of the Kap Edvard Holm Intrusion. The largest area forms the ridge stretching west-north-west from Kap Edvard Holm. This consists of basalts and thick gabbro sills, cut through by the coastal dyke swarm. The southern face of the ridge is precipitous and dangerous from falling stones and the northern is a good deal scree-covered; observations are thus rather incomplete. The highest basalts now preserved are adjacent to the gabbro forming the headland of Kap Edvard Holm; they are dipping at about 40° east-south-east, and are altered by the gabbro and injected by acid material; the coastal dyke swarm is here moderately dense. Further west-north-west along the ridge, lower horizons of the basalts are seen to be dipping more steeply, and the dyke swarm is much denser. A gabbro sill at least 300 m thick is injected into these basalts; it shows feeble banding parallel to the dip of the basalts and abundant inclusions of basalt occur near its base. Acid veins are so abundant that in some places a breccia of basalt and gabbro, surrounded by acid material has been produced. Still further west-north-west the basalts are less metamorphosed and resemble those

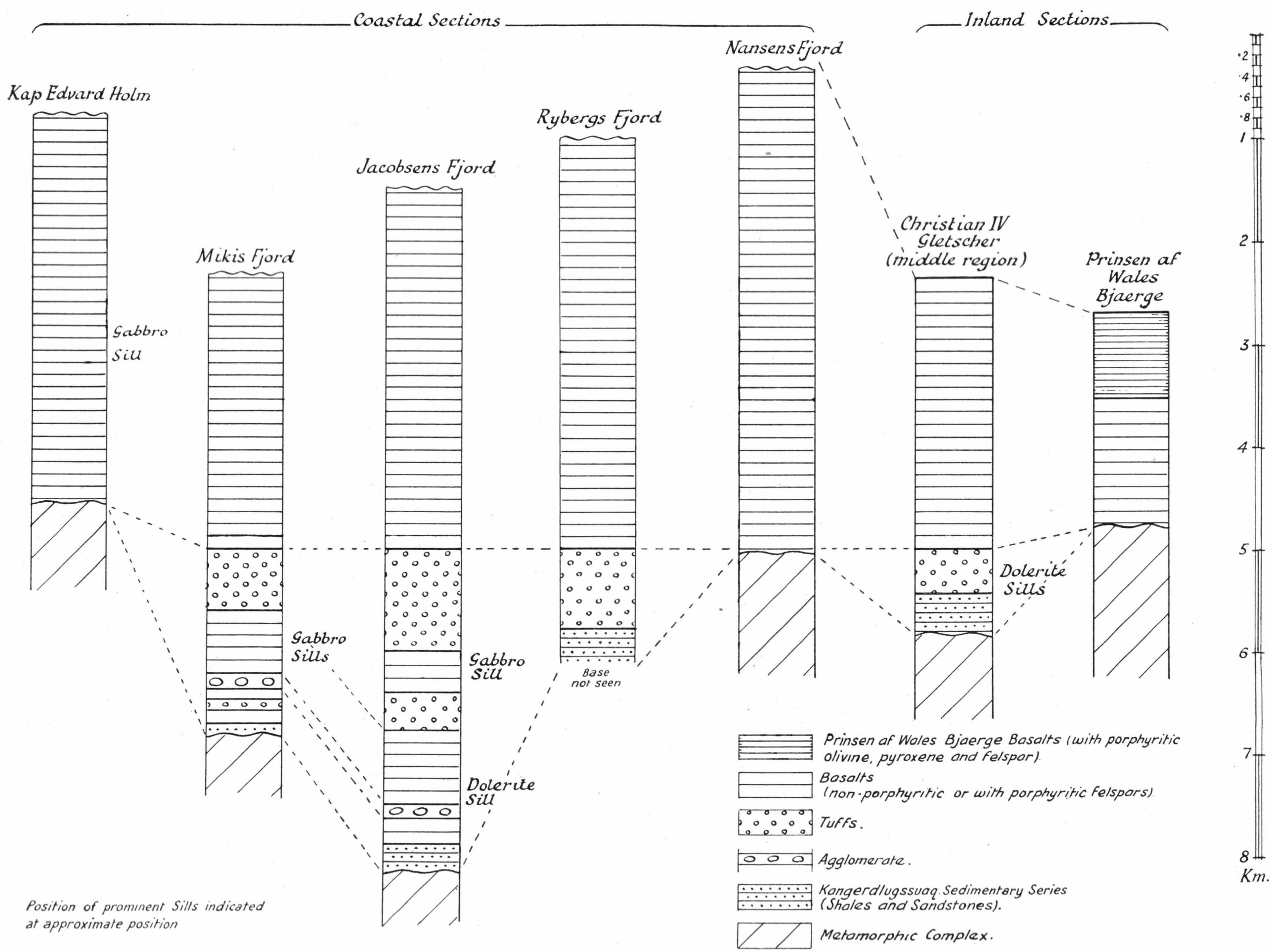

Fig. 3. Vertical sections arranged on the assumption that the Main Tuffs represent a definite time horizon. Erosion of the top of the series in the coastal sections is indicated by a wavy line, while the view that the original top surface is still preserved in some places inland is indicated by the straight line at the top of the last two columns. The presence of gabbro or dolerite sills has been indicated only where they are of considerable thickness.

from Mikis Fjord which have undergone decomposition of spilitic type. Here the basalts are dipping at 60° east-south-east and the dyke swarm is particularly dense. Where the descending ridge ends against the south-east distributary of Hutchinsons Gl. the basalts are seen resting directly on the gneisses without any intervening sediment. The estimated thickness of basalts and included gabbro sills is 4 km (Fig. 3); the dykes, being roughly perpendicular to the lavas, do not affect this estimate significantly. On Amdrups Pynt, immediately north of the Kap Edvard Holm intrusion complex, basalts are found resting on the gneisses with only a thin, tuffaceous sediment between. The thickness of the basalts, which are thoroughly metamorphosed, is of the order of 100 m, and the dip averages 25° south. Keglen Ø to the east of Kap Edvard Holm consists of basalts with thin crystal tuffs dipping south-east at 10° [1934, p. 35]. The position of these basalts in the lava series is not known but is surmised to be high, both from their position and the fact that the tuffs consist of fragments of perthitic felspar and trachyte, derivatives of a magma type considered to have been available only late in the sequence of igneous activity of the region.

To the south of the Kap Edvard Holm intrusion and within the limits of the map, 50 m of metamorphosed tuffs were found on Nordre Aputiteq. They occur adjacent to the gabbro which forms the bulk of the island, and they consist mainly of fine grained types with occasional coarser bands having blocks up to 30 cm across. These tuffs are regarded as belonging to the Plateau Basalt Series but so far they have not been correlated with any particular horizon elsewhere.

The sequence of the lavas and tuffs in the country between Kangerdlugssuaq and Mikis Fjord has been given in the paper on the Skærgaard intrusion where also a map on the scale of 1:40.000 is to be found [1939, pp. 14—18 and map 1]; the sequence is summarised in Fig. 3. Further east, in J. P. Jacobsens Fjord the sequence is rather similar (Fig. 3). A low horizon is exposed in the valley running north-north-west from the head of the fjord but the base of the series and the sediments below are not actually seen until the watershed into Sødalen has been crossed. The band of coarse agglomerate, which occurs in Mikis Fjord, forms a conspicuous feature in the valley at the head of Jacobsen Fjord. It contains blocks a metre across and, as in Mikis Fjord, many of the blocks are rounded and have a chilled crust, features suggesting a peculiar origin. Between the lower lavas red partings are not conspicuous, and about the head of the fjord many of the basalts have undergone spilitic alteration and are considered to have been extruded under water, like those from the east end of Mikis Fjord. In the middle stretch of the fjord there is a thick tuff horizon with intercalated lavas and a thick gabbro sill; these tuffs, from their position and character, clearly belong to what has been called the Main Tuff horizon[1]) of Mikis Fjord and Hammerdalen [1939, pp. 14—18]. The higher lavas, lying above the Main Tuffs, extend to the mouth of the fjord. They dip at about 30° to the south and are cut through by the coastal dyke swarm, which is here very dense. The estimated thickness of the lava-tuff series now visible in J. C. Jacobsens Fjord is $6^1/_2$ km and some of the upper lavas have certainly been removed by erosion.

In Rybergs Fjord the Main Tuffs rest directly on the Kangerdlugssuaq Sediments (Fig. 2); the lavas, tuffs and the coarse agglomerate which underlie the main tuffs in Mikis and J. C. Jacobsens Fjord are missing, and presumably the sediments continued to be deposited till a later period. In Nansens Fjord, lavas rest directly on the metamorphic complex, and in the lower 300 m no tuffs were found. It is likely that the main tuffs are here missing and that the region about Nansens Fjord stood up as an island of gneiss, not only while the sediments were formed, but while two to three kilometres of lavas and tuffs were accumulating in the region to the west. The lavas at present seen in Nansens Fjord were roughly estimated to be 5 km thick, and the upper part of the series, as in J. C. Jacobsens Fjord has been removed by erosion.

In the middle region of Christian den IV's Gl. the lower part of the Plateau Basalt Series was particularly examined in the rock walls surrounding the small glacier running north-west from Peak 2.000 m of the Skærmen. Two or three hundred metres of tuffs without any conspicuous sedimentary horizon, but injected with abundant dolerite sills, are succeeded by several basalt flows with conspicuous red partings; higher up there appeared to be another thin horizon of tuffs which was not reached, while above lay the uninterrupted plateau basalts from which the Watkins Bjærge are carved (Pl. 1). The tuffs are for the most part fine-grained though at one horizon basalt blocks up to 30 cm across occur. In the lower tuffs a few small, well-rounded pebbles of gneiss were found, indicating that there was occasional wash of pebbly material into the area, perhaps from the gneiss island which is presumed to have existed at that time to the south round the head of Nansens Fjord. The tuffs are green and brown in colour and shaley in texture especially in the upper part; some contain undecomposed basic glass. These tuffs are in a different state from the flinty tuffs of Mikis and J. C. Jacobsens Fjords, which were deposited in water, and it is considered that the inland tuffs were accumulated subaerially. This inference is supported

[1]) In the early paper on the general geology from Kap Dalton to Angmagssalik, the various tuff horizons were confused [1934, pp. 34—35]. Field work in 1935—36 enabled them to be distinguished and the correct sequence was given in the Skaarguard paper [1939, pp. 14—15].

by the red partings between the basalts which immediately overlie the tuffs. From a distance it appeared that the southern end of the Skærmen is formed of sediments underlying the tuffs, and evidence that tuffs overlie the sedimentary series on the west side of Christian den IV's Gl. was obtained from fallen blocks. The tuffs in this inland region are correlated with the Main Tuffs of the coast, the difference between them being regarded as the result of the submarine formation of those now found along the coast, and the subaerial formation of those in the inland region.

The stupendous south wall of Watkins Bjærge shows 2.200 m of basalt lavas overlying the tuffs just described, and taking into consideration the slight dip to the north, there must be about $2^1/_2$ km of basalts between the tuffs and the summit of Watkins Bjærge (Pl. 1). These lavas which were examined at Ivory Gull Nunatak, at the foot of Gino Gl. and on the upper 1.500 m of the highest peak of Watkins Bjærge (Gunnbjørns Fjæld), were all classed in the field as basalts. Many have porphyritic felspars as, for example, the thick flow which forms the highest exposed rock of the Watkins Bjærge. Red partings are of frequent occurrence and the whole $2^1/_2$ km apparently accumulated subaerially.

On Urbjærget to the north of Kangerdlugssuaq, basalts, comparable in a general way with those of Watkins Bjærge, rest directly on deeply weathered gneisses, and the surface is irregular in detail as already mentioned (p. 16). The lowest lava is a fine-grained, non-porphyritic tholeiite about 6 m thick, and similar types form the lower 150 m of the lava series. Well developed red partings do not occur but the gneisses on which the lavas rest have been weathered deeply, giving a friable rock, almost a gravel, which is not likely to have been under water. High on Urbjærget there are red stained upper parts to the flows but still no well developed red partings. It is suggested that here the lavas were poured out subaerially and that between successive flows there was not time for the formation of a true red parting. Above the lower, non-porphyritic lavas are several much thicker ones, averaging 50 m, which have porphyritic felspars. Then follow flows which are sometimes porphyritic and sometimes non-porphyritic. In the inland regions it was noticed that the flows with porphyritic felspars were thicker on the average than those without, although exceptions were found. Tuffs do not occur on Urbjærget, and were not found in the other parts of the Prinsen af Wales Bjærge visited. It is considered that the lavas in this area were formed later than the main tuffs (see Fig. 3). A similar series of lavas to those on Urbjærget were examined on the southern Frederiksborg Nunatakker, on Sewards Nunatakker and on the nunataks south of Trekantnunatakker to the north-west of Kangerdlugssuaq.

Fig. 4. View among the Prinsen af Wales Bjærge showing the upper porphyritic lava series with variable dips, resting on the almost horizontal normal plateau basalts. The section described in the text was observed on the mountain above the leading dog.

The upper parts of the Prinsen af Wales Bjærge and of the Trekantnunatakker are cut from a set of lavas different from the typical plateau basalts, in that the flows are not parallel to each other but lie at various angles with as much as 30° difference in dip in a relatively short distance (compare Fig. 4 and Pls. 1 & 2). On first seeing this upper series from a distance it was thought that the irregular lie of the basalts had been produced by tilting due to laccolitic intrusion. When the rocks were reached it was found that these irregularities of dip were widespread in a distinct series of lavas lying above the typical plateau basalts, and they have been given the name Prinsen af Wales Bjærge lavas. The series was particularly examined on the mountains lying 3 km north-west of the point where the 2° dip arrow is marked, 25 km north-north-west of Urbjærget (see map Pl. 6). The flows are mainly porphyritic and of no great thickness, but some are fine-rained, and indeed the thickest lava found was fine-grained throughout, which is contrary to the usual relation between thickness and the presence of phenocrysts. The large porphyritic crystals, which may be very abundant, are olivines, pyroxenes, tabular plagioclases and iron ore. The ground mass is frequently rich in pyroxene, and in some cases contains abundant analcime. Occasional narrow dykes or veins of a fine-grained basic rock were seen. The lack of parallelism between the flows is not due to tectonic movement or later intrusion of magma but is presumably due to the greater viscosity of these lavas when extruded. The existence of a former volcanic vent was suggested by the limited rock exposures at Tjælderbjærget, and perhaps others will be found when the region is examined in more detail. It seems likely that the lavas forming this upper series did not flow far from their point of extrusion. The present extent of the Prinsen af Wales Bjærge lavas is not great (see Pl. 6), but large blocks of similar lavas occur as inclusions in the large Kangerdlugssuaq intrusion on the west of the fjord. This shows that the upper porphyritic series formerly extended far south of its present outcrop. It is not likely that the series extended far to the east as the moraines of glaciers draining the inland area did not show these types of lavas where examined on the coast between Nansens Fjord and Kap Dalton. The total thickness of lavas in the region north of Kangerdlugssuaq is 2 km, and of these about 800 m consist of the Prinsen af Wales Bjærge prophyritic series (Fig. 3).

2. Correlations and Age.

The thick tuffs, called the Main Tuffs, which are found in Mikis, J. C. Jacobsens and Rybergs Fjords and in the middle region af Christian den IV's Gl. are believed to represent a definite period of explosive igneous activity and to provide, therefore, a basis for correlation which has been made use of in figure 3. Below the Main Tuffs in Mikis Fjord there are 1.500 m of basalts, tuffs and agglomerates. In J. C. Jacobsens Fjord the Main Tuffs are thicker and are split by basalts and a gabbro sill but the sequence below is similar to that in Mikis Fjord. In Rybergs Fjord and in the central region of Christian den IV's Gl., the Main Tuffs are present but they rest directly on the Kangerdlugssuaq sediments. On Kap Edvard Holm to the west and in Nansens Fjord to the east the Main Tuffs, with the lavas and tuffs below them, were not accumulated; any tuffs that may have been deposited in these places are assumed to have been washed into the Mikis and Jacobsens Fjords area. It is worth noting that in various parts of the basalt area of West Greenland an early phase was explosive [cf. Noe-Nygaard, 1942].

Thanks to the relatively high dips in the coastal areas the thickness of lavas there can be estimated. In Mikis and J. C. Jacobsens Fjords $2^1/_2$ and $3^1/_2$ km of basalts later than the Main Tuffs are visible, and in Nansens Fjord, $4^1/_2$ km. On Kap Edvard Holm 4 km of lava believed later than the Main Tuffs can be seen, but this thickness includes some gabbro sills. The large number of dykes of the coastal swarm have no significant effect on these estimates, since they are approximately perpendicular to the lavas. In all the coastal sections the uppermost lavas have been removed by erosion, and it is likely that around Mikis and J. C. Jacobsens Fjords the thickness removed is greater than elsewhere because the dips are high and, for a given volume eroded, a lower horizon of the plateau basalts would be reached. It seems likely that before erosion the thickness of lavas above the Main Tuffs in Mikis and J. C. Jacobsens Fjords would have been at least as great as in the Kap Edvard Holm and Nansens Fjord regions, that is, at least $4^1/_2$ km. If this is so then the total thickness of lavas in J. C. Jacobsens Fjord must have been at least $7^1/_2$ km. Inland in the Watkins Bjærge, the total thickness of lavas, all of which were poured out later than the Main Tuffs, is $2^1/_2$ km, and in the Prinsen af Wales Bjærge only 2 km. Physiographic evidence from certain inland plateaus suggests that few or none of the lavas there have been removed by erosion[1]), and therefore, that the pile of lavas at present to be observed in the Watkins Bjærge and Prinsen af Wales Bjærge areas represents the total thickness of lavas accumulated there. Whether lavas are entirely lacking a short way further west under the ice cap is not known, but considering the rapid thinning between the outer coast and these inland mountains, a distance

[1]) The physiographic evidence will be given in a later paper. As, however, the thickness of the inland lavas is of importance in the later discussion of the tectonics, it may be noted that the evidence depends on the existence of ice covered basalt plateaus. The surfaces of the plateaus are parallel to the lava flows and this surface is regarded as the original top surface of the lava pile.

of only 100 km, it seems likely that the lavas do not persist much further west, and certainly do not stretch the 700 km to the west coast of Greenland.

The thick series of lavas above the Main Tuffs has not so far been subdivided except inland where the porphyritic Prinsen af Wales Bjærge series has been distinguished. Lava fields covering wide areas are to be expected to show both a vertical variation dependent on time of formation, and also a horizontal, regional variation. These two factors are liable to complicate the task of subdivision. Such slender observations towards the solution of the problem of subdivision as have been made suggest that the first kilometre or so of lavas later than the Main Tuffs are mainly free from prophyritic felspars from Kangerdlugssuaq to Nansens Fjord. These apparently form a lower mainly non-porphyritic group. For the Blosseville Coast it has already been suggested [1934, p. 33] that a mainly non-porphyritic series lies immediately below the Kap Dalton sediments, and that this series probably extends from Kap Brewster at least as far south as Kap Ewart forming an upper mainly non-porphyritic group. From NORDENSKJOLDS observations [1909] it is probable that a thin series of non-porphyritic basalts also overlies the sedimentary horizons where developed north of Kap Dalton [1935, p. 26]. Below and to the westward of the upper non-porphyritic series underlying the Kap Dalton sediments, there is a kilometre or so of lavas in which porphyritic felspars are abundant, and perhaps these are roughly equivalent to the inland lavas of Watkins Bjærge which are also often porphyritic and overlie what is called above the lower non-porphyritic group.

The lavas now exposed in Knud Rasmussens Land and the Blosseville Coast were extruded aubaerially, except round the mouth of Kangerdlugssuaq. In the latter area a great thickness of lavas, both below and for some distance above the Main Tuffs, apparently accumulated under water. Sinking of the lava pile concomitantly with extrusion must have taken place in this area. Sinking must also have taken place during, or soon after, the accumulation of the Plateau Basalt Series about Kap Dalton since the marine Kap Dalton sediments formed immediately or soon after the extrusion of the highest basalts[1]).

[1]) Professor H. BACKLUND [1944] has postulated that the thick basalt pile between Kangerdlugssuaq and Scoresby Sound has been largely formed by successive injections of sills and not by extrusion of lavas on the surface. As Professor BACKLUND has rightly emphasized, there are unsolved problems connected with the Kap Dalton sediments [BACKLUND 1944 pp. 68—70 and WAGER 1935 pp. 27—30] and other unsolved problems connected with the origin of the Tertiary basalt plateaux in general. Nevertheless on the field and general evidence available the writer considers as untenable the hypothesis that the basalt plateau of Knud Rasmussens Land has been built up by sill injection.

The age of the East Greenland plateau basalts is better established than for any other part of the Thulean province as it is possible to estimate the period when extrusion was ending as well as when it began. The earliest basalts are late Senonian or just post-Senonian on the evidence of the belemnites from the Kangerdlugssuaq Sedimentary Series, and they are contemporaneous with the presumed early Eocene flora from the upper part of the sedimentary series. The evidence from Kap Dalton given in a previous paper [1935, pp. 11—13] shows that the highest basalts of that region immediately preceded the deposition of fossiliferous sediments of Lower or Middle Eocene age [Ravn, 1933] or possibly slightly later age according to Sorgenfrei [1940]. From the general lie of the basalts along the coast and the tentative correlations suggested in a previous paragraph, it is likely that the basalts beneath the sediments at Kap Dalton are equivalent to a high horizon of the lavas in the Kangerdlugssuaq region. Perhaps a few lavas north of Kap Dalton are slightly later than the Kap Dalton sediments [1935, p. 26], but whether this is so or not it seems clear that basalt extrusion was ending in about Middle Eocene times. In East Greenland, West Greenland, and the British area, the beginning of basalt extrusion was simultaneous within narrow limits. Simultaneous extrusion of lavas in such widely separated regions can scarcely be regarded as coincidence, but rather as the result of some major process within the earth which affected the conditions over this great distance.

The evidence available, although by no means unequivocal, suggests that the Cretaceous-Eocene sediments and the plateau basalts of the east and west coasts of Greenland belong to two distinct areas of accumulation which are not now joined across Greenland under the inland ice, and which were not joined at the time of their formation. The distribution of Tertiary plutonic intrusions in East Greenland follows a north-north-east direction along the coast from Kap Gustav Holm to Shannon Ø and the original spread of plateau basalt, although of considerable width, probably followed the same direction.

III. TECTONICS

a. The Coastal Flexure and Related Dyke Swarm.

Round the mouth of Mikis Fjord the basalts are dipping at 45° southwards; traced northwards the dip decreases gradually so that at the elbow bend in Mikis Fjord the dip is 12°, and in the hills still further north the dip is only 7°. The steady reduction in the dip of the basalts from the capes inland is not a local phenomenon but is found again in Jacobsens Fjord and further east.

Recent Norwegian soundings show that off this stretch of coast there is a continental shelf lying 200—300 metres below sea level and stretching for two hundred kilometres from the coast [Iverson, 1936]. Marine erosion and deposition have no doubt contributed to the formation of the continental shelf, but in addition it seems clear that beneath the sea the dip of the lavas must become less and eventually flatten out, since otherwise we can obtain no geologically reasonable conception of the structure. In other words the structure, partly visible to us in the seaward increasing dip of the lavas of the Mikis Fjord area, must be regarded as part of a large scale flexure of the Earth's crust. A reasonable form for this flexure in the neighbourhood of Mikis Fjord is shown in Fig. 8B. In drawing this section the plateau basalts, with the Kangerdlugssuaq Sedimentary Series where present, have been taken as 8 km thick (cf. p. 27); the dips observed in the headlands have been assumed to be the maximum attained in the flexure; and the original top surface of the basalts under the Denmark Strait is considered to have been 2 km below present sea level, making the thickness of sediments forming the continental shelf just under 2 km. There is no evidence for this particular figure of 2 km except that the oceanic plain beyond the continental shelf is here of roughly this depth. Any reasonable modifications in these various assumptions would not alter the general features of the postulated structure. To make our knowledge quantitatively more complete, resort would have to be had to geophysical methods.

From Mikis Fjord to Nansens Fjord, a distance of 75 km, the lavas on the outer headlands have high dips which decrease in passing up the fjords; over this distance, therefore, there is an intense[1]) and big scale flexure. Beyond Nansen Fjord as far as Kap Grivel the dip of the lavas on the outer capes only reaches between 2° and 5°. Traced inland the dips decrease to zero just south of the Watkins Bjærge. Along this stretch of coast there is evidence of only a slight flexure, but this is considered to effect a considerable relative vertical displacement of the land and sea areas because the low dips persist over a considerable distance (Fig. 8A). In drawing the section the thickness of the plateau lavas has been taken as 4 km, a mean between the thickness determined in Nansens Fjord and in Watkins Bjærge. On the next cape to the N. E., Kap Savary, the dip of the lavas is again 10° seaward, and dips of about this value persist as far as Barclay Bucht (see map. 1934, Pl. 12), while inland the dips are much less. Thus over this stretch a moderate flexure exists. The axes of the intense flexure from Mikis Fjord to Nansens Fjord and of the moderate flexure from Kap Savary to Barclay Bucht lie along the same smooth curve which follows the general run of the coast. In the middle stretch where the flexure is feeble, the general run of the coast lies a little north of the curve defined by the axes of the strong and moderate flexures (Fig. 5).

South of Kangerdlugssuaq the observed dips on the ridge extending N. W. from Kap Edvard Holm fit into the same general flexure pattern as N. E. of Kangerdlugssuaq, although a rather different part of the flexure is preserved. Thus, a dip of 60° is seen at the most inland exposure of basalts and this decreases to 40° on the headland adjacent to the gabbro intrusion. On N. Aputitek tuffs, considered to belong to the Plateau Basalt Series, dip only 30° seaward, and on Keglin Is. the dip of basalts is only 10°. Basalts are not exposed inland of Kap Edvard Holm until the Trekantnunatakker are reached but it is certain that they once spread over the intervening area because of the abundant blocks which have been incorporated in the Kangerdlugssuaq intrusion. Thus, inland from the Kap Edvard Holm exposures the dip of the basalts must have rapidly become less and eventually levelled out to join the almost horizontal flows of the Trekantnunatakker. It is suggested that about Kap Edvard Holm and Igdlutarajik the part of the flexure which happens to be preserved is partly on one side of the septum of the flexure and partly on the other (Fig. 8C). In drawing this section the thickness of the basalts is assumed to be 4 km which is the thickness now preserved on Kap Edvard Holm. Although basalts are only preserved in proximity to the Kap Edvard Holm intrusion it does not appear that their regional dip has been significantly modified by the intrusion.

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[1]) The flexure is described as "intense" when the dip amounts to 10° or more, and as "slight" when the dip is under 10°.

The coastal flexure has been described first and without mention of the associated dyke swarm — although the latter is often the more striking phenomenon in the field — in order to emphasise that the flexure can be inferred from direct observation of the lie of the lavas without any corroborating evidence from the dyke swarm. The remarkable association of the dyke swarm and the flexure under certain conditions is, however, of great interest in itself and also of value in tracing the position of the flexure where more direct evidence is not available.

The distribution of the swarm of basic dykes which follows the general trend of the middle East Greenland coast (Fig. 5) has already been briefly described [1934, pp. 41—43 and 1938]. From Kap Wandel to Nansens Fjord, a distance of 350 km, the dyke swarm is dense; for the short stretch from Nansens Fjord to Kap Grivel there are only sporadic dykes; while beyond, a dyke swarm of moderate density is found again and extends at least as far as Kap Dalton, a further distance of 170 km. Within the limits of the geological map (Pl. 6) the position of the dense dyke swarm along the coast is indicated by short red lines in the direction of strike. Along the outer coast from Kap Hammer to Kap Nansen dyke material is more abundant than the lavas which it injects, and the direction of the dykes is much more easily seen than the lie of the lava flows (Pl. 4, Fig. 1). On Flad Ø and Deception Ø to the south of Kangerdlugssuaq, the dykes cut the metamorphic complex and are so abundant that between half and two-thirds of the material of these islands consists of basic dykes. The abundance of dyke material is shown in the strike view of a headland near Poulsens Fjord (Pl. 5, Fig. 1).

Along the coast east of Kangerdlugssuaq the dyke swarm is densest on the headlands where the dip of the lavas is greatest, and decreases inland where the dip of the lavas is less. On Kap Hammer, for instance, where the lavas dip seaward at 55° there are well over 100 major dykes per mile across the strike, but at the elbow bend of Mikisfjord where the dip of the lavas is 12°, the swarm averages about 20 dykes per mile, while still farther north in Vandfaldsdalen where the dip of the lavas is 7°, dykes occur but they cannot be considered to form a swarm (Fig. 6). Another systematic feature is the inclination of the dykes relative to the dip of the lavas. The inclination of the dykes varies in such a way that the dykes are approximately perpendicular to the lavas, whatever the dip of the latter may be (cf. Fig. 8B). Thus, east of Kangerdlugssuaq on the outer coast, the dip of the dykes is inland at about 60°, and here the lavas are dipping seaward at 40° or 50°. Farther north, where the dip of the lavas is less, the dip of the dykes is greater; and where the lavas are dipping at 10°, the dykes have a dip of 80° or 85° north. Exactly similar relations between the density of the swarm, the dip of the lavas,

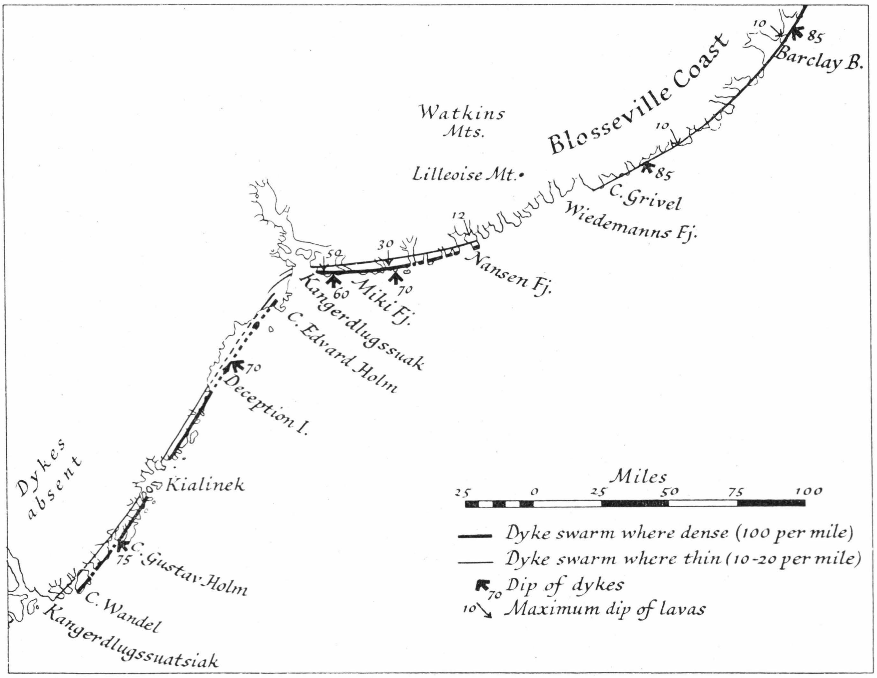


Fig. 5. The general distribution of the coastal dyke swarm. The curves showing the dense part of the dyke swarm also define the position of the axis of the coastal flexure. (Reprinted, by permission, from the Geological Magazine, Vol. 75, 1938).

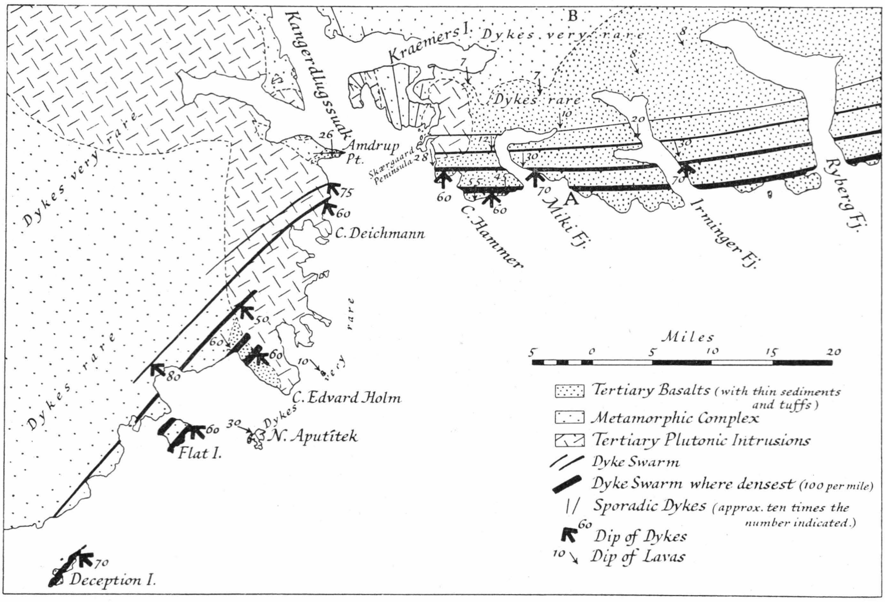


Fig. 6. The dyke swarm near Kangerdlugssuaq, where the direction changes through 50° and an en echelon arrangement is developed. (Reprinted, by permission, from the Geological Magazine, Vol. 75, 1938).

and the dip of the dykes are found in all the fjords between Kangerdlugssuaq and Nansens Fjord.

Beyond Nansens Fjord, the dip of the lavas on the capes is between 2° and 5°, and no dyke swarm is found although sporadic dykes trending in various directions occur. Further north-east the dip of the lavas on the capes becomes about 10° again; here a moderately dense dyke swarm of 10 to 20 dykes per mile is found, and the average dip of the dykes is inland at 85°. Beyond the limits of the map on Kap Ewart and Kap Dalton, a change from the regular relationships takes place which requires further investigation. Thus about Kap Dalton most of the dykes are perpendicular to the lavas although faulting and tilting have produced an inland dip of the lavas [1935, fig. 2]. To the south of Kap Dalton for some distance the dykes of a thin swarm are not perpendicular to the lavas but dip seaward at about 70° to 80° parallel to the normal faulting at Kap Dalton, while the lavas dip seaward at 10°. A distant view of the country north of Kap Dalton also showed irregularities from the normal disposition.

Comparison between the distribution and intensity of the dyke swarm on the one hand, and the trend of the coastal flexure and its intensity on the other, shows that the dyke swarm is absent where the dip of the lavas is much under 10°, that it is moderate when the dip is about 10° to 20°, and intense where the dips are still higher. The relationships persist over a wide area and can safely be taken to prove a genetic connection between the dyke swarm and the flexuring, since it is unreasonable to postulate that the dyke swarm was injected independently of the flexuring, and that the subsequent flexuring always coincided with the position of the dyke swarm. During flexuring there would be tension in the upper crust where the flexure is convex upwards, and it is in just such a zone of tension that a dyke swarm might be expected to occur. This is well illustrated by the conditions in the neighbourhood of Kap Edvard Holm (Fig. 7). The densest part of the dyke swarm cuts the gneisses and the inland part of the basalt outlier where the lavas are dipping at 60°. The swarm is less dense further seaward where the lavas dip at 40°; and dykes are rare on Nordre Aputitek and Keglin Island where the dips of the lavas are still less. The dip of the dykes is 80° in the metamorphic complex to the west of the basalt outlier, and becomes about 60° further seaward where the swarm is densest. Still further seaward the dykes decrease in number until they cease to form a swarm. The relations between the dip of the lavas and the density of the dyke swarm indicate that the dense swarm is confined to the convex part of the flexure. The formation of the dyke swarm in East Greenland appears to have taken place in the following way; first, slow bending of the Earth's crust occurred causing tension in the convex zone of the flexure; when this reached a critical value[1]) dyke formation took place and the tension in the crust was temporarily relieved; then further bending occurred causing further tension and dyke injection, and so on. The flexuring movement must have proceeded sufficiently slowly for each injection of dyke-forming magma to have cooled to a strong rock before the next fracturing and dyke injection

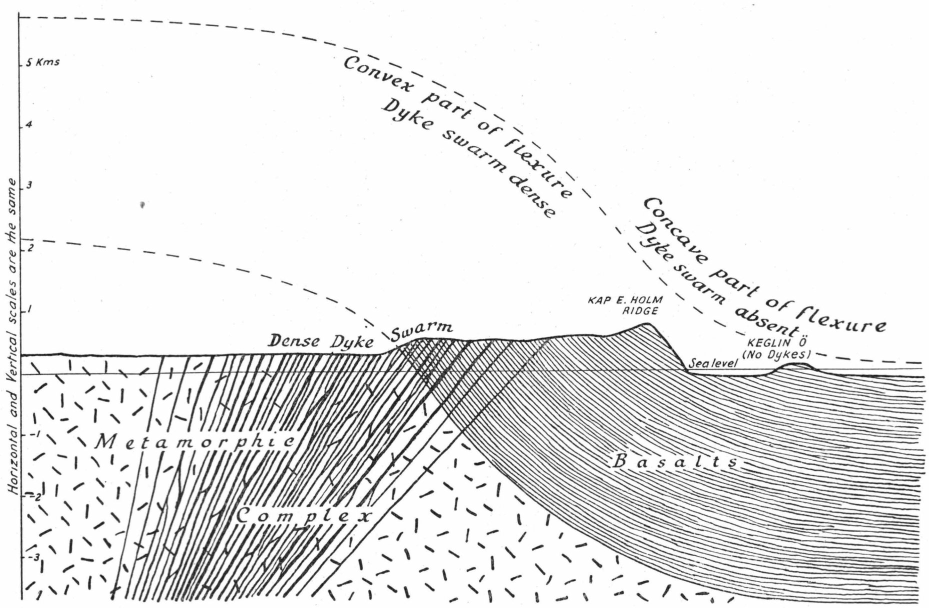


Fig. 7. Generalised section of the flexure and dyke swarm in the neighbourhood of Kap E. Holm, showing the absence of dykes in the concave part of the flexure.

because successive fractures normally break new ground instead of opening up earlier dykes.

The intimate connection which exists between the flexuring movement and the dyke swarm in Knud Rasmussens Land may be used to deduce the structure where basalts are absent. Thus south of Kap Edvard Holm basalts have so far only been found in position on Kap Gustav Holm. The dyke swarm, however, persists all the way from Kap Edvard Holm to Kap Wandel, and over this distance we can safely deduce a flexure of the crust which has resulted in uplift of the inland region and down-sinking of the sea area. The limited evidence from the dip of the basalts on Kap Gustav Holm supports this [cf. 1934, Fig. 4].

[1]) This value will depend on the hydrostatic pressure of the intruding magma as well as on the tensile strength of the rocks as shown by ANDERSON [1942 Chap. III].

In the early stages of the mapping when the region inland of Kangerdlugssuaq had not been reached, and when the dyke swarm was thought of as the result of regional tension without flexuring, it was anticipated that the apparent change in direction of the dyke swarm near Kangerdlugssuaq would prove to be due to the intersection of two swarms having different directions. Mapping has shown, however, that the swarms are not continued either to the north-east or to the west of the mouth of Kangerdlugssuaq. There is in fact a real change in the direction of the dyke swarm (Fig. 6) which can be partly seen on the nunataks along the seaward end of Hutchinson Gl. but is mainly hidden beneath the waters of the fjord. The change in direction amounts to 50°, and the radius of curvature is estimated at about 15 km. Round the point of curvature a side stepping or "en echelon" arrangement is found which is shown diagrammatically in Fig. 6. This unexpected behaviour was to some extent understood when the relation between the dyke swarm and flexuring was proved. For some undetermined reason the flexure dividing the up-lifted coastal mountain area from the down-sunken Denmark Strait turned through an angle of 50° at Kangerdlugssuaq and the dyke swarm, being due to the flexuring process, followed the same course.

The structural difference in level on the two sides of the flexure in the Kangerdlugssuaq neighbourhood amounts to at least 8 km (Fig. 8 B). There has been uplift of the land over a big area and down-sinking of the sea floor probably over a similarly extensive region. This is the fundamental feature of the tectonics of this part of Greenland and it will be referred to as the major epeirogenic movement. The flexure and dyke swarm enable this major epeirogenic movement to be proved and dated, but compared with it they are small tectonic events consequent on the major movement. From the parallelism of the flexure and the general trend of the coast it is clear that the distribution of land and sea in this part of Greenland is the direct result of the major epeirogenic movement. This movement was on a grand scale and ranks among the major tectonic features of the Earth's crust.

Structures closely comparable with the East Greenland flexure and dyke swarm are not common. As pointed out by du Toit [1938] and again by Cloos [1940] there is a striking similarity between the Lebombo flexure and dyke swarm of south-east Africa [see du Toit 1929] and that in East Greenland. As in East Greenland, the Lebombo flexure occurs along part of the edge of a Pre-Cambrian shield and thick lava flows, mostly basic, have been involved in the flexuring process. In distribution and density the dyke swarm also seems comparable with that in East Greenland. In places the edge of the Deccan in India seems to be a flexure but no well defined dyke swarm is reported [cf.

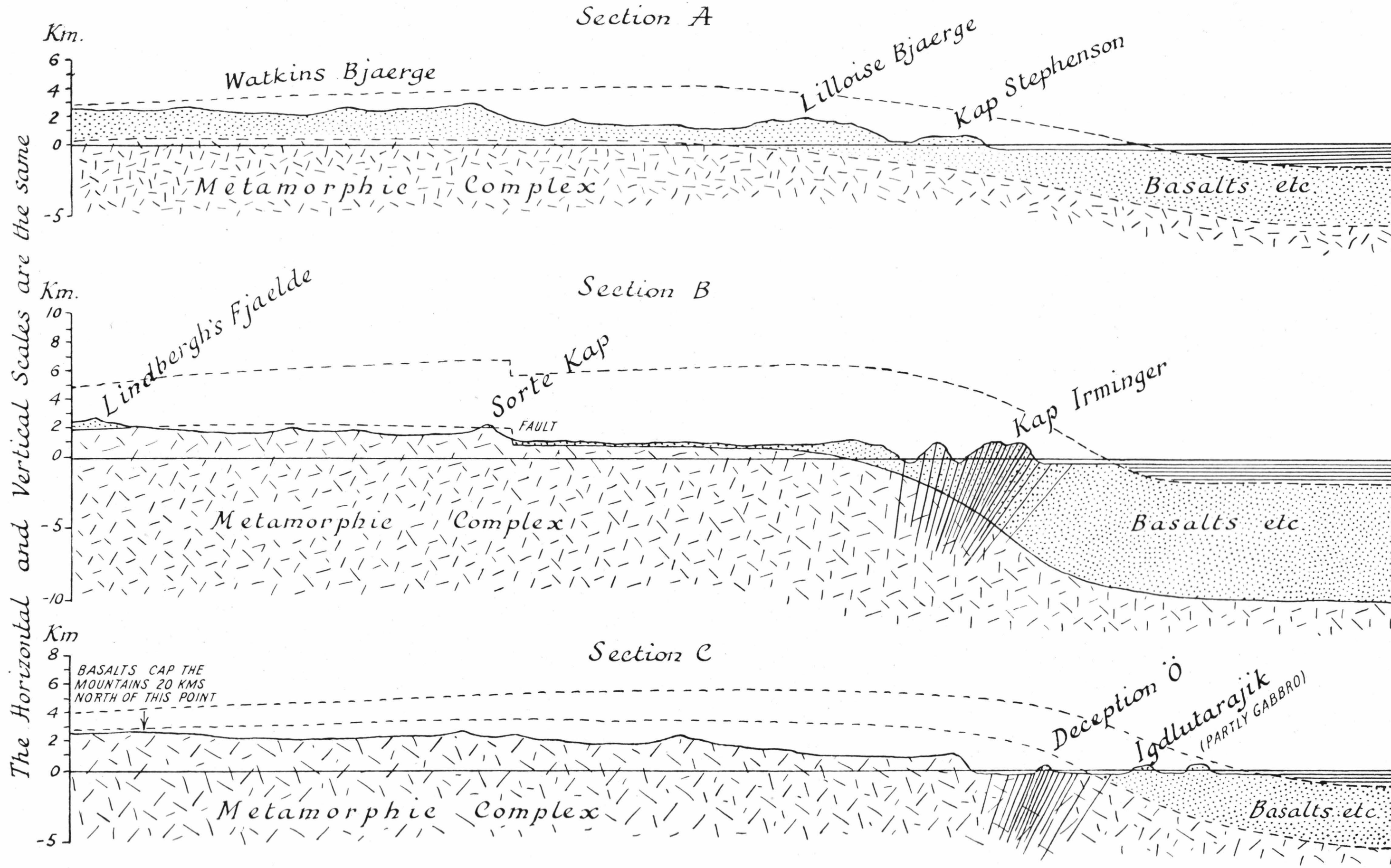


Fig. 8. Sections at right angles to the East Greenland coast, showing the flexure and the dyke swarm where present. (See text, p. 30 et seq.). The presumed recent sediments in the Denmark Strait, shown by horizontal pattern, are given the arbitrary thickness of 2 km.

Blandford, 1867]. Minor dyke swarms and tilted lavas are known from West Greenland, but so far nothing closely comparable with the conditions described here. Most dyke swarms such as those in Scotland [see Richey, 1939] do not appear to be associated with flexuring, and such big scale flexurings of the crust as have been proved are not usually associated with a dyke swarm.

b. Folding in the Inland Region.

The geological map (Pl. 6) shows clearly that the western half of Knud Rasmussens Land is carved out of an elongated dome whose axis runs E—W approximately through Domkirkgebjærget. This is still the highest mountain composed of the metamorphic complex on the east side of Kangerdlugssuaq. Erosion has not gone so far that the anticlinal region has become low land, but instead a direct relation still persists between the summit levels and the anticlinal structure, just as there is still a close connection between the position of the coast and the flexure of the crust. The northern flank of the inland dome shows dips of 2°—5°; further northwards these become less until, in Gronaus Nunatakker, the lavas are horizontal or dip south at low angles. North of the inland dome the basalts are either essentially level or lie in a shallow syncline, which runs from Sewards Nunatakker through the upper part of Christian den IV's Gl. and thence to Geikie Plateau. The southern flanks of the dome also show dips of 2°—3° and these normally increase as the coast is approached to give the high dips of the coastal flexure.

To the south-west of Kangerdlugssuaq there are few lavas or sediments preserved by which the inland structures can be directly determined, although, from evidence already mentioned (p. 31) it is clear that wide areas of the gneisses forming the coastal mountains must at one time have been covered by plateau lavas. There has evidently been uplift of this region comparable with that of Knud Rasmussens Land, and the evidence provided by the dyke swarm and the few remnants of the basalts indicate that the eastern edge of the uplifted area is also a sharp flexure. The summit level of the coastal mountains reaches 2.600 m in a belt trending S. E. from Redekammen while along the edge of the ice cap the level is slightly less. To the east of Kangerdlugssuaq the summit levels of the gneiss mountains still correspond to the dome structure, and we may reasonably conclude that the structure to the S. W. of Kangerdlugssuaq can be inferred from the summit levels of the region. This evidence indicates that there is a slight anticlinal structure with a crest along what is now the middle part of the coastal mountain belt. Looked at broadly the major epeirogenic movement concomitant with the coastal flexure produced an inland plateau which, however, was warped in places. The age of the warping cannot so far be definitely established but it seems reasonable to regard it as having occurred at the same time as the general uplift which was synchronous with the coastal flexure and dyke swarm.

c. Faulting.

The coastal flexuring and the inland doming has apparently taken place with little faulting. In the inland region a fault having a downthrow to the south-east of 800 m passes through Sortekappasset. It probably extends as far as the range separating Sorgenfri Gl. and Christian den IV's Gl. (see p. 16) but it has there become relatively unimportant and no indication of it was found on the east side of Christian den IV's Gl. The fault apparently extends along the upper part of Sidegletscher and along the narrow, south-west trending valley which enters Sidegletscher where it turns south; a branch may also extend along the glacier to the north of Sidegletscher. The throw of the Sortekappasset fault is probably much less when it reaches Kangerdlugssuaq than at Sortekappasset, and no evidence for the fault was found on the west side of the fjord. A less important fault, roughly parallel to the Sortekappasset fault and to the south, probably cuts through the country just north-east of Sodalen; it seems to have a small throw opposite to that of the Sortekappasset fault, but the position of this fault was not definitely located and it is not indicated on the map. No other faults of significant throw were noted in the inland area travelled over, and it is believed that they are rare or absent.

In the coastal regions a fault was definitely proved, cutting Amdrups Pynt in an east-north-east direction. This fault throws basalts down against the gneisses, and in character is a reversed fault, dipping inland at about 80°. The direction of the fault is the same as that of the dykes of the coastal swarm on the nunatak to the south, and the direction of the throw it also such that it has the same tectonic effect as the coastal flexure. Other faults of this character may exist in the zone of flexuring, but have not been proved.

d. The Tertiary (Thulean) Igneous Activity in Relation to the Tectonics.

The particular relations between the dyke swarm and the coastal flexure show that the dykes were being injected while the flexure was forming, that is, while the major epeirogenic movements were in progress, and it is worth while briefly considering whether other aspects of the igneous activity have any simple relation to the tectonics. Consideration of the sequence of igneous events is also required in establishing a geological chronology for the area.

Some warping of the basalts seems to have taken place during their accumulation, and therefore, to have preceded the coastal flexure. Thus, the lower few kilometres of plateau basalts round the mouth of Kangerdlugssuaq which immediately overlie the shallow water sediments were formed under water, and it is clear that some sinking took place during accumulation to allow of this. Elsewhere red partings indicate subaerial extrusion and there is no direct evidence of the height above sea level attained by the top surface of the lava pile. However, at Kap Dalton, the Middle or Lower Eocene marine sediments at, or near the top of the plateau basalt series were deposited with no great time interval upon the highest basalt of the area [1935, p. 13] showing that the basalt pile sank concomitantly with, or soon after its formation. If the amount of sinking of the basalt pile were proportional to its thickness, and if, as suggested earlier, the thickness of basalts inland was less than along the present coast, then the slight resultant warping would have been in the same direction and in approximately the same position as the later coastal flexure. Since there is much good evidence that the Earth's crust sank under the weight of the Pleistocene Ice caps, it seems likely that similar sinking would take place under an extensive and thick pile of basalts.

Dykes other than the coastal swarm are fairly abundant round the outer half of Kangerdlugssuaq (Fig. 9). Several large basic dykes run N. N. W. from the centre of curvature of the dyke swarms but others have quite different directions. A late dyke swarm cuts the Kangerdlugssuaq intrusion and has the same N. N. W. direction. Two large dykes in this direction also cut the metamorphic complex inland from Deception Island. On the other hand in the inland parts of Knud Rasmussens Land dykes are rare, only a few having been noted, although the steep faces of the mountains provide ample opportunity for detecting any that may exist. Dykes are also fairly rare inland of the coastal swarm in the region to the S. W. of Kangerdlugssuaq. Thus dykes are rare except for the coastal swarm and those round the outer part of Kangerdlugssuaq. The latter seem to have some relation to the point where the flexure changes its direction.

The distribution of the chief types of sills likewise seems to have some relationship to the coastal flexure and inland dome. Thick sills or thin laccolites of gabbro cut the basalts an Hængefjældet and Tinden on the east side of Kangerdlugssuaq near the mouth [1939, p. 18] and similar thick sills were also found cutting the Main Tuffs in J. C. Jacobsens and Rybergs Fjords. Where these gabbro sills are in the line of the coastal dyke swarm they are cut by it, and therefore, were intruded before the dyke swarm, or at any rate before much of it. In the east-west part of Mikis Fjord a columnar dolerite sill was found in the mountain south-west of the house, and at the east end of the Fjord similar dolerite sills occur totalling 100 m in thickness. These sills are cut by the relatively thin dyke swarm which occurs there. Another columnar dolerite sill cuts the lower basalts near the head of J. C. Jacobsens Fjord, and also appears in the south wall of the bay leading to Schjeldrups Gl. Similar sills cut the main tuffs in Rybergs Fjord (Fig. 2). These columnar dolerite sills represent the attenuated development of an abundant suite of sills cutting the sediments and tuffs on the south and east flanks of the inland dome, especially from the upper part of Schjelderups Gl. to the Skærmen. In the steep faces of the basalt mountains on the north of the inland dome from Watkins Bjærge to the Prinsen af Wales Nunataks it would be expected that occasional transgressive contacts would be seen if any of the sheets of basic rock were sills, but none were noted, and sills are considered virtually absent. The columnar dolerite of Lindsays Nunatak to the north-west of Prinsen af Wales Bjærge may be an exception, or it may mark the position of a volcanic neck.

In relation to the tectonics, the Tertiary sills may provisionally be classified into two groups as follows:

a. Thick gabbro sheets or thin laccolites found in the zone of abrupt flexuring from Rybergs Fjord to Kap Edvard Holm; these were formed before the dyke swarm, or before the greater part of it.

b. Columnar dolerite sills, which occur abundantly in the sediments and tuffs of the south and south-east flanks of the inland dome; the age relation of these to the dyke swarm is not known, except that some, for instance those in Mikis Fjord, are earlier than some of the dykes of the coastal swarm. Sills are rare or absent in the lavas on the north side of the dome and in the lavas of the Blosseviile coast; only occasional irregular sheets are found in the metamorphic complex around Kangerdlugssuaq and southwards.

Within the area of the map, there are four major plutonic complexes:

1. The Kangerdlugssuaq complex, which lies west of Kangerdlugssuaq and is 35 km across; this consists of various syenites ranging from quartz- to nepheline-bearing types.

2. The Kap Edvard Holm complex, south-west of the mouth of Kangerdlugssuaq; this is largely gabbro, but is penetrated by the quartz-syenite masses of Kap Deichmann and Kap Boswell.

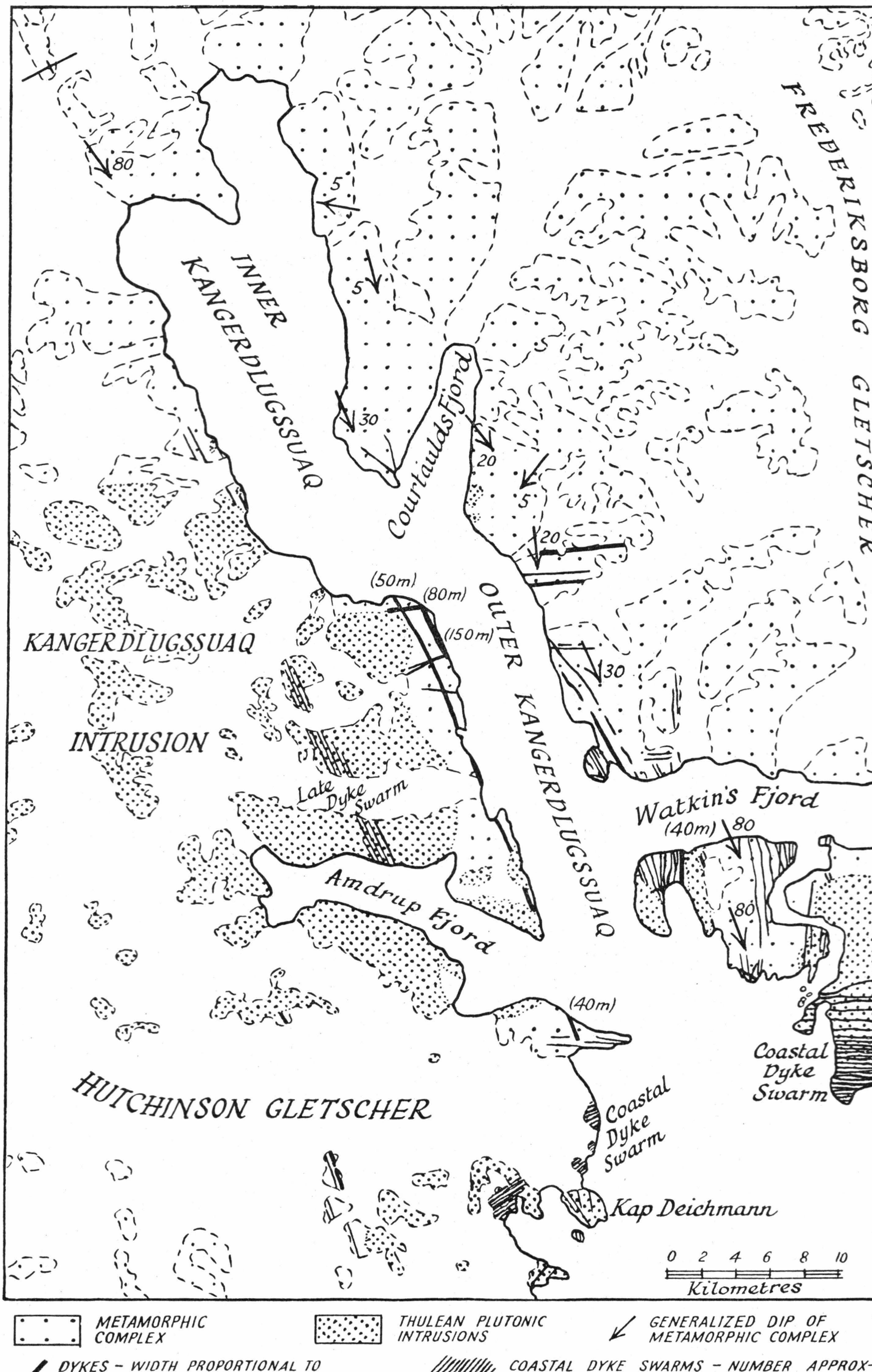
3. The Skærgaard intrusion on the east side of Kangerdlugssuaq. This consists largely of gabbros and ferrogabbros, and has already been described [1939].

4. The Lilloise plutonic complex, 150 km east of Kangerdlugssuaq; this has not so far been reached and the extent has only been estimated from a distance. The nature of the rocks comprising it, believed to be mainly syenites and nepheline-syenites, has only been judged from erratics which have been carried to the coast by glaciers [1934, p. 36].

These varied plutonic intrusions show no particular spatial relationship to the flexure and doming beyond the proximity of three of them to the place where the flexure changes direction and is most intense. However, these plutonic complexes belong to a series (see fig. 10) now known to stretch along the margin of the Greenland Shield from Kap Gustav Holm at least at far as Kap Parry, 800 km to the north [Tyrrell, 1932; Schaub, 1938; Bierther, 1940, p. 178]. That this linear distribution is the real distribution and not due to the ice cap covering other examples seems reasonably certain from their absence in the inland mountain belt which is now known at a number of points.

Certain of the plutonic intrusions are earlier than the coastal flexure. Thus the Skærgaard Intrusion to the east of Kangerdlugssuaq is cut by the dyke swarm, and tilting subsequent to solidification is also indicated by the present disposition of the layering which is a feature of this intrusion. It is of interest to find that this massive gabbro intrusion has been bent by the flexuring process just as easily as the lava pile. The basic part of the Kap Edvard Holm intrusion is also cut by the dyke swarm and is thus earlier than the flexuring. On the other hand, the syenite masses intruded into the gabbros of the Kap Edvard Holm intrusion are in line with the marginal part of the coastal dyke swarm, and are not cut by it. They are, therefore, later than the flexuring. The large Kangerdlugssuaq syenite complex to the west of Kangerdlugssuaq lies north of the coastal dyke swarm, as is also the case with the Lilloise syenite intrusion, and the age of these relative to the flexuring cannot be directly established although for the Kangerdlugssuaq intrusion there are reasons for considering it of later age.

Fig. 9. Sketch map showing the chief basic dykes of Kangerdlugssuaq and the dip of the gneisses of the metamorphic complex in the mountains bordering the fjord. The coastal dyke swarm and a late swarm cutting the Kangerdlugssuaq Intrusion, which trends north-north-west from Amdrups Fjord, are only indicated diagrammatically. Dykes are not entirely absent from the northern and western parts of the area but are rare.


INNER KANGERDLUGSSUAQ
Courtaulds Fjord
FREDERIKSBORG GLETSCHER
KANGERDLUGSSUAQ INTRUSION
OUTER KANGERDLUGSSUAQ
Watkin's Fjord
Late Dyke Swarm
Amdrup Fjord
HUTCHINSON GLETSCHER
Coastal Dyke Swarm
Coastal Dyke Swarm
Kap Deichmann
(50m)
(80m)
(150m)
(40m)
(40m)
80
5
5
30
20
5
20
30
80
80
0 2 4 6 8 10
Kilometres
METAMORPHIC COMPLEX
THULEAN PLUTONIC INTRUSIONS
GENERALIZED DIP OF METAMORPHIC COMPLEX
DYKES – WIDTH PROPORTIONAL TO LINE; WIDTH ALSO SHOWN: (80m).
COASTAL DYKE SWARMS – NUMBER APPROXIMATELY TWENTY TIMES THOSE SHOWN

In a general way the Tertiary plutonic intrusions occur along the present margin of the Greenland Shield, and evidence has been given above that the distribution of plateau basalts follows the same direction. The coastal flexure is also marginal to the Shield being, indeed, the tectonic feature which limits it. Some of the plutonic intrusions were formed before the flexuring and others after, but all are part of the same igneous cycle to which the lavas belong. In these ways at least, and no doubt in others as yet not proved, the igneous activity and the tectonic phenomena are related.

IV. SUMMARY OF THE GEOLOGICAL HISTORY OF MIDDLE EAST GREENLAND

Subsequent to the forging of the metamorphic complex which probably took place in Pre-Cambrian times, the area which is here described as Middle East Greenland, that is, Angmagssalik (66° N.) to Scoresby Sound (70° N.), was for long dominantly subjected to upward movement with concomitant erosion. Towards the end of the Mesozoic era, when next there is definite information, the area seems to have been of subdued relief and near sea level. In the Kangerdlugssuaq area a local marine transgression of approximately Senonian age produced thin sediments resting on the metamorphic complex, and a similar and perhaps contemporaneous marine transgression took place further south on what is now Kap Gustav Holm. Within a short time of the maximum development of the Cretaceous transgression volcanic activity broke out in the Kangerdlugssuaq region giving the Lower Lavas and Tuffs. The deep-seated preparation for this igneous event was no doubt of long duration but evidence of its nature is lacking.

The Lower Lavas and Tuffs of Kangerdlugssuaq, which were contemporaneous with the later Kangerdlugssuaq sedimentary rocks of latest Cretaceous or very early Eocene age, mark the beginning of intensive igneous activity in East Greenland, extending in a N. N. E. direction over a distance af 1.200 km, from 66° to 75° N. Southwards, the coast line has the same N. N. E. direction and there are many basic dykes, which almost certainly form part of the same igneous episode. This summary deals mainly with the southern and central part of this belt of igneous activity, i. e., from 66° to 69°30′ N. which is the region of its greatest development. For this region the principal igneous and tectonic events have been tabulated in chronological order (Table I, p. 46).

The eruption of vast quantities of basalt to give the Plateau Basalt Series, attaining in places a thickness of certainly $6^1/_2$ km and probably a good deal more, is the greatest igneous event in the region judging by the quantity of magma involved. The time taken for the accumula-

Table I. Sequence of Thulean Geological Events in Middle East Greenland.

	Southern Region (66°—68° N. approx.)	Kangerdlugssuaq Region (68°—68°30′ N. approx).	Northern Region (68°30′—69°30′ N. approx).
		Minor Dyke Swarm cutting Kangerdlugssuaq intrusion, also other late dykes.	
	Intrusion of Granties e. g. at Kialinek etc.	Intrusion of Granites and Syenites e. g. K. Deichmann and K. Boswell intrusions and probably also the Kangerdlugssuaq Complex.	? Intrusion of Lilloise complex.
	Epeirogenic Movements, Coastal Flexure and Dyke Swarm.	Epeirogenic Movements, Coastal Flexure and Dyke Swarm. Some doming and faulting inland.	Epeirogenic Movements, Coastal Flexure and Dyke Swarm. Also probably the Kap Dalton faulting.
			? possible late basalts north of Kap Dalton.
			Kap Dalton sediments with Middle or Lower Eocene Marine Transgression.
			Alkaline lavas known from pebbles in Kap Dalton Sedimentary Series.
Eocene	Basic Intrusions e. g. at Nualik and Kialinek.	Basic Intrusions e. g. Skærgaard and Kap E. Holm. Period of Sill intrusion in limited areas.	
		? Prinzen af Wales Bjærge lavas.	
	Plateau Basalts.	Main Plateau Basalts.	Main Plateau Basalts.
		Explosive Volcanic phase giving the Main Tuffs.	
		Upper part of Kangerdlugssuaq Sedimentary Series with plant remains (probably very early Eocene) and contemporaneous Submarine Lavas, Tuffs and Aggolmerate (The Lower Basalts and Tuffs).	
Cretaceous	Kap G. Holm Sedimentary Series with a Marine Transgression perhaps contemporaneous with that of Kangerdlugssuaq.	Lower part of Kangerdlugssuaq Sedimentary Series with Marine Transgression of approximately Senonian age.	

tion of the Plateau Basalt Series can be estimated from the fossils found immediately below and above the series as approximately equal to the duration of the Lower Eocene, and this may be taken to be of the order of 5—10 million years. The fact that the sediments immediately underlying and overlying the thick Plateau Basalt Series are both of shallow water marine origin shows that during, or soon after the extrusion of the basalts there must have been sinking of the basalt pile comparable in amount with its thickness.

Some basic intrusions, e. g., the Skærgaard and Kap Edvard Holm complexes were formed during or soon after the main period of basalt outpouring. This also seems to have been the chief period of sill intrusion although this phase never reached large proportions.

The chief tectonic event affecting the area, namely, the elevation of what is now the coastal mountain belt of East Greenland and the sinking of the area which is now the Denmark Strait, took place subsequently to the formation of the main plateau basalts. The junction between the two areas of differential epeirogenic movement is marked in Middle East Greenland by a flexure of the crust. Where the flexure is intense with dips of more than 10°, a dyke swarm is developed which follows the convex part of the flexure. The intensive flexuring and associated dyke swarm occur along much of the Middle East Greenland coast and, as it is likely that all the flexuring took place during the same limited period of time, we are provided with a useful method of dating certain local events. The coastal flexure and dyke swarm almost certainly came after the formation of the Kap Dalton sediments, which are Middle or Lower Eocene. The main part of the inland doming of Knud Rasmussens Land is considered to have been incidental to the general epeirogenic uplift and to have developed at that time.

In Middle East Greenland, the major epeirogenic movement can be seen to have produced relative vertical movement of the land and sea areas amounting to at least 8 km in the Kangerdlugssuaq region (cf. Fig. 8) and probably approaching this amount for some hundred or so kilometres to north and south. Not all of this impressive differential vertical movement is to be ascribed to the coastal flexure stage and it is suggested that the total movement as now determined by the lie of the rocks can be analysed into the following parts:

1. Early slight flexuring due to differential sinking of the lava pile as it accumulated.
2. The main epeirogenic movement and associated flexuring, with a dyke swarm where flexuring was sufficiently intense.
3. Possible later up-warping of the edge of the uplifted area as a result of isostatic adjustments to erosion and to the development of the ice cap.

The possible later up-warping has not been proved but physiographic evidence to be discussed in a later paper shows that the whole of the doming of Knud Rasmussens Land is certainly not to be ascribed to it, although some of it may be. Whatever up-warping in response to erosion may have taken place reduces the amount of the differential vertical movement to be ascribed to the main period of coastal flexuring. The early feeble flexuring and the later up-warping, if confirmed, must be thought of as passive responses to other events; only the main epeirogenic movement was an active tectonic process. If the chronology of the Thulean igneous activity set forth above is accepted, then the early slight flexuring is late Cretaceous to Lower Eocene, the main epeirogenic movement and flexuring is about Middle Eocene in age, while the later up-warping, if it has taken place, must have extended from that time to the present day.

After formation of the coastal flexure and dyke swarm, local igneous activity continued with the formation of certain of the plutonic intrusions, e. g., the syenites of the Kap Edvard Holm complex and the alkali granites of Kialinek; these are in the line of the dyke swarm, but are not cut by it. The plutonic intrusions, which can be proved later than the coastal flexure, are granites or syenites and it is likely that the alkaline Kangerdlugssuaq and Lilloise complexes are of similar late date. The late plutonic intrusions mark the close of the igneous activity so far as has been determined except for a small dyke swarm trending N. N. W. which cuts the Kangerdlugssuaq intrusion, and certain other sporadic dykes. The subsequent geological history is recorded in the erosion of the uplifted land area and in the deposition of the sediments forming the continental shelf.

In Middle East Greenland there is good evidence that extrusive igneous activity began in the latest Cretaceous or earliest Eocene times, and that it was essentially over by Middle Eocene times. Consideration of the sequence of the remaining igneous and tectonic events, as shewn in the table on page 46 suggests that they are unlikely to have persisted for longer than the remainder of Eocene time. In reaching some conception of the total time occupied by the igneous activity of East Greenland we have more data than in the British area as there are two episodes fixed by palaeontological evidence instead of one. The term Thulean has been widely used since it was first put forward by Washington to describe the North Atlantic petrographic province. The presumed early Tertiary igneous activity of Great Britain and also the late Tertiary to present day igneous activity of Iceland have both usually been included in the term. Until recently it appeared that the igneous activity of Iceland began in early Tertiary time and continued to the present day, but Hawkes [1938, p. 294] has given

Fig. 10. The distribution of Thulean basalts and plutonic complexes in East Greenland. North of Scoresby Sund the basalt series is relatively thin and the areas indicated include some sheets intrusive into Mesozoic sediments. The known occurrences of Upper Cretaceous and Eocene sediments are indicated in brackets after the names of localities where they occur.

evidence that in Iceland there was a period of early Tertiary activity separated by a time of quiescence from the late Tertiary to present day igneous activity. Hawkes, therefore, has suggested that it would be more useful to restrict the term Thulean to igneous activity of approximately early Tertiary times, and with this the present writer agrees. East Greenland provides evidence of impressive igneous activity lasting from latest Cretaceous or earliest Eocene time to about the end of the Eocene. Thus for East Greenland the term Thulean as re-defined by Hawkes, is particularly convenient since it may be allowed to include the latest Cretaceous activity, not strictly included under the term Tertiary, and at the same time the late Tertiary igneous activity as developed in Iceland and Jan Mayen and the Azores, which may perhaps

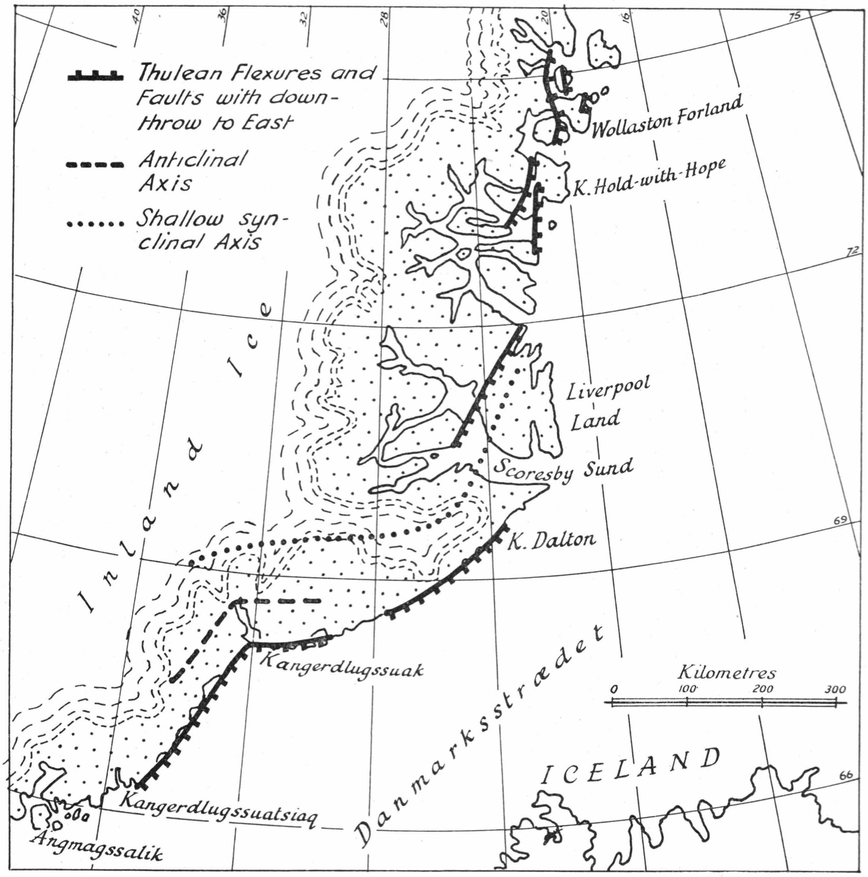


Fig. 11. Sketch map, showing late structural features in East Greenland.

better be considered as a distinct later episode, is excluded. The tectonic activity taking place contemporaneously with the Thulean igneous activity and probably related to it, will also be described as Thulean.

Published geological descriptions and maps of the northern part of the East Greenland area of Thulean igneous activity (70°—76° N.) show that the tectonic conditions may be considered in some respects homologous. The shallow syncline north of the Knud Rasmussens Land dome continues to the N. E. as the Jameson Land synclinal area. This region is bounded on the west by a fault or a flexure trending N. N. E. and throwing up to the west giving the highest land of the area to the west of the syncline. Other faults with similar throw and trend which can be proved later than the Mesozoic, or in some cases later than the Thulean basalts, have also been mapped. These faults are comparable with the small-scale antithetic faulting at Kap Dalton which has the same general effect and trend. The sketch map, Fig. 11, shows the chief late structural features of East Greenland and indicates in a general way how the tectonic conditions of Middle East Greenland extend northwards[1]). In Middle East Greenland the flexured lavas allow the major epeirogenic uplift of the land and subsidence of the sea area to be seen clearly. From Kangerdlugssuaq to Angmagssalik similar movement may be inferred with confidence from the dyke swarm and the occasional relics of plateau basalts. For the northern area from 70° to 75° N. stages in the same down-sinking are shewn by the visible faulting, and it is at least possible, and perhaps probable, that the same total effect has been produced by means of large faults off the coast which are hidden by the waters of the sea.

Thulean tectonic movements have been primarily responsible for the present disposition of land and sea in Middle East Greenland, and they have also been responsible for the uplift of the coastal mountain belt. From a valuable analysis of the topographic conditions in the Fjord region immediately north of Middle East Greenland together with the geological evidence available, AHLMAN [1941, pp. 157—162] has shown that a Tertiary uplift of the coastal mountain region has also occurred there. Looked at broadly the coastal mountain topography of the whole southern two-thirds of Greenland is sufficiently similar to that of Middle East Greenland to make it probable in the writer's opinion, that epeirogenic uplift of the whole of this large area took place in early Tertiary times. This point will be returned to in a later paper on the geomorphology of Middle East Greenland.

[1]) CLOOS [1939 p. 181] has briefly considered whether the Middle East Greenland coastal flexure may not overlie step faulting comparable with the visible step faulting of the northern area. For this there is no direct evidence at present, and it seems rather that similar stresses have produced different types of tectonic response in the two areas. It may be that deep burial of the sial layer by plateau basalts and general heating due to igneous action have been important factors in the development of the flexure in Middle East Greenland while elsewhere fracture structures have developed.

V. HYPOTHESES IN EXPLANATION OF THE THULEAN TECTONICS OF EAST GREENLAND

In Middle East Greenland the effect of Thulean Earth movements has been to raise a belt of mountains 100 to 300 miles wide and reaching a height of 10.000 to 12.000 ft. in many places. Such a mountain belt is comparable in proportions with the Alps, but there could be no greater contrast in the visible geological structures. The work of generations of geologists in the Alps has finally established that the rocks which are accessible to examination have suffered the effect of powerful horizontal compression producing an extremely complex pile of over-folded and over-thrust sheets. The East Greenland mountains, on the other hand, have been formed by vertical uplift which has only tilted the basalt sheets a few degrees at most from their original horizontal position, except along the narrow zone of coastal flexuring which joins the uplifted mountain belt to the downsunken sea area. In Middle East Greenland in the rocks accessible to view there is no evidence of any horizontal compression during Thulean times, but instead, the dyke swarm formed during part of the time indicates a zone of tension in the upper crust. The large scale Thulean tectonic events, described as objectively as possible in the preceding pages, do not seem capable of explanation by processes taking place in the superficial layers of the crust accessible to the ordinary methods of geology. It seems that they must either be left as unexplained facts, or hypotheses about the behaviour of material within the Earth must be put forward. Although the testing of these hypotheses will lie outside the range of ordinary geological methods it is likely that geophysical methods will soon be developed by which they can be partially tested.

The gentle subsidence of the plateau basalts during accumulation which has been proved in certain parts of the area, fits in well with the view that adjustments take place so that there is maintenance of approximate hydrostatic equilibrium in the crust. The period of passive subsidence was succeeded by the active major epeirogenic movement, resulting in the elevation of the present land and the further down-warping of part of the basalt area to give the Denmark Strait. In seeking an explanation of this active tectonic movement, it is proposed to bring forward only hypotheses which are in harmony with the maintenance of approximate hydrostatic balance in the crust. With this limitation, the big Thulean epeirogenic movements of East Greenland might be explained as the result either of lateral transfer of material within the Earth, or of a change in density of certain of the materials of the Earth.

The hypothesis that local changes in density of certain outer layers of the Earth produce variations in the level of the Earth's surface was advocated by Fermor [1914] and others; and du Toit has recently re-considered the idea in some detail, naming it the paramorphic principle [1937, pp. 229—242]. In a brief comparison of the East Greenland coastal dyke swarm and the Lebombo swarm in Africa, du Toit [1938] has pointed out that sinking of the basalt area to the East of Kangerdlugssuaq below the level which is expected on the basis of hydrostatic adjustment to the weight of the basalt pile, might be due to inversions of the mineral phases present in the sial to others of higher density as a result of the high pressures to which the sialic crust is subjected beneath the thick basalt cover. In this way the bulk density of the deeply-buried, sialic rocks would be increased, and the level of the top of any column of rock in hydrostatic equilibrium would sink. Such a mechanism may have contributed to the down-sinking of the basalts off the coast, but it does not account for the simultaneous uplift of Knud Rasmussens Land where the sial was also covered by 2 km or more of basalts. Thus it seems necessary to develop some additional or alternative hypothesis.

A mechanism in conformity with the hypothesis of hydrostatic balance in the crust which could account for part of the Thulean uplift of Knud Rasmussens Land has been briefly sketched out in a previous paper [1938]. The mechanism suggested involved the idea of subcrustal migration of material. It was suggested that the base of the sial crust, where it lay beneath the thick cover of the basalts, became relatively fluid as a result of increasing temperature, and that the sial then flowed laterally until the sial-sima junction became parallel to the geoid, the change in thickness of the sial due to migration causing the area covered most thickly by basalt to sink. In this way the basalt surface beneath the sea off Kangerdlugssuaq might have reached the depth of one or two kilometres below sea level, and the same process might account for part of the uplift of Knud Rasmussens Land. It was pointed out, however, that to account for the whole Thulean uplift of Knud Rasmussens Land a greater migration of sial would have to take place, that is a greater than that required to bring the sial-sima juction parallel to the geoid.

The hypothesis of sub-crustal migration of material seems the most promising line of explanation, but migration of an intermediate layer of basaltic composition, rather than migration of sial is now suggested as more likely on general geological grounds. A modified form of the migration hypothesis, which has already been outlined [1940] may be conveniently summarised by means of Fig. 12. In this diagram the uplift of Knud Rasmussens Land is shown as the result of the thickening beneath it of an intermediate layer of basaltic composition, while the sinking of the Denmark Strait area is shown as the result of the thin-

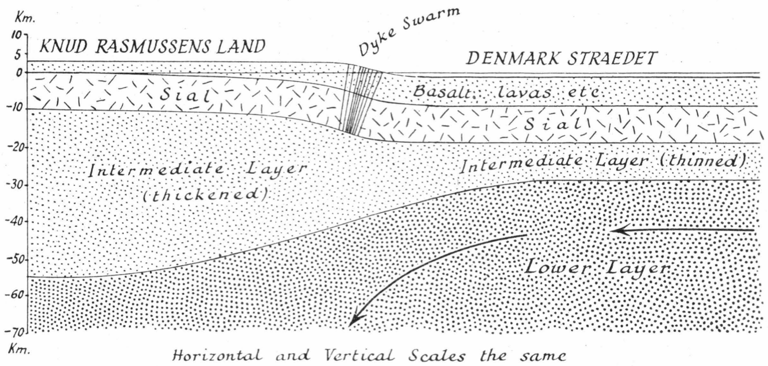


Fig. 12. An interpretation of the structure of the Earth's crust beneath East Greenland and the Denmark Strait. (See text. pp. 54—5). The direction of possible convection currents in the lower layer are shown by arrows. (Reprinted, by permission, from Nature, vol. 145, pp. 938—9, 1940).

ning of this layer. The excess of the intermediate layer under Knud Rasmussens Land is considered to be due to migration of part of the intermediate layer from under the Denmark Strait. The sial layer and overlying plateau basalts are considered to have remained unchanged in thickness and to have responded only by vertical movements to the hydrostatic forces produced by the change in thickness of the intermediate layer.

In reaching the conception of the mechanism of Thulean Earth movement in East Greenland, which is illustrated by Fig. 12, the following generalised data has been used. The thickness of the basalts in the inland region has been taken as $2^1/_2$ km, and as 8 km below the Denmark Strait. The main Thulean epeirogenic movement together with the early feeble flexuring due to differential sinking has been considered to have resulted in uplift of the inland region until it lay $2^1/_2$ km above sea level, while the simultaneous down-sinking of the Denmark Strait has been considered to have occurred so that the surface of the basalts lay 1 km below sea level. These are conservative estimates, much less than the figures for the immediate neighbourhood of Kangerdlugssuaq, and, moreover, they leave 2 km of relative movement to be accounted for by post-Thulean adjustments to erosion. The hypothesis on the nature of the outer shells of the Earth which has been adopted is that of a sial layer 10 km thick with density 2.6, an intermediate layer of basaltic composition 20 km thick with density 2.9, and a lower layer with density 3.3. The particular solution given shows the intermediate layer, normally 20 km thick, reduced to 10 km under the Denmark Strait, giving down-sinking of about 1 km, and increased to 45 km under the coastal mountains, giving uplift of about $2^1/_2$ km. In the present early stage of the hypothesis here put forward, reasonable modifications in the values of any of these quantities will not significantly affect the general scheme suggested. Moreover, other hypotheses can be devised, based on other conceptions of the nature of the various Earth layers, such, for instance, as Daly's vitreous substratum and anti-root hypothesis, and the East Greenland geological evidence is at present not sufficient to decide between them.

The hypothesis of variations in thickness of the intermediate layer seems more satisfactory on general grounds than variation in thickness of the sial layer. Thus during the postulated migration of material from beneath the Denmark Strait to the coastal mountain area, the crustal rocks did not yield by overfolding or thrusting as happened during the formation of the Alps and other ranges. Therefore a strong crustal layer not yielding to horizontal forces but only to vertical forces giving uplift or sinking, must be postulated. The change from a strong crust to sub-crustal material which, according to the hypothesis, was able to migrate, is likely to have coincided with a discontinuity in composition. Thus it seems more probable that the crustal material not yielding to flow would be the sial with overlying plateau basalts, and that the material, the migration of which produced the vertical movements, would be the next lower layer, here taken as an intermediate layer of basaltic composition.

Although East Greenland Thulean tectonics seem so different in the field from those encountered in such mountain ranges as the Alps, there is a strong similarity between the hypothesis of migration of material which has been suggested in explanation of the East Greenland mountains and the usual conception of the origin of the Alps. In both cases tangential movement of material is postulated resulting in thickening of some layer of the Earth; in the case of the Alps it it generally assumed that the sial layer and the sedimentary veneer have been thickened, while in the case of the East Greenland mountains thickening of an intermediate layer below the sial layer is suggested. The major

Thulean Earth movements[1]) in East Greenland must be regarded as typically epeirogenic in character, but if the suggested explanation of their origin should prove correct, then the difference between mountain building in the Alps and in East Greenland is not a difference between tangential compression and some unspecified vertical movement, but is due in both cases to tangential compressive forces causing thickening of some layer of the Earth, the sial layer in the case of the Alps, and a lower layer in the case of the East Greenland mountains[2]).

The hypothesis of subcrustal migration of material within the Earth with maintenance of approximate hydrostatic equilibrium which is here tentatively favoured as an explanation of the Thulean tectonics of East Greenland is put forward without offering any explanation of the origin of the forces causing the migration of the sub-crustal layer. It is clear, however, that sub-crustal convection currents as postulated by various geologists and recently considered in some detail by Holmes [1928 and 1933], Meinesz [1934], Griggs [1939], Gutenberg [1939, pp. 184—188] and others would provide an adequate mechanism, the intermediate layer being considered moved by the drag of steadily flowing convection currents in the layer beneath.

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[1]) The major epeirogenic Earth movement in East Greenland has been described (p. 48) as an active process and contrasted with the passive movements due to loading and unloading of the crust. It should be pointed out, however, that the so-called passive movements, like the active, are frequently regarded as taking place by means of migration of material within the Earth. In the case of what is here called an active epeirogenic movement the cause of movement must be considered deep seated in origin, while the so-called passive type of movement is considered to be caused by external loading or unloading of the crust.

[2]) Since putting forward the hypothesis that the coastal mountain belt of Middle East Greenland is due to thickening of the intermediate layer [Wager 1940] Professor B. Gutenberg [1943] has given valuable seismological evidence of the same deep structure beneath the Sierra Nevada of North America. This high mountain region, like Middle East Greenland, shows no evidence of overfolding as found in the Alps, and Gutenberg interprets the seismological evidence (eg. his Fig. III) as indicating a normal thickness for the granitic layer and an increased thickness for the intermediate layers (i. e. the layers between the granite layer and the Mohorovicic discontinuity). Thus Gutenberg believes that the Sierra Nevada is supported in part at least, by roots of intermediate composition as is suggested for the Middle East Greenland mountains.

VI. THULEAN TECTONICS AND THE FORMATION OF THE NORTH ATLANTIC

The impressive early Tertiary uplift of the middle stretch of East Greenland and the contemporaneous subsidence producing the Denmark Strait gives a glimpse of the manner and time of formation of a small area of the North Atlantic Ocean basin. Such movements may either have been limited to this region, or they may have occurred where ever Thulean igneous activity occurred, or they may be samples of what took place at that time round much of the North Atlantic. In East Greenland evidence of subsidence is only found where plateau basalts or the coastal dyke swarm occur and it might well be argued that the subsidence was in some way related to the igneous activity and especially to the great thickness of the plateau basalts developed there. An alternative hypothesis is that similar subsidence has occurred elsewhere but has not been detected where the plateau basalts are not available as an indicator.

Many well known lines of evidence show that some particularly significant geological event happened at the end of Cretaceaus and the beginning of Tertiary times. In stratigraphy the effects of this event are shown by the change from the wide spread Upper Cretaceous marine transgression to the equally wide spread Tertiary regression. Suess stressed the world-wide nature of these happenings and seems to have thought of it as an eustatic change of sea level due to oceanic subsidence. The student of vulcanicity finds this same time marked in the North Atlantic by impressive igneous activity, which is similar in nature and sequence in widely separated localities.

While there is much indirect evidence for some big scale geological event at the end of Cretaceous times, the nature of it remains obscure. A widely held hypothesis is that of De Geer [1910] and others who postulated that the North Atlantic was formed at this time by the subsidence of a land area coextensive with the North Atlantic, the so called Thulean Continent. This continent, of which Iceland and the Færøes are believed to be remnants, is generally considered to have been widely covered by basalts before its disappearance. Two ways have been suggested by which the Thulean Continent became replaced by the North Atlantic Ocean, viz. direct sinking and continental drift. The hypothesis of direct sinking has had recently few supporters among geologists and geophysicists because it has seemed that it would necessarily be at variance with the maintenance of approximate hydrostatic equilibrium in the Earth's crust. The hypothesis of continental drift, in which the land area formerly occupying the position of the present North Atlantic is supposed to be the Greenland of today which drifted away from Europe leaving the Atlantic depression in its wake, has had on the other hand considerable support among geologists though little among geophysicists [cf. Holland, 1937 and 1941]. Direct evidence for the tectonic events which both of these hypotheses imply, has so far been of the scantiest. It has generally been assumed that the necessary faulting, flexuring and stretching of the crust took place just off the present coast and so is hidden from direct observation. The Thulean tectonics of Middle East Greenland, however, provide evidence that in one region at least just such Earth movement occurred as would be expected during the replacement of a Thulean Continent by an ocean basin.

In considering the possible relation between the Thulean tectonics of East Greenland and the formation of the North Atlantic Ocean basin, there is one factor which cannot be appropriately dealt with here. This factor is the similarity in geomorphological development between Middle East Greenland—where the evidence for elevation and subsidence is clear—and other parts of Greenland and even of Scandinavia and Baffin Land, where we have little or no evidence of such movements. The geomorphological similarity requires detailed analysis before it can be used effectively in this discussion and it is intended in a later paper to describe the geomorphic features of Middle East Greenland as a contribution to this problem. For the present, all that can be said is that the similarity seems to the writer to be sufficiently great to suggest that the greater part of Greenland has undergone similar and simultaneous uplift as Middle East Greenland. The geomorphological similarity between Scandinavia and East Greenland, often commented upon in general terms, has recently been forcibly re-stated by Ahlman [1941, pp. 178—181]. It seems likely that a careful comparison of the geomorphology of Greenland with that of Scandinavia and Baffin Land might give satisfactory evidence that other parts of the North Atlantic area have undergone the same Thulean tectonic movements as Middle East Greenland.

The relation of Thulean igneous activity to the postulated tectonic movements leading to the formation of the North Atlantic Ocean basin is a tantalising problem. The similarity of Thulean igneous activity in East Greenland and Great Britain suggests the possibility of similar tectonic events. On the other hand, may the converse be assumed, viz. that the absence of igneous activity along other parts of the North Atlantic coastline indicates the absence of similar tectonic events? De Geer's original hypothesis of foundering included in its scope the whole North Atlantic and the geomorphic development in Greenland and Scandinavia mentioned above may be taken to suggest that the tectonic events were essentially similar over long lengths of coast-line whether Thulean igneous activity took place or not. In Middle East Greenland elevation and subsidence with fracturing and flexuring was accompanied by igneous activity but it is suggested that essentially similar tectonic events may have taken place elsewhere without igneous activity. This position is tenable, if it is supposed that the tectonic movements of uplift and subsidence do not necessarily involve igneous activity, but rather that additional factors are required before igneous activity occurs. When De Geer's hypotheses or others on the formation of the North Atlantic are being considered it would seem to be unjustifiable to assume that the general tectonic conditions around the North Atlantic coasts would necessarily be similar where Thulean igneous activity is present, and dissimilar where it is absent.

The evidence from East Greenland must at present be regarded as about equally favourable to De Geer's hypothesis of subsidence as to the hypothesis of continental drift. The direction of the deep-seated currents within the Earth which may have been responsible for the migration of the intermediate layer is the same as would be required to produce the appropriate continental drift. Perhaps it will ultimately be found that both direct sinking and continental drift have been involved in the formation of the North Atlantic.

The chief value of the East Greenland evidence for the problem of the origin of the North Atlantic is that it gives definite proof for a small area of movements of the kind long anticipated from various lines of indirect evidence. Moreover, there is a chance that geomorphic similarities may provide an argument for extending the area over which similar movement can be inferred.

While speculative views have been put forward in the last two sections of this paper, it is hoped that in the earlier sections the facts gathered from the Kangerdlugssuaq region of East Greenland have been stated sufficiently clearly and without influence by the hypotheses developed later, to render them available to others who may be seeking to understand the nature of the Earth movements which have taken place round the coasts of the North Atlantic.

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EXPLANATION OF PLATES

Plate 1.

The Watkins Bjærge from the south-south-east, showing 2.500 m of almost horizontal basalt lava flows. The small pyramid (a a_1) is Gunnbjørns Fjæld, 3.700 m, the highest point of the range. (Air photograph from about 4.000 m taken by the 7th Thule Expedition).

Plate 2.

The coastal mountains inland from Kap Vedel, showing seaward dip of the Plateau Basalts. a a_1 is Ejnar Mikkelsens Fjæld, d d_1 the eastern end of Watkins Bjærge and b b_1 Kap Vedel. The large glacier in front of Ejnar Mikkelsens Fjæld is Borgraven and the regional seaward dip of the lavas can be seen in the wall of Vedel Fjord leading to the glacier and also on the point c c_1. The lavas on the Kap Vedel peninsula do not appear to be dipping seaward because a strike view is seen. (Air photograph from about 4.000 m taken by the 7th Thule Expedition).

Plate 3.

Fig. 1. Kap Grivel with the mountains east of Kap Savary in the distance showing basalts dipping seaward at between 5° and 10°.

Fig. 2. Sortekap (a a_1) and the sedimentary ridge (b) stretching south-east from Sortekappasset. Sortekap consists of a small cap of dark sediments and sills largely snow covered, resting on rocks of the metamorphic complex which have a light brown or pink colour. The dark argillaceous sediments of the low ridge (b) have been faulted down at least 800 m by the Sortekappasset fault.

Plate 4.

Fig. 1. The dyke swarm cutting lavas, 3 km north-west of Kap Hammer. The dyke material is more abundant than the lavas and variation in the colour of the dykes and some variation in their direction can be seen. The dip of the lavas is from left to right, but this cannot be detected in the photograph.

Fig. 2. Air photograph looking from mountains near Kap Hammer (a) towards the Watkins Bjærge (b). The mountains in the foreground are composed of the Plateau Basalt Series cut by the dense dyke swarm, and neither the dip of the lavas nor the trend of the dykes can be made out, the composite rock mass behaving as if it were a massive rock. The close-up photograph of the dyke swarm (fig. 1 above) is of the coast near (c). The seaward dip of the lavas where the dyke swarm is thin, can be seen in the mountains above the inner part of Mikis Fjord (d d_1).

Plate 5.

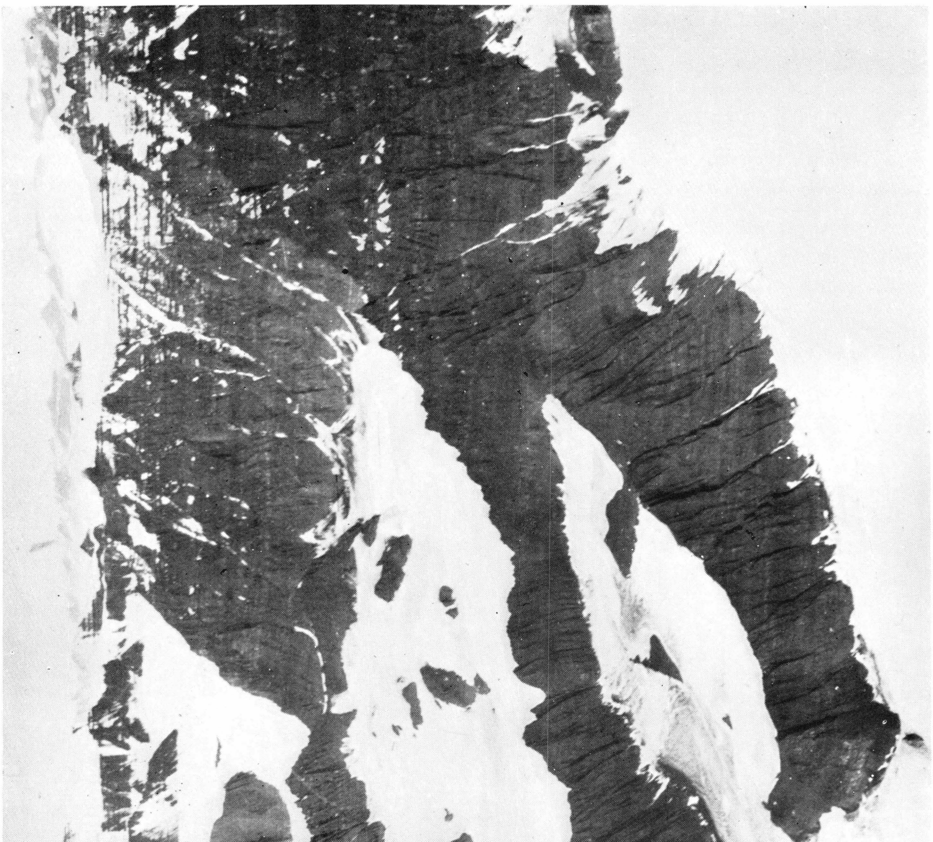
Fig. 1. Cliff, 800 m high, between Poulsens Fjord and Kap Gustav Holm, showing the dyke swarm cutting through the metamorphic complex. Dyke material is more abundant than the gneiss. The strike of the dykes is almost parallel to the cliff face and the average dip is inland at 70°.

Fig. 2. Hængefjældet from the south-west showing thick dykes with rather low dip, cut by later narrow dykes with rather higher and more irregular dip. By some fluke of sensitivity, the photograph has recorded the dykes more clearly than they can be seen in the field. The occurrence of two types of dykes making up the coastal swarm is a local phenomenon not noted elsewhere. The photograph makes the dykes appear to have a lower dip than is actually the case.

Plate 6.

Geological map of the southern part of Knud Rasmussens Land and the Kangerdlugssuaq Region.

Færdig fra Trykkeriet den 31. December 1947.



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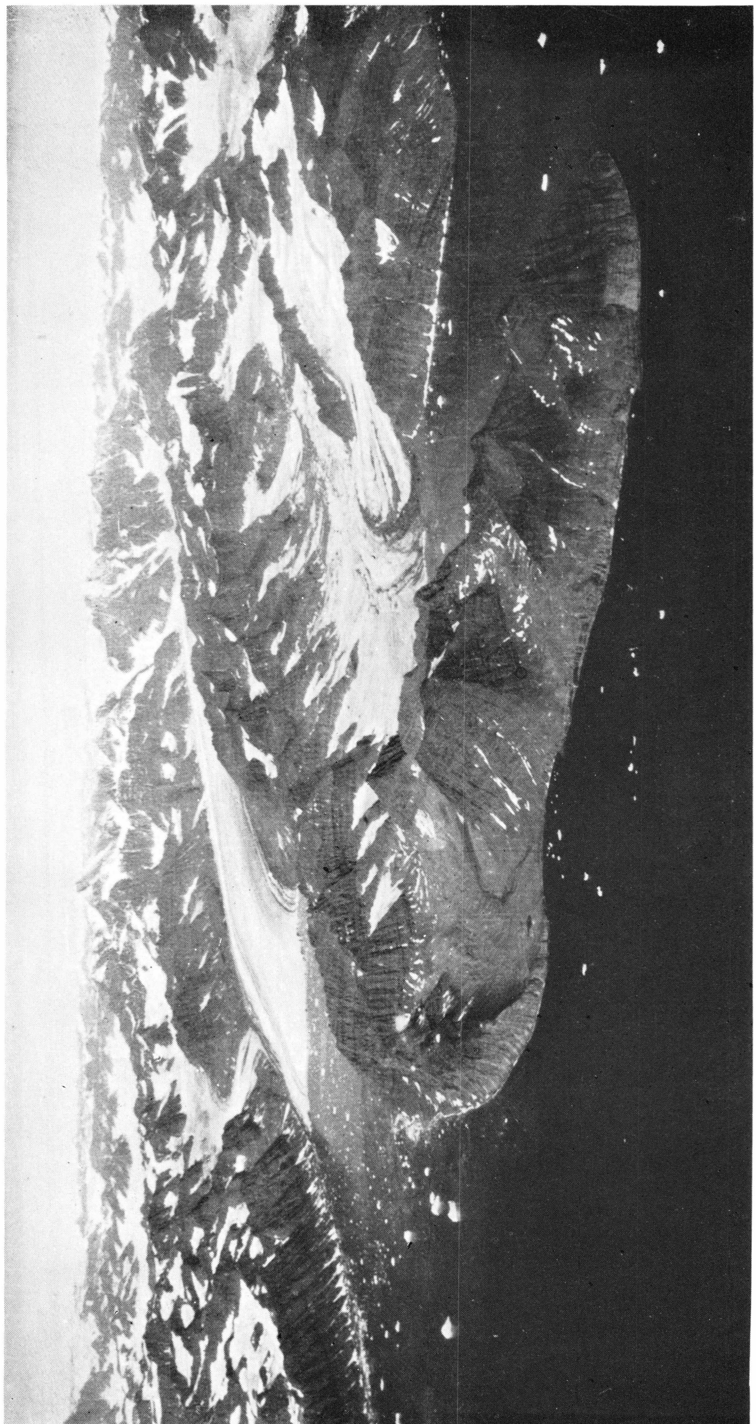
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d_1

Fig. 1.

a

a_1

b

Fig. 2.

Fig. 1.

Fig. 2.

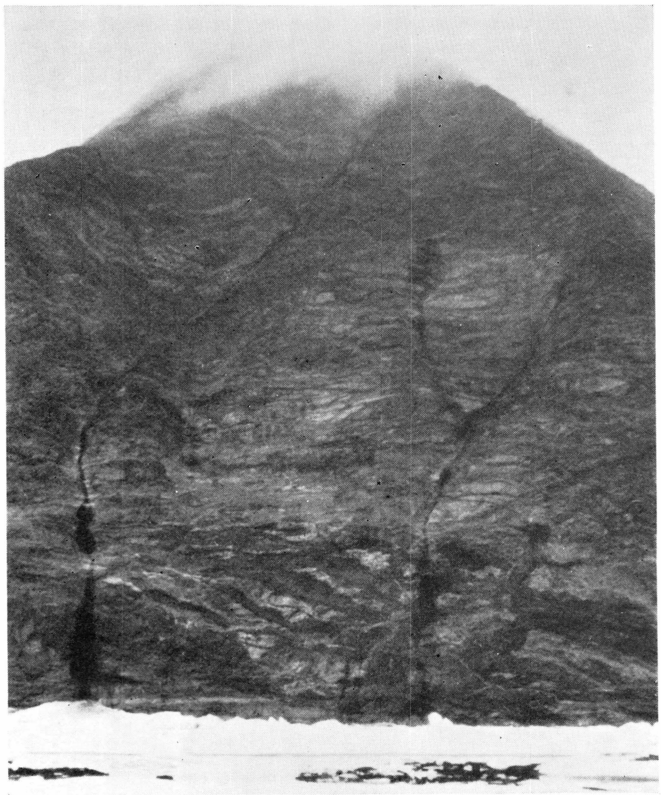
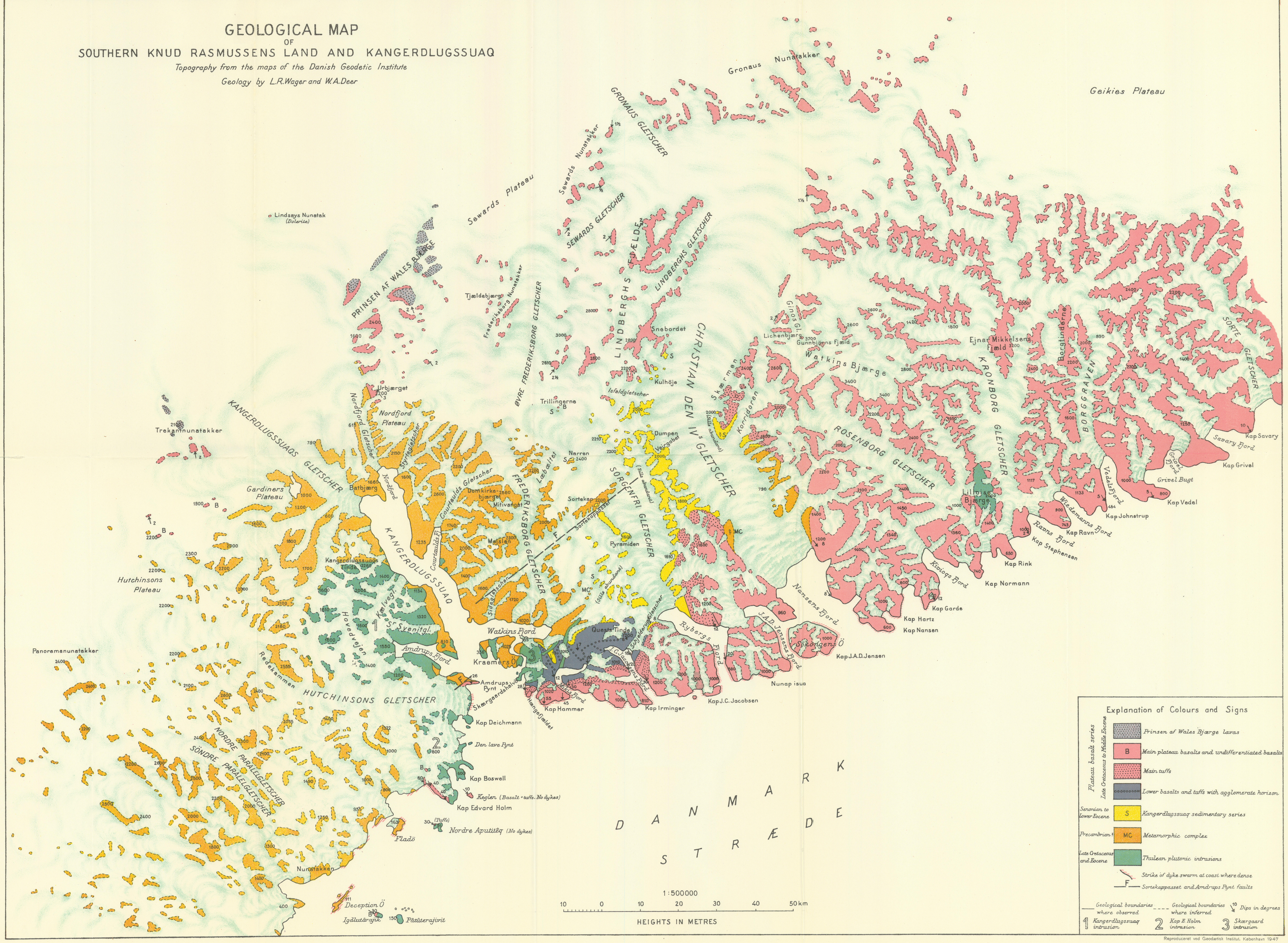


Fig. 1.

Fig. 2.


GEOLOGICAL MAP
OF
SOUTHERN KNUD RASMUSSENS LAND AND KANGERDLUGSSUAQ
Topography from the maps of the Danish Geodetic Institute
Geology by L.R.Wager and W.A.Deer
Explanation of Colours and Signs
Plateau basalt series
Late Cretaceous to Middle Eocene
Prinsen af Wales Bjærge lavas
B Main plateau basalts and undifferentiated basalts
Main tuffs
Lower basalts and tuffs with agglomerate horizon
Senonian to Lower Eocene
S Kangerdlugssuaq sedimentary series
Precambrian
MC Metamorphic complex
Late Cretaceous and Eocene
Thulean plutonic intrusions
Strike of dyke swarm at coast where dense
F Sortekappasset and Amdrups Pynt faults
Geological boundaries where observed
Geological boundaries where inferred
Dips in degrees
1 Kangerdlugssuaq intrusion
2 Kap E Holm intrusion
3 Skærgaard intrusion
1:500000
10 0 10 20 30 40 50 km
HEIGHTS IN METRES
DANMARK STRÆDE
Geikies Plateau
Gronaus Nunatakker
GRONAUS GLETSCHER
Sewards Plateau
Sewards Nunatakker
SEWARDS GLETSCHER
Lindsays Nunatak (Dolerite)
PRINSEN AF WALES BJÆRGE
LINDBERGHS FJÆLDE
LINDBERGHS GLETSCHER
CHRISTIAN DEN IV's GLETSCHER
ØVRE FREDERIKSBORG GLETSCHER
FREDERIKSBORG GLETSCHER
SORGENFRI GLETSCHER
ROSENBORG GLETSCHER
KRONBORG GLETSCHER
BORGGRAVEN
SORTE GLETSCHER
KANGERDLUGSSUAQS GLETSCHER
KANGERDLUGSSUAQ
HUTCHINSONS GLETSCHER
NORDRE PARALLELGLETSCHER
SÖNDRE PARALLELGLETSCHER
Trekantnunatakker
Gardiners Plateau
Hutchinsons Plateau
Panoramanunatakker
Nordfjord Plateau
Urbjærget
Watkins Bjærge
Lichenbjærg
Gunnbjørns Fjæld
Ejnar Mikkelsens Fjæld
Lilloise Bjærge
Watkins Fjord
Amdrups Fjord
Kraemers Ö
Amdrups Pynt
Kap Hammer
Kap Irminger
Kap J.C. Jacobsen
Nunap isua
Kap J.A.D. Jensen
J.A.D. Jensens Fjord
Nansens Fjord
Kap Nansen
Kap Hartz
Kap Garde
Kap Normann
Kap Rink
Kap Stephensen
Kap Ravn
Kap Johnstrup
Kap Vedel
Grivel Bugt
Kap Grivel
Savary Fjord
Kap Savary
Kap Deichmann
Den lave Pynt
Kap Boswell
Kap Edvard Holm
Keglen (Basalt + tuffs. No dykes)
Nordre Aputitêq (No dykes)
Fladö
Deception Ö
Igdlutârajik
Pâtûterajivit
Nunatakken