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Under Ledelse af Lauge Koch

ON THE CRYSTALLINE BASEMENT AND THE BASAL PART OF THE PRE-CAMBRIAN ELEONORE BAY GROUP IN THE SOUTHWESTERN PART OF SCORESBY SUND

BY

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WITH 16 FIGURES IN THE TEXT
AND 13 PLATES

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In Memory of

PAUL STERN

CONTENTS

Summary.

Explorations carried out in July and August 1958 in the lake districts between the innermost parts of Vestfjord and Gaasefjord (southwest corner of Scoresby Sund) ascertained the existence of an angular unconformity of sub-Groenlandian age. The paper deals with the general geology of that area which has been laid down in a geologic map and a section. It describes the crystalline basement of pre-Groenlandian age ("Archaean"), its autochthonous to parautochthonous Groenlandian sedimentary cover, the Caledonian crystalline rocks thrust westwards over the basement and its sediments, and touches on the Tertiary plateau basalts overlying all the other formations as horizontal sheets.

The psephitic series above the unconformity, representing the base of the Eleonore Bay Group, is discussed in more detail. From the character of deposition, the wide range of grain-size and roundness, the lack of alteration of the minerals, the microscopic fabric and the chemical composition of the clay matrix, and the varve structure of the clay beds, it is deduced that this series represents glacial sediments deposited in water.

The limestones and the thick pelitic series above the psephitic beds make it possible to think of a correlation with the type sections of the Petermann region and thus permit us to conclude that the sediments concerned represent the basal part of the Eleonore Bay Group. Accordingly this group starts and ends with glacial deposits.

I. PRESENTATION OF THE PROBLEMS

Geologists who have for the past thirty years attentively followed the literature on the pre-Cambrian rocks and the Caledonian mountain chain of East Greenland will have noticed that two unsolved problems have become increasingly obvious:

1. The base of the Eleonore Bay Group (Groenlandian).[1])

A whole team of stratigraphers have subdivided the pre-Cambrian sediments of the Eleonore Bay Group (Eleonore Bay Formation), described by Dr. LAUGE KOCH in 1929 and magnificently exposed in the sections of the East Greenland fjords, and have estimated their total thickness at more than 10 km. From no other part of the world a so complete and so well established cyclically divided sedimentary sequence of the substratum of the deepest fossiliferous Cambrian strata is known. Its enormous thickness, borne out by the geological maps and sections, can nowhere be seen from one point, at any rate, in the East Greenland fjords. But a flight from Ella Ø, the type locality of the Cambro-Ordovician and of the Tillite Group overlying the Eleonore Bay Group, to Alpefjord, which is the type locality of the deeper parts of the group and some 80 km away, will give a clear idea of it. On such a trip constantly deeper-lying members of the obliquely tilted sedimentary series will come into view one after the other.

Yet the *stratigraphic base* of the Eleonore Bay Group has not been found here during all these years of intensive research. This is not only due to the fact that towards the coast younger beds lie on the ancient sediments and accordingly there deeply bury the base. Far more significant is a major complication which becomes manifest in the inner fjord ramifications and which long was *the great problem* of the geology of East Greenland: There, the pre-Cambrian formations, of which the sequence, macro-structure (cross-bedding, ripple-marks), and composition are doubtlessly sedimentary, although their fabric is more clearly recrystal-

[1]) Readers not familiar with the terms "Groenlandian" and "Caledonian crystalline complex" are referred to the Appendix at the end of this paper.

lized than most authors admit, turn into gneiss and migmatites both laterally, i.e. in a westerly direction, and in depth. In several places the sediments are underlain and surrounded by massive granite, as is precisely the case in Alpefjord. In other words, this means that, in the area of the inner fjord ramifications, the geosynclinal series of the Eleonore Bay Group grades laterally and vertically into the so-called "Central Metamorphic Complex", the crystalline backbone of the Caledonian mountain chain.

H. G. BACKLUND (1930, 1932) and E. WEGMANN (1935) were the first to demonstrate this connection which had been presumed by LAUGE KOCH (1929) but was denied by the geologists of the Cambridge East-Greenland Expedition and the Louise A. Boyd Expedition. It was, however, not definitely established until in the years after the war the geological mapping of the fjord zone traced the stratigraphic gradation of the Eleonore Bay Group in the crystalline series as well. (FRÄNKL 1953, HALLER 1953).

The conditions found along the western margin of the "Central Metamorphic Complex" where, towards the inland ice, it borders on another huge pre-Cambrian sedimentary sequence correlated with the Eleonore Bay Group of the fjord zone—the Petermann Series—serve as a touchstone for the correctness of this opinion. There, too, detailed investigations proved the members of the pre-Cambrian deposits to grade into the strongly metamorphic Caledonian crystalline complex (WENK and HALLER 1953). But no stratigraphic base was discovered here either. There is good reason to believe, though, that it is to be found in the lowermost part of the low-grade metamorphic series of Maalebjerg near Gerard de Geer Gletscher.

For the reasons just mentioned, the geologists participating in the investigations agree that the base of the Eleonore Bay Group is *not* to be found within the central zone of the Caledonides. There, the ultrametamorphic processes taking place during the orogeny had materially and structurally transformed the original basement, and the beds filling the geosyncline. The rocks of both were partly replaced by such of granitic character and the whole was welded into a Caledonian crystalline zone.

The basal plane of deposition can only be recognized as such in the marginal zone of the mountain chain. Only there can it be expected to have remained unaffected by the mobilization of matter and the flow-movements arising from the basement. The most reliable indicator of the extent of this transformation in the depth is constituted by the degree of metamorphism of the Groenlandian. In the Central Metamorphic Complex, this Caledonian metamorphism is similar over a wide region and in accordance with mesothermal conditions; but it decreases distinctly in the marginal zone.

In connection with our problem, however, the eastern border of the mountain-range—at any rate in the area between 70° and 75° N. lat. dealt with here and with the exception of Liverpool Land—is of little interest, as the base of the geosynclinal series is deeply buried under younger deposits. Even though we might suppose that in the outer fjord zone the pre-Cambrian sedimentary series rests on an intact Groenlandian crystalline basement, this would be merely an unverifiable postulate. The base may only be exposed *to the west*, along the edge of the inland ice, and this leads us on to the second problem.

2. The western edge of the Caledonian mountain chain in Central East Greenland and its boundary towards the pre-Cambrian basement.

It is probably well known that the crystalline series along the whole west coast of Greenland and along the east coast, from the southernmost tip to Angmagssalik and Kangerdlugssuaq, that is, to 68° N. lat., is termed "Archaean", while the East Greenland crystalline series north of 70° N. lat. is named "Caledonian". The Caledonian mountain chain extending southward from Northeast Greenland must, accordingly, strike into the sea between Scoresby Sund and Kangerdlugssuaq[1]). Also it follows that in this region the Caledonian mountain chain must be bordered on the west by the "Archaean" and its sedimentary cover.

Up to 1958, the only area within the whole of East Greenland where this had been demonstrated by geological investigations in the field was the western part of Dronning Louise Land (76° to 77° N. lat.). PEACOCK (1956, 1958) has shown that there the "Archaean" crystalline rocks ("Western Gneisses") are overlain, with clear unconformity, by a horizontal cover of quartzitic sandstones (Trekant Series = Thule Group) with basal breccias and conglomerates.

PEACOCK and HALLER (1956b) state that the Archaean of Dronning Louise Land occurs along the western edge of the Caledonian mountain chain and that the latter was thrust westward on to the Archaean basement and its autochthonous sedimentary cover. Opinions differ only in regard to the folding and transformation of the metamorphic sediments of the Britannia Sø Group occurring in the border zone. While PEACOCK (1958, p. 116), on the basis of the observed continuous increase of metamorphism towards the east, assumed this metamorphic group to be contemporary with the Caledonian "Eastern Gneisses", HALLER (1956b pp. 15 and 23) concludes from structural indications that the Britannia Sø Group was folded and migmatized *after* the deposition of the Thule

[1]) The field results of the summer of 1958 support this view.

Formation, but *before* the Caledonian main phase, and that we here are concerned with pre-Caledonian structures. This postulate of a hitherto unknown orogenic phase, has important consequences for our conception of the geology of Greenland. Considering the normal superposition of the Thule Group on the basement west of Britannia Sø, and particularly in view of the continuous upper pre-Cambrian to Cambro-Ordovician sedimentation of the Eleonore Bay Group to the southeast of that region, the new postulate is still in need of verification. However, this question has little connection with the facts associated with our problem, viz. that the presence of "Archaean" and unfolded Thule sandstone has been established in North Greenland and along the east coast as far south as lat. 76° N., but that these two series have not yet been found in the adjoining, and geologically much more thoroughly explored central part of East Greenland further south. There every trace of Thule sandstone is absent. Various reasons, however, favour the assumption that a pre-Groenlandian crystalline series, the "Archaean", exists west of the crystalline ridge of the Caledonian mountain range (the Central Metamorphic Complex). These are as follows:

1. The occurrence of *low-grade metamorphic pre-Cambrian sediments of the Eleonore Bay Group* and the *dying out of the Caledonian folding* along the inland ice in the region of Kejser Franz Josephs Fjord and in the northwestern part of Scoresby Sund.

2. The presence of boulders of gneiss, granite, and migmatites, in company with *unmetamorphic and low-grade metamorphic Groenlandian* and *Lower Palaeozoic sediments* together with Tertiary dolerites in the moraines of the inland ice glaciers within the same area.

3. The swarm-like occurrence in the western part of Scoresby Sund of vertical Tertiary NNE-striking *dolerite dykes*, which are known to be absent from the central Caledonian crystalline zone, but follow the eastern margin of the orogenic zones again.

Other indications, especially the somewhat naive supposition that mountain-ranges of different age are always recognizable by their trend, have largely failed.

If now we consider again the starting point of the discussion, viz. the supposed boundary between the "Archaean" and the "Caledonian" along the coast between 68° and 70° N. lat., the idea suggests itself that the large, ice-free regions in the extreme southwest of Scoresby Sund must be of special importance for the problems exposed above. The results gained in the summer of 1958 in fact showed the lake-lands of western Gaaseland (fig. 1) to hold a key position.

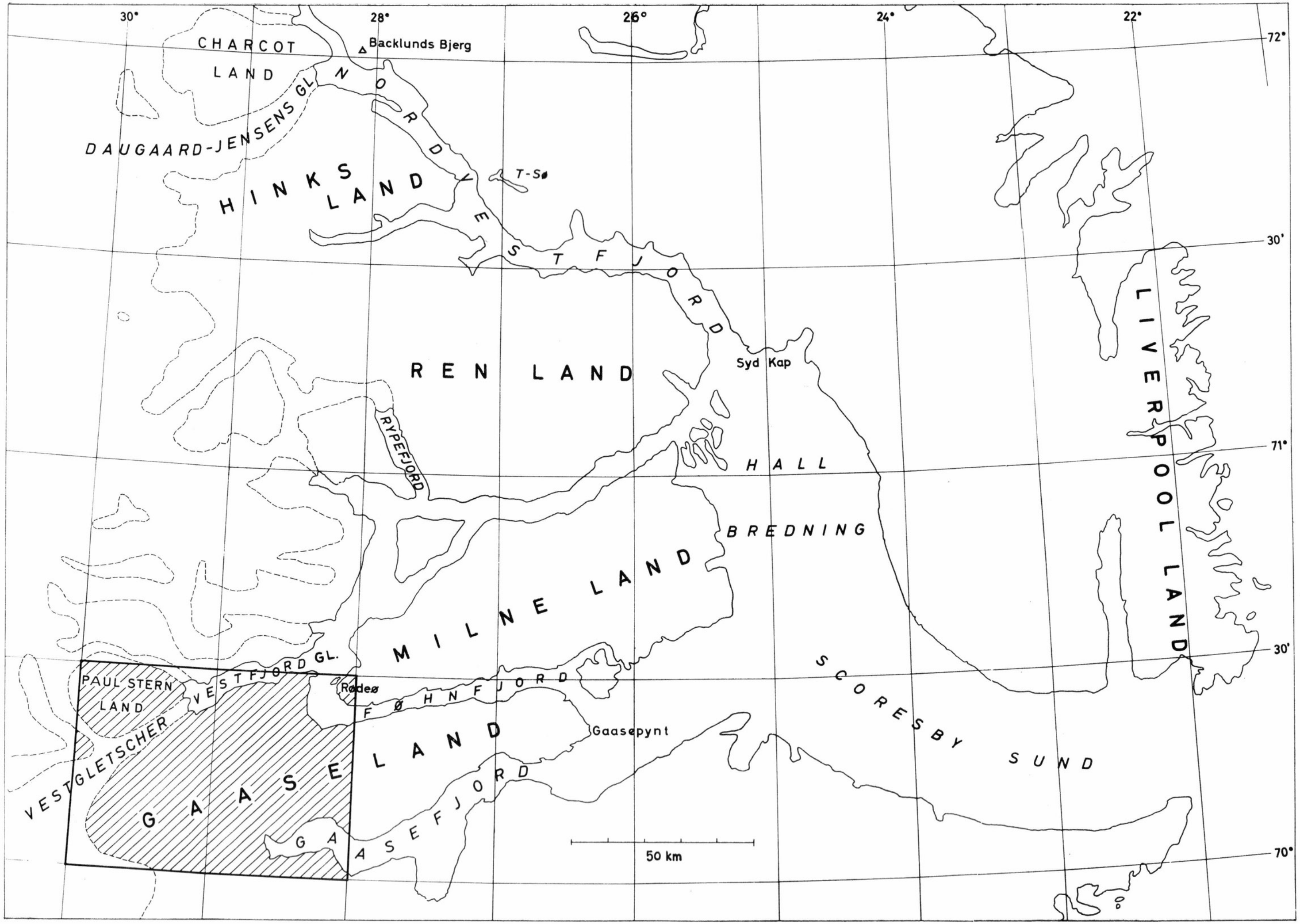

Fig. 1. Sketch map of Scoresby Sund showing situation of the working area.

II. PROGRESS OF THE INVESTIGATION OF THE SOUTHWESTERN CORNER OF SCORESBY SUND

On the occasion of a flight across the southwestern fjord branches of Scoresby Sund, on August 15. 1957, Dr. Lauge Koch landed on the lake called afterwards Gnejssø, which is situated south of Vestfjord Gletscher. He was the first geologist to set foot on this westernmost portion of Gaaseland (fig. 2) and ascertained that the peninsula projecting from the southern bank of the lake was made of steep crystalline series of the type forming the bed-rock of the skerries of the Baltic, and that, to the south, this complex is horizontally overlain by low-grade metamorphic sediments.

Two days after, the place was visited again by Dr. Koch and the writer. It was then confirmed that two formations, utterly different in regard to structure, rock content, and degree of metamorphism, are present, namely, a steep and high-grade metamorphic basal group of veined gneisses with boudinaged basic beds and of reticulated migmatites, overlain by a horizontal series mainly of marble, with sericite-chlorite-phyllites and carbonate-bearing chlorite-schists. This green-schist-marble series is strikingly similar to an analogous rock association on Hinks Land in the northwestern part of Scoresby Sund which is exposed along the southern edge of Daugaard-Jensen Gletscher and had just been investigated during the preceding weeks. The rocks belonging to the basal portion of the upper low-grade metamorphic sequence at Gnejssø are strongly sheared and rolled out. The immediately adjacent portions of the crystalline basement are mylonitized and, farther away, highly cataclastic, so that even from a distance of only a few metres it is impossible to ascertain where exactly the two adjacent masses touch. The marginal zone therefore possesses the character of a shear zone. Yet, from a greater distance, observations and measurements clearly established an unconformity. The question had to remain open whether it was a tectonically flattened stratigraphic unconformity or an imbricate structure of two different units of rock separated by a zone of phyllonites and mylonites. The fact, inferred from the local debris, of a gneiss-amphi-

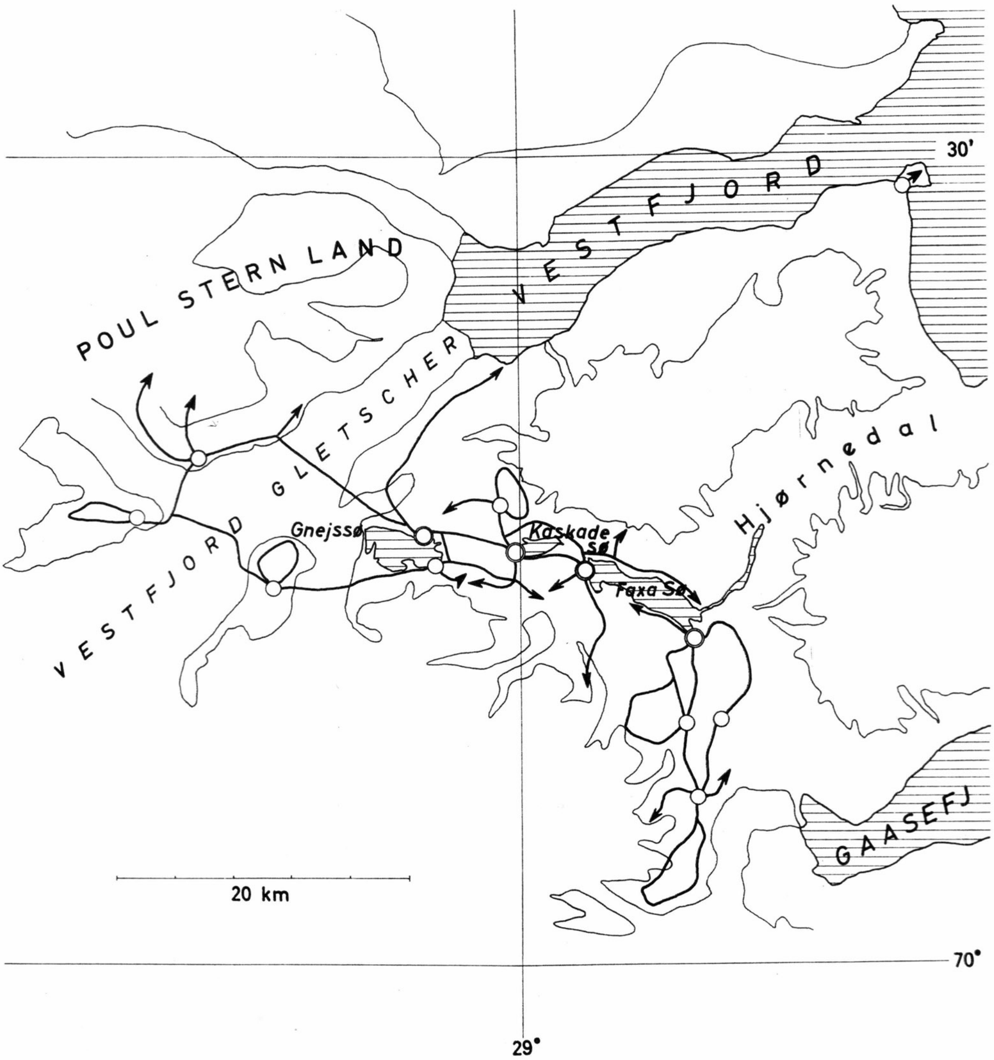

Fig. 2. Sketch map of western Gaase Land showing routes followed in 1958.

bolite-pegmatite group overlying the slightly undulated marble-greenschist series, further complicated the geological situation.

On reconnaissance flights it was observed that the horizontal series rich in marble is widely distributed in the region around Vestfjord Gletscher. It was surprising, however, that from the distance, we could perceive the boundary between the marble series and its likewise yellowish-weathering crystalline basement in few places only, and that, accordingly, we did not succeed in estimating the extension of the basal crystalline series from the air. In addition, the relations to the adjacent part of the lake plateau of western Gaaseland remained obscure. These reconnaissances convinced us that only a careful geological investigation in the field would clear up the intricate, but decidedly significant conditions. Such a field campaign on the lake-covered plateau would be greatly facilitated by the possibility of employing seaplanes. In the following year Dr. KOCH entrusted the present writer with this task.

In July and August 1958, the whole lake plateau of western Gaaseland, from Vestfjord Gletscher to Gaasefjord was investigated in co-operation with P. STERN and J. PAPAGEORGAKIS and geologically mapped as far as an excellent outline map on the scale of 1:100.000 by the Geodetic Institute, Copenhagen, reached. P. STERN extended his investigations to the adjacent area of Vestfjord Gletscher, which he crossed on a ten-day glacier trip to the nunatak peaks at the edge of the inland ice, and later to where the glacier descends into Vestfjord. Our routes and camp sites can be seen on the sketch map (fig. 2).

Thanks to the excellent organization of the expedition, our team of six could land on Faxa Sø on July 15, 1958, in a Catalina plane with complete equipment, and only 24 hours after leaving our homes in Switzerland, we were able to pitch the tents in our working area in Gaaseland. The field-work was commenced in the steeply folded Caledonian crystalline rocks around Faxa Sø. Along horizontal shearing planes with huge blastomylonites, this series is thrust on to Caledonian metamorphic parautochthonous sediments of the lower Eleonore Bay Group at Kaskadesø. The above-mentioned greenschist-marble series overlying the Gnejssø crystalline belongs to these sediments. By July 26th, our study of the exposures between Kaskadesø and Gnejssø convinced us that the "basement"-like Gnejssø complex represents a pre-Groenlandian crystalline series, the so-called "Archaean"; as it is always horizontally overlain by the same sedimentary series, which is identified with the bottom part of the Eleonore Bay Group, and as, moreover, apart from the shearing zones at the immediate contact, the picture of a clear unconformity always presented itself. But final proof of this fact was only furnished by the discovery of a basal psephitic series preserved in pockets of the pre-Groenlandian plane of erosion in tectonically sheltered places. Erratic boulders of these rocks were found on July 27th and the beds in situ we discovered on July 28th in classic exposures at the northern bank of Gnejssø. Thus the main problem had been solved already after two weeks of field work. The investigation of Vestfjord Gletscher afterwards confirmed the discoveries at Gnejssø, supplied additional finds of coarse-grained clastic sediments, and revealed the extension of the pre-Groenlandian crystalline basement and the gently undulating parautochthonous sediments of the Lower Eleonore Bay Group. The simultaneously started investigations in the region towards Gaasefjord concerned the structure and metamorphism of the Caledonian crystalline series, the basal part of the pile of Tertiary plateau basalts horizontally overlying all the other formations, and the relationship of these basalts to the widely distributed vertical dolerite dykes piercing the crystalline rocks. These results will be published later.

Our account would not be complete if, in conclusion, we did not speak of the decisive part contributed by aircraft to the work of our group carrying on its investigations 400 km from the expedition headquarters. The planes enabled us to make reconnaissance flights, they provided for additional supplies and maintained the contact with the leader of the expedition for us. And apart from our experience gained in the previous summer, it was the careful study of the various series of air photographs taken by the Geodetic Institute of Copenhagen and by the Danish East Greenland Expeditions under Dr. Lauge Koch that had helped us to plan our work months before and had enabled us to recognize the geological key points beforehand and to arrange the program in such a way that we could make full use of the short Greenland summer.

We, in fact, had been lucky in our selection at the writing desk of sites for our first three base camps; they all three happened to be situated in the immediate neighbourhood of important exposures.

In an unexplored region observations from the air are indispensable for obtaining a general view of the geological pattern which alone makes possible the planning of investigations and the tracing of the different rock zones ascertained by field evidence. The value of reconnaissance flights is in no way reduced by our restriction that they can never take the place of geological field investigations and that, for the *crystalline series*, observations from the air are subject to uncertainty. Thus, we should be lacking in criticism if, for instance, we attempted to decide from the air about the presence of lenses of peridotite, amphibolite or garnet-rich compact micaschist, of layers of quartzite or light-coloured gneiss, and of Caledonian or pre-Caledonian rocks. This may be illustrated by the fact that even from a mountain commanding a wide view (plate II), like Point 1166, towering 650 m above the lake plateau, we can only detect in a few places, in good light and with field glasses, the boundary between the crystalline inlier of Gnejssø and the surrounding area. It will always be the task of the "little man with the hammer" to solve the problems realized during air reconnaissance flights. And if a key position proves inaccessible, this will not render more probable the diagnosis put forward by the geologist judging the conditions from the air.

Fig. 3. Aerial view of the southern bank of Gnejssø. C = Caledonian crystalline overthrust mass. M = Marble-Chlorite-phyllite Series, parautochthonous, Ps = Basal Psephitic Series, Groenlandian, A = Autochthonous migmatitic basement, Pre-Groenlandian (Archaean). Photograph by E. Wenk.

III. GEOLOGICAL AND PETROLOGICAL RESULTS

The geological observations made in the field are represented in the map and in the profile (plates XII and XIII). Combined with our collections of rock samples, this compilation of our observations constitutes the tangible result of our investigations in the summer of 1958. If our comments are cautious and brief, this is mainly due to the fact that, for the time being, our area of investigation bears the character of an island in an unexplored sector and that we do not wish to disturb the work of future explorers in the neighbouring areas with ideas which in 1958—it is true—we discussed in the tent or evolved in the monologues of our field diaries, but we were unable to contribute much to their elucidation.

For the present, the geology of the Gnejssø region stands isolated, and only in the north interpolations gained from observations during our reconnaissance flights permit to compare it to some extent with the known, but 180 km distant, Caledonian crystalline series of Nordvestfjord. In the south, the nearest outcrop of the crystalline series we know of lies near Kangerdlugsuaq (Wager & Deer 1934, 1939, 1947), which is 250 km away; it is separated from our occurrence by the inland ice and the plateau basalts.

In the area around Vestfjord Gletscher and on the broad ice-free land strip between Vestfjord Gletscher and the innermost stretch of Gaasefjord, from bottom to top the following four geological units can be distinguished:

1. *Autochthonous migmatitic-granitic crystalline basement. Pre-Groenlandian* ("Archaean").
2. *Parautochthonous Groenlandian sediments with greenschists* resting *unconformably*, and with a *basal psephitic series*, on the basement; but the sedimentary cover is for the most part dislocated, gently folded and of low-grade metamorphism caused by the Caledonian orogeny.
3. *Medium-grade metamorphic Caledonian crystalline rocks*, *allochthonous* in the region around Gnejssø as thrust-sheets covering units 1 and 2; at Faxa Sø, however, already rooting in the depth and, from here to Gaasefjord and Gaasegletscher, forming rather regular folds with gently plunging axes.
4. *Cretaceous to Lower Tertiary plateau basalts* and associated dolerite dykes of the Brito-Arctic province; the subhorizontal basalt sheets cover the Caledonian crystalline series along an undulating peneplain lying 1250 to 1550 m above sea-level in the lake district.

From plate XIII the connection of these four units can be seen.

1. Autochthonous crystalline basement, pre-Groenlandian ("Archaean").

As will appear from the map (pl. XII), the crystalline basement complex is chiefly exposed in the banks of Vestfjord Gletscher and its tributaries; this is an area about 35 km long and 5 to 20 km broad. If we include the ice-covered parts, the area will be larger than 300 km^2. From the map and the section we can see that only the orographically deepest portions consist of basement material. The gently undulating surface of the basal crystalline series rises at a low angle towards the west-northwest, as shown in the section (XIII). While at Kaskadesø, along the eastern edge of an inlier-like outcrop (pl. I), it occurs at 300 m, at Gnejssø (pl. II) at 480 to 600 m, and at the southeastern edge of Vestfjord Gletscher at 600 to 800 m, it reaches altitudes of more than 1400 m in the nunataks along the northwestern flank of the glacier. Thus, in its observable portion, the autochthonous crystalline basement does not descend towards the ice edge, but disappears there solely on account of the rapid rise of the relief. This observation may be of interest to future investigators, but should not be generalized, for arguments of a different nature lead us to expect that the top of the basement will plunge farther to the west. It may be regarded as a stroke of good fortune that the basement complex is so excellently exposed in the easily accessible lake area. If the bottom of the valley were located 120 m higher at Gnejssø, and only 50 m higher west of Kaskadesø, the pre-Groenlandian would not be exposed there.

Along the northern and eastern shores of Gneissø a homogeneous, coarse-layered, and compact, light-grey, but yellowish-weathering microcline-augengneiss, in places exhibiting a rather massive texture and passing into granite, is the main rock of the crystalline basement. Characteristic of this rock is its high proportion of a clear microcline, which is free from inclusions and throughout distinctly twin-latticed. This mineral will be of importance in the subsequent discussion; for in the same form it is also abundantly present in the immediately overlying psephites—not only as a component of the boulders, but primarily as a part of the psammitic fraction— being actually indicative of these deposits. In contrast to the microcline, the plagioclase of the light-coloured gneisses is always filled with sericite-(paragonite-?) scales and clinozoisite; albite to oligoclase-albite occur. Biotite is abundant in some samples; in others only muscovite-sericite and chlorite are present, together with epidote in varying quantities. Evidently we are here concerned with mineral transformations due to the shearing movements resulting from the overthrust of the Caledonian crystalline series upon the basement and its parautochthonous sedimentary cover. Thus, only the deepest and freshest rocks of the crystalline basement can be of service for an absolute determination of the age[1]). Along the northern edge of Vestfjord Gletscher P. STERN collected rather massive varieties, some with pale pink microcline. One of these samples represents a microcline-alkaligranite poor in quartz.

The light-coloured gneisses described above are often banded; nevertheless, they seem to be younger than the adjoining irregular migmatite zones, of which plate III gives a characteristic picture. These rock complexes, inhomogeneous and exceptionally diverse as to texture and composition, are best exposed in the large peninsula at the south shore of Gnejssø and in the roches moutonnées west of Kaskadesø; in the northern bank of Gnejssø they are only well developed locally. In these zones occur dark bands and masses, frequently boudin-like and net-veined by light-coloured rock material, which surrounds them. The dark phase consists of green to colourless actinolitic hornblende, biotite, rarely pyroxene, a yellow to grass-green delessite-like chlorite, and epidote, in addition to saussuritized plagioclase (oligoclase). The rocks are amphibolites and dark gneisses. Unfortunately only few thin sections are available from the light-coloured mobile phase. In the Kaskadesø region it chiefly consists of plagioclase gneiss with saussuritized feldspar, whereas the vein

[1]) For age determination see Postscript on p. 49.

material at Vestfjord Gletscher contains the aforesaid clear and ideally twin-latticed microcline.

Together with quartzites of unknown origin all the hitherto mentioned rock types additionally occur as blocks in the overlying psephitic series. There, they are penetrated by carbonate along cracks.

A characteristic peculiarity of the somewhat displaced crystalline basement is the dyke-like occurrence of metamorphic basic rocks. The above-mentioned steeply tilted microcline-augengneisses of the peninsula projecting from the northern shore of Gnejssø are discordantly intersected by a 20—50 m thick, flat-lying, dark-coloured rock-sheet, as shown in the

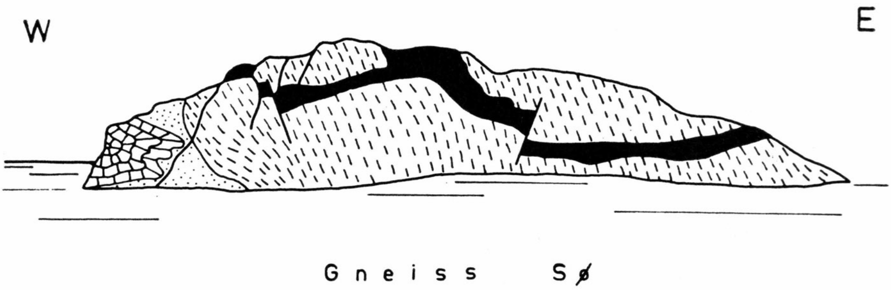

Fig. 4. Sketch of the peninsula projecting from the northern bank of Gnejssø. Basic dyke (black) cutting augengneiss (dashed); Marble- and Basal Psephitic Series (dotted) on the left.

sketch of fig. 4. Evidently it is a basic dyke younger than the gneiss; but the rock has been transformed into amphibolite and, independent of the texture of the neighbouring rock, its planes of schistosity run parallel with the dyke wall. The dyke rock is a chlorite-epidote-albite/oligoclase-amphibolite, containing in addition titanite, quartz and carbonate. Similar dykes occur along the northwestern edge of Vestfjord Gletscher and on the first two nunataks on either side of this glacier (pl. IV a). They never extend into the overlying parautochthonous sedimentary series of the Groenlandian but are abruptly cut off by the base of the latter. The microscopic examination ascertained the existence of both titanite- and epidote-bearing quartz-saussurite-amphibolite as well as diablastic garnet-andesine-amphibolite with relics of pyroxene. The crystalline basement rock of these areas is much fresher than that of the tectonically strongly disturbed region around Gnejssø.

These metabasalts, as they are called in Scandinavian terminology, seem to characterize this deep gneissic complex, together with the fresh microcline rocks, whereas the other varieties in some measure represent ubiquitous types.

Similar "transgressive sheets of plagioclase amphibolite" have already been recorded by Wager (1934, p. 17) from the east coast of Greenland, between Angmagssalik and Kangerdlugssuaq:

"On Kap Japetus Steenstrup an almost horizontal sheet of plagioclase amphibolite, some 100 feet thick, cuts transgressively across the gneisses of the Metamorphic Complex. ... The transgressive plagioclase amphibolites must be distinguished from the plagioclase amphibolites already described because they are clearly later than the grey gneiss or any period of flow of the grey gneiss. Where they occur the foliation and banding of the grey gneiss are almost vertical, while the transgressive sheets are almost horizontal (plate 5 fig. 1) and have a foliation parallel to their extent. Yet the transgressive sheets consist of plagioclase amphibolite which like that of the Metamorphic Complex has no relics of igneous minerals. It is clear that the transgressive plagioclase amphibolites were injected after the last yielding by horizontal compression of the rocks of the Metamorphic Complex, and in a period when a clear-cut fracture was possible. As, however, the injection took place at such a time that then or afterwards a typical plagioclase amphibolite was produced they are regarded as forming a late stage in the building of the Metamorphic Complex."

The outstanding feature of the whole, still problematic phenomenon is probably the complete adaptation of the basic dyke rocks in mineral composition and fabric (s-faces) to metamorphic conditions and in a way that makes it impossible to demonstrate any essential movements parallel with s (= dyke wall and planes of schistosity). The same applies to many of the dykes of the St. Gotthard massif in the Alps which are recorded as "lamprophyres" in the literature. Only once before during his seven summer campaigns in East Greenland the author had come across this phenomen, namely at Nordvestfjord southwest of T—lake, in a complex which, to the best of our knowledge, must be regarded as a pre-Groenlandian crystalline series transformed and reactivated in Caledonian times.

As to their geological occurrence, there exists a certain resemblance between the metabasalts of the Vestfjord Gletscher-Gneissø complex and the pre-Cambrian basic intrusive rocks in the Thule sandstones, which, though, are not metamorphic. The metabasalts might, however, be the metamorphic feeding channels of rocks analogous to the Thule intrusives. They are not related to the basalts-dolerites of the Upper Cretaceous Tertiary Brito-Arctic province, for they are discordantly pierced by them.

The strike and dip symbols in the cover-sheet of plate XII and the stereographic projection of the s-faces and fold axes on fig. 5 a show the steep crystalline basement to strike N 35° W, in general—that is, very nearly magnetic north—and the fold axes to pitch towards the southeast at an average of 20 degrees. The fold axes measured in the field correspond to the constructively computed zonal axis of the s-faces — which is the

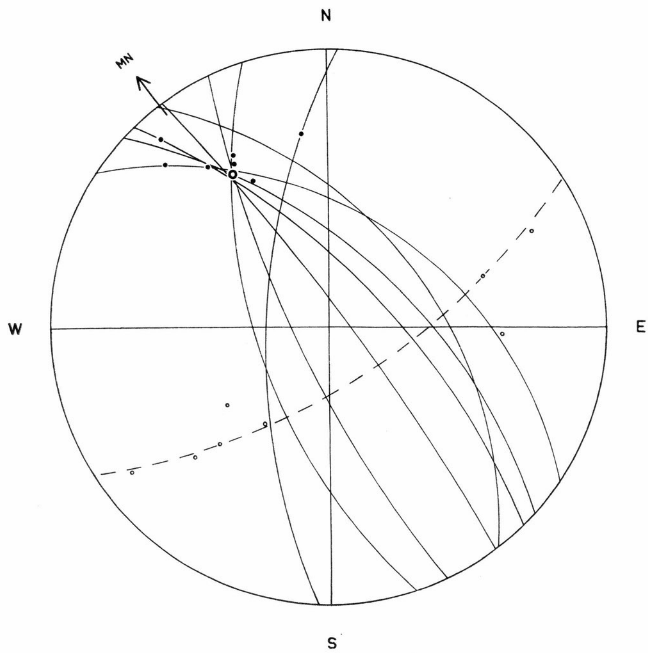

Fig. 5a.

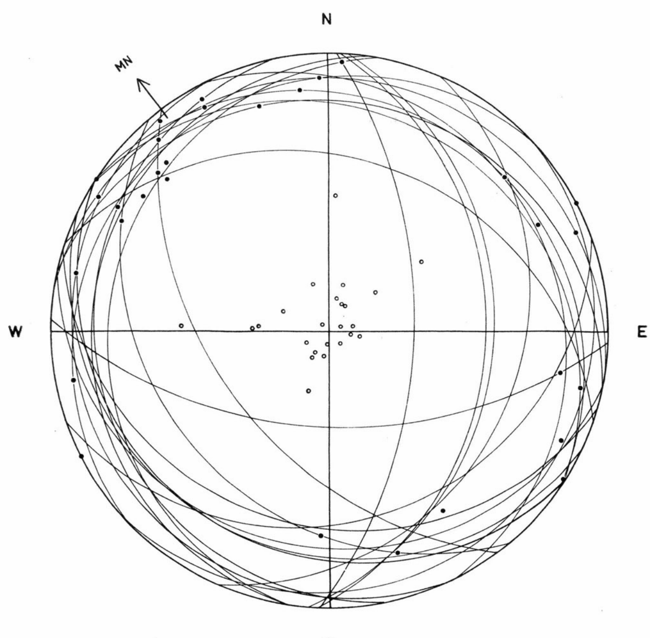

Fig. 5b.

Fig. 5. Stereographic projection of minor structures observed in Gnejssø area. Fig. 5a. Pre-Groendandian basement, Fig. 5b. Parautochthonous Groenlandian sediments. Zone-circles = s-planes, black dots = lineations and axes of minor folds, circled dots = poles of s-planes.

major fold axis. Fig. 5 b shows that within the same region the parautochthonous Groenlandian and the Caledonian crystalline series exhibit entirely different structural patterns.

From the direction of strike of the pre-Groenlandian basement we at first expected it to reappear at Gaasegletscher. But our field observations disproved this assumption; the basement dips and is overlain by Caledonian gneisses and amphibolites. In this connection we must, however, point out that, according to WAGER (1934, p. 9), the »*Metamorphic Complex« of the Kangerdlugsuaq region which in all probability is of pre-Groenlandian age too*, strikes west-north-west to east-south-east like the migmatites of Gnejssø.

2. Parautochthonous Groenlandian.

As was mentioned above in the report on the investigations carried out in 1958 (Chapter II), the demonstration of an angular unconformity between the crystalline basement and the Groenlandian, with a basal psephitic series, was one of the main results of our campaign.

The normal sequence above the unconformity consists of the following members from below upwards:

(a) *Basal Psephitic Series*, thickness 0—50 m.

The peneplaned crystalline basement described in the preceding chapter is covered with conglomerate-like deposits, which are preserved sporadically in depressions and on the west side of humps in the undulating old land surface. These small and isolated occurrences, distributed all over the area visited, are indicated in the geological map. (pl. XII).

The aspect of the most easily accessible locality on the northern bank of Gnejssø is shown in pl. IV b and figs. 6 and 7. The geological conditions are here complicated by the synclinal folding and shearing of the psephitic series together with the crystalline basement (fig. 4) and by the epithermal metamorphism, both of them phenomena which are associated with the thrust of the Caledonian crystallines over the adjacent "Archaean" basement to the west. Plate IV, b gives a view of the overturned limb of the recumbent syncline and shows a pebbly bed in the upper part of the picture. The banded series seen in the lower half of the picture consists of indurated layered clay beds alternating with arkose and greywacke. For the most part the rocks contain no or very little carbonate; only locally, as for instance at the point whence the photograph was taken, an arkose containing more than 25 per cent. of carbonate is met with. At the figured outcrop, the rocks exhibit a low-grade metamorphism, with albite, sericite, and chlorite as newly formed minerals. As shown by the rock section in fig. 7, chiefly the fine-grained beds and

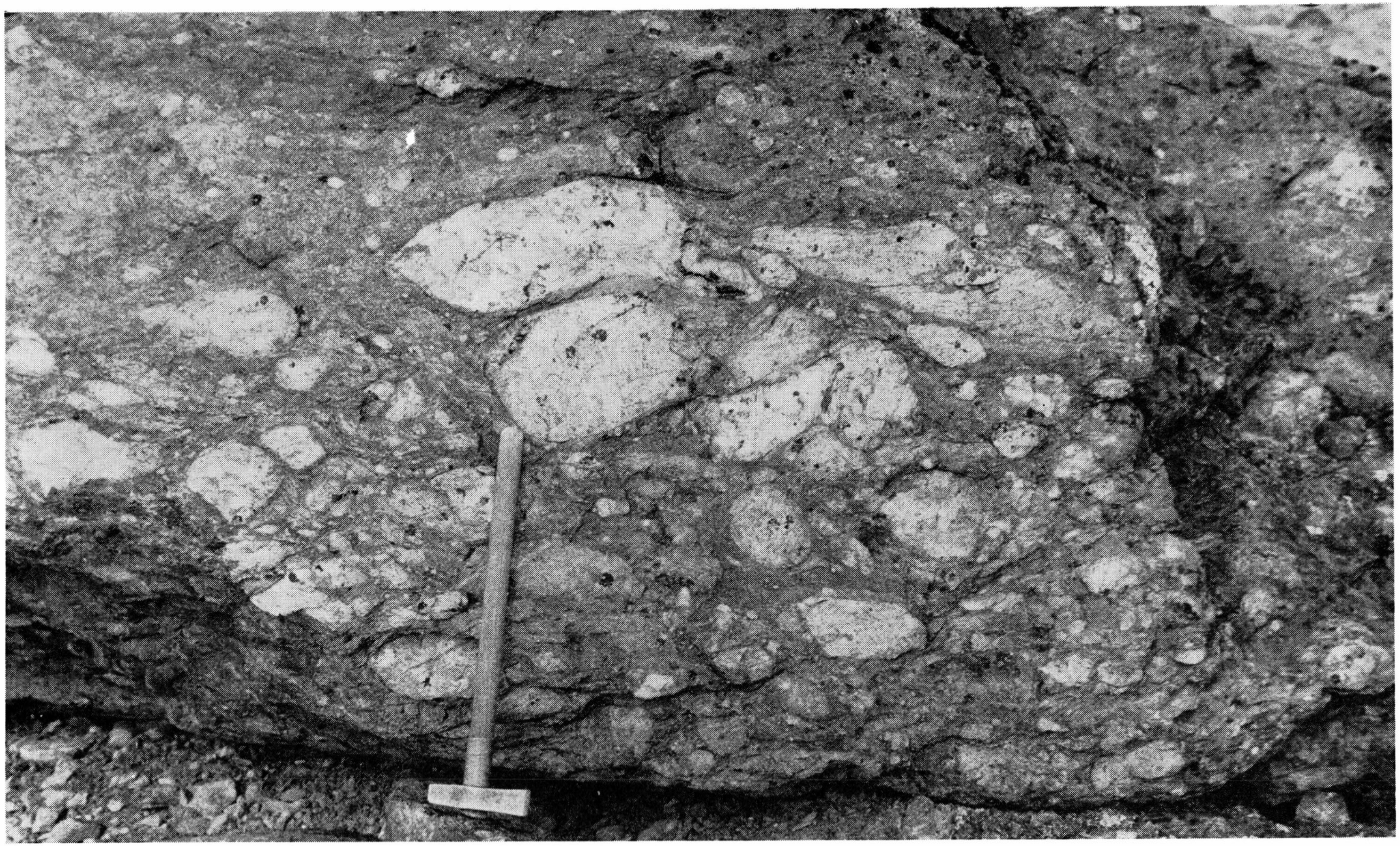

Fig. 6. Psephitic rock from the peninsula in the northeast corner of Gnejssø (compare plate 4, figure b). Photograph by E. WENK.

the cement of the coarse-clastic horizons were affected by the deformation and transformed into B-tectonites, while the pebbles and boulders to a great extent preserved their shape and mineral content. In the southern bank of Gnejssø the pebbly series is more strongly deformed, and at Kaskadesø farther eastward it is even replaced by a mylonitic horizon. To the west, however, in Paul Stern Land, the psephitic rocks are well preserved.

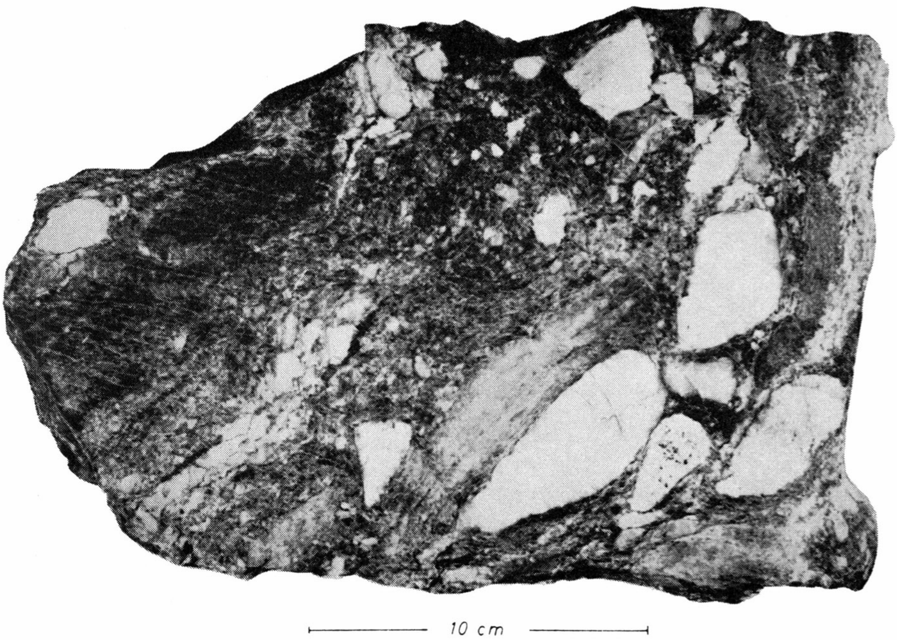

Fig. 7. Deformed psephitic rock from the peninsula in the northeast corner of Gnejssø. Angular and subangular fragments of quartzite, microcline-gneiss, and granite in a strongly deformed arenaceous-argillaceous matrix. Photograph by H. HERES.

Brief guide for excursions to the psephitic exposures on the peninsula at the northern bank of Gnejssø:

This easily accessible classical outcrop can be reached from the bay located in the northeastern corner of Gnejssø and extending far northward. A small valley offering suitable tent places debouches from the northwest into this bay. Following the small rivulet, one climbs upwards for about 15 minutes over patches of vegetation. The mountain to the north consists of microcline-augengneiss grading into veined gneiss, which is rather massive locally and on its top bears a mantle of marble. The gneiss is pierced by a thick dyke-like flat sheet of metabasalt, and this, in its turn, is cut across by two narrow Tertiary dolerite dykes.

At the first flat part of the valley bottom, at a roche moutonnée between the two dried-up lakelets, migmatitic gneiss is overlain by a few metres of quartz-phyllite and some marble. These bands are traceable into the top mantle of the above-mentioned mountain. The same succession—migmatite at the base, marble at the top, and in the interval between them some metres of quartz-phyllites—is met with throughout the whole slightly undulating passe landscape which begins here. On closer inspection it will be noticed that the quartz-phyllites are always deposited in depressions between the migmatitic ridges. This makes us

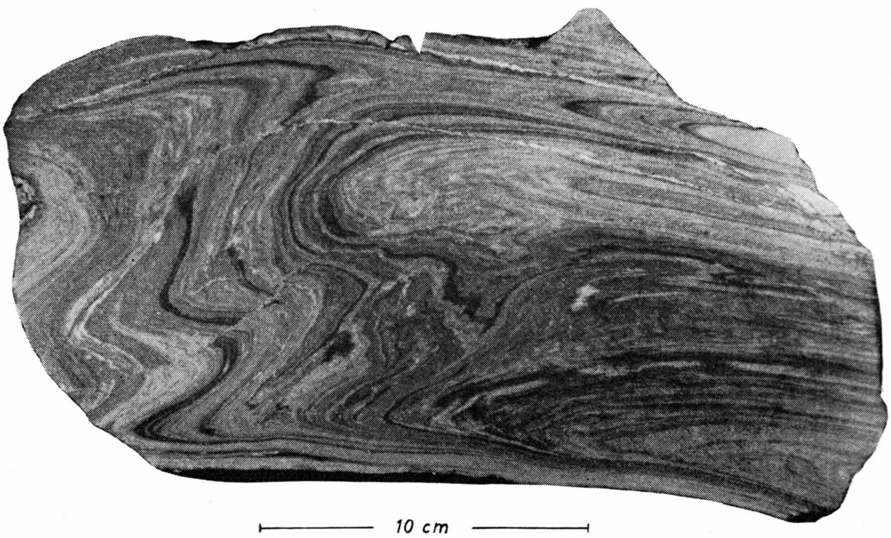

Fig. 8. Folded marble from the peninsula in the northeast corner of Gnejssø (left hand part of figure 4). Photograph by H. Heres.

suppose that the quartz-phyllites may be deformed conglomerates. Decisive for this question is the occurrence not very far to the northwest, at the immediate southwestern bank of the lake (roughly 80 m long) located at the watershed north of the peninsula (120 m above the surface of Gnejssø), of quartzite and granite pebbles, many of which are well preserved, in the phyllite zone, which here also rests on gneiss and is overlain by finely crystalline marble with lenses and beds of carbonate-chlorite-phyllite. From this point the zone can be traced southward without interruptions across the ridge to the place situated about 10 minutes farther on and characterized by a large stone cairn, and onwards to the steep slope at the southern tip of the peninsula. Considering the increasingly steep and finally overturned position of the beds and the occurrence of strongly folded and sheared marble in the core of the syncline (fig. 8), we may also get an idea of the tectonic complications of the region. The descent to the starting point of the excursion can be made in a due northeast direction.

The exposures of faintly metamorphic psephite in a much clearer geological position in the southern corner of Paul Stern Land can only be reached from Gnejssø after a 10-hours troublesome traverse of the glacier.

Microscopic and chemical study of the psephitic series.

The microscopic examination is in the main based on the observations made in the well preserved occurrences in Paul Stern Land. Its geological position will be seen from plates V and VI. Plate VII shows the nature of the exposures and proves the association of the indurated boulder-beds found there with varve-structured clays, while the figures of plate VIII present microphotographs of the matrix of the psephites.

In general the basal psephitic series can be characterized as follows: The indurated sediments containing pebbles, boulders, and blocks form well defined beds. The coarse, psephitic fraction, however, rarely composes more than one-third of the rock volume of these strata. Medium-grained psammitic and fine-grained pelitic material is everywhere admixed, and in the succession the psephitic beds alternate with psammitic and often with finely varved pelitic beds. A vast range of size grades is, indeed, characteristic of the individual beds as well as of the clastic series as a whole.

The rock fragments embedded in the series are up to 60 cm in diameter and consist essentially of quartzite, microcline-granite, gneiss, and amphibolite. The three last-mentioned types form the bedrock in the surroundings of Gnejssø and Vestfjord Gletscher. Sediment pebbles were not seen.

The roundness of the rock fragments differs widely. Along with well rounded pebbles and boulders (especially quartzite and granite) also subangular and angular blocks occur.

The matrix of the psephitic beds is composed of a psammitic as well as a pelitic fraction, and the same is true for the medium-grained members of the sedimentary series. Apart from rock-fragments of microscopic scale, quartz and clear, non-perthitic and perfectly twin-latticed microcline are the main constituents of the sand fraction sometimes associated with small flakes of biotite which hardly show any evidence of alteration. The lack of weathering and decomposition is indeed a characteristic of these clastic minerals. Microcline with the same qualities occurs also in the above-mentioned granites and augengneisses of the basement complex which forms the bedrock of the psephitic series. This point is certainly not incidental, especially not if we consider that perthitic and cloudy potash feldspars are far commoner in East Greenland than this clear microcline.

The important pelitic fraction (ca. 30 Vol $^0/_0$) of the matrix consists of sericite, which is either an original constituent of the rock or was formed from other clay-minerals during the consolidation and induration of the rocks long before the Caledonian folding period. Plate VIII shows thin-section photographs of the matrix of block-beds and displays the unsorted character of the rocks and the highly different roundness of the grain fragments: associated with well-rounded grains occur angular fragments with concave fractures, typical of till deposits.

The chemical analysis of the matrix of the rock Gaa. 123 from the south corner of Paul Stern Land, the structure of which is shown in plate VIII, gave the following results:

SiO_2	64.2	weight %
Al_2O_3	15.5	
Fe_2O_3	1.8	
FeO	2.6	
MnO	0.03	
MgO	2.4	
CaO	1.0	
Na_2O	0.5	
K_2O	8.6	
TiO_2	0.3	
P_2O_5	0.14	
H_2O	1.6	
CO_2	0.8	
	99.47	

Analyst Dr. H. Schwander, 1959.

The high contents of alumina and potash confirm the argillaceous-arenaceous nature of the matrix. The low Ca and Na contents support the microscopic observation that hardly any plagioclase could be identified.

Obviously many of the facts mentioned are diagnostic for glacial conglomerates, such as tillites and indurated boulder clays. This problem of considerable geological interest is discussed below.

Origin of the psephitic series.

If we are to describe in some detail the psephitic basal series, genetic points of view will have to be considered even in the name-giving.

The possibility can at once be excluded that we are here confronted with the products of cataclastic and mylonitic processes which have arisen during an orogeny. All arguments speak in favour of a clastic-sedimentary nature of the rocks and of their origin as epicontinental deposits in a post-orogenic period of erosion. In fact, the psephitic series, together with the sediments overlying it, was then deformed at a later stage, particularly in the Gnejssø region.

In an attempt to find a name for the rock, the term breccia must be left out of consideration, since the coarse material has for the most part rounded edges, and well rounded components also occur. The concept conglomerate is more fitting, but is not the right term for the rock present here, in so far as the block fraction in no way predominates in volume, but occurs within a much finer-grained matrix and is sometimes concentrated into beds and sometimes irregularly scattered. In the coarse-grained varieties, the psephite, psammite, and pelite derivatives each make up about one third of the rock. According to the dominance of one or the other grain size group, we may speak of conglomerates with a large amount of arkosic or clayey matrix, of conglomeratic grey-wackes, pebbly argillaceous arkoses, or of boulder clays. Some of the beds of the series may be termed greywackes, arkoses, and varved clays, but none simply conglomerates, considering the never lacking clayey matrix.

The peculiar distribution of the grain-size which is reflected in this nomenclatural misery is a well-known characteristic of glacial deposits. However, before discussing this interpretation, we must also take into consideration the group, nomenclaturally difficult to define, of unsorted deposits of débris and mud streams produced by torrents and earth slides in the mountains. But such a mode of origin is rendered unlikely in the first place by the morphological character of the pre-Groenlandian denudation plane, which—as shown by the profile in pl. XIII—represents an ideal peneplain, the final product of an erosion period of long duration, with no great variation in relief. Secondly, the sporadic occurrence of clastic sediments in depressions in the peneplain all over the area, tells against it. Thirdly, this interpretation would not be in accordance, either, with the coarse alternation of the series which is recognizable in most occurrences, and with the beds and lenses of banded shales, for only in places is the structure irregular.

For the term *tillite*, in the wide sense of the word which permits the transport of morainic material on drift ice and in water, speak the following arguments:

1. Poor sorting, occurrence together of a very wide range of grain-sizes.
2. Extreme variation in the rounding of the pebbles.
3. Angular, concave chips in the arkose-like psammitic derivatives.
4. Predominance of local débris (microcline granite) in addition to well-rounded quartzitic material transported over great distances.
5. Clayey matrix, often finely varved.
6. Lack of weathering of the mineral débris; biotite and microcline remaining fresh.
7. Chemical composition; matrix rich in Al and K.

8. Series deposited in layers, but for the most part poorly bedded; in places chaotic structure. Banks rich in blocks not always restricted to the base of the clastic series.

Since soft sedimentary rocks are absent among the block material, no scoured boulders occur. Nor was any glacial striation observed on the surface of the crystalline basement, but considering that the results of the microscopic examination speak positively in favour of a tillite origin, this observation in the field needs occasional checking—more particularly in the nunatak regions in which the boundary plane between the crystalline basement and the sedimentary cover is not strongly deformed. Thus, as with the many other tillite occurrences in the world, we lack the final conclusive proof of the glacial origin of the formation.

With the reservation that actualistic considerations are still applicable to this epoch dating back presumably 800 to 1000 million years, the *interpretation* of the basal Groenlandian series of the Gnejssø region *as a tillite deposit is the most probable.* Thereby, of course, nothing has as yet been said regarding the question whether the glaciation was of a local or a regional character.

The Eleonore Bay Group accordingly begins and ends with glacial deposits; in spite of its abundance of quartzitic sandstones, it nowhere includes typical conglomerates throughout its whole series — in contrast to the Palaeozoic cycle of East Greenland.

Though the Gnejssø tillite could be compared with the tillite in the base of the Animikie Series, we do not venture to discuss correlations with the Canadian shield. This problem must await the results of the absolute age-determination of the basement rocks from Vestfjord Gletscher, in progress in the laboratory of Dr. J. L. Kulp.

(b) *Marble-Chlorite-phyllite Series*, thickness 250 m.

Throughout the area this sedimentary series overlies the steeply tilted crystalline basement (Archaean) as a flat sheet. Where the sporadic occurrence of the basal psephitic series is lacking, the marbles rest directly on granite and migmatite. We must assume that already at the time of deposition of the calcareous sediments, the psephitic series was only preserved locally in depressions. The boundary plane between the crystalline basement and the sedimentary cover formed a pre-destined zone of dislocation for the subsequent Caledonian movements. Also the marble series itself, being a readily deformable rock zone, was affected by the differential movements. The horizontal position of the sedimentary sheet does not conceal the many recumbent small-scale folds and shearing zones within the carbonate-rich beds (fig. 8). Through the overthrust of the Caledonides the discussed series at Kaskadesø has been reduced to a few metres of carbonate-mylonite, while at the western part of Gnejssø it is well developed, and in Paul Stern Land, along the edge of Vestfjord Gletscher, attains a thickness of 250 to 300 m.

The series consists in the main of light-grey, but ochreous weathering fine-grained marble, which is rough to the touch and contains some quartz, often albite, and, on account of an increasing content of chlorite, passes into carbonate-chlorite-phyllite and more rarely into carbonate-sericite-phyllite. The carbonate grains are generally laminated, and the twin lamellae are sometimes bent. Coarse-grained calcite forms narrow veins and, together with quartz, also lenses.

The following partial analyses of the acid-soluble part of the Gnejssø marbles show that calcite is by far predominant, while dolomite is of more subordinate occurrence:

	Gaa. 5	Gaa. 16	Gaa. 17	Gaa. 524
Weight % CaO	36.4	49.0	49.8	49.4
Weight % MgO	1.7	1.6	1.3	3.5

The metamorphic carbonate rocks sometimes build up compact massive rock walls, but in other cases owing to the intercalation of grey-green phyllites and schists, exhibit a well-bedded development. The interbedded dark-coloured rocks are of very different thickness, they have no regional extension, but frequently wedge out. The following rock types are represented:

chlorite-phyllites
calcite-chlorite-phyllites
clinozoisite-bearing albite-sericite-chlorite-phyllites and -schists
albite-clinochlore-hornblende-schists
calcite-albite-pennine-sericite-phyllites.

In some rocks albite is the predominant constituent, and, in association with clinozoisite-epidote, sericite, pennine, clinochlore, and colourless to faintly greenish hornblende, characterizes the metamorphic facies (greenschist facies). Petrographically it is an association of greenschists; whether we are here confronted with metamorphic greenstones, cannot be ascertained in Gaaseland owing to the absence of relics. An indication in this respect is only furnished by the remarkably high content of albite (Na).

Analogous prasinites with a varying carbonate content, which in the hand-specimen are indistinguishable from these greenschists of Gaaseland, and hornblende-schists occur, likewise together with marbles, but in much greater thicknesses, in Hinks Land at the southern edge of Daugaard-Jensens Gletscher. There, however, associated serpentines point clearly to their appurtenance to an ophiolitic suite. At Gnejssø the close alternation and association of the greenschists with carbonate deposits might also point to their derivation from dolomitic-marly sediments or tuffitic beds. The question, however, cannot yet be solved in Gaaseland. It seems very unlikely, however, that the marble-greenschist associations, in all probability corresponding to one another, should differ genetically between the two occurrences.

(c) *Phyllite-Mica-schist Series*, thickness more than 1500 m in Paul Stern Land.

This monotonous, but very thick, series is only fully developed in Paul Stern Land, where it builds up the whole highly glaciated top region. It was examined in the section in Snehorn, yet it would seem that the mountains farther to the north-east exhibit more continuous stratigraphic sections. Owing to tectonic disturbances only the deeper portions are preserved on the Gaaseland side of Vestfjord Gletscher.

The *basal band* is formed by 6—10 m thick beds of sericite-quartzite. This band is developed on either side of Vestfjord Gletscher, separating the purely pelitic series from the underlying carbonate sediments.

Above follows a sequence, 800 to 1000 m thick, of low-grade metamorphic pelitic sediments (sericite-phyllite and garnet-biotite-phyllite) with occasional lenses and large masses of plagioclase-amphibolite with gabbroic relic structures.

The upper part of the sequence, at least 500 m thick, but very likely up to 1000 m thick,—it is difficult to estimate owing to glaciation and is rather inaccessible—consists in the main of garnet-cyanite-staurolite-mica-schists, but beds of medium- to coarse-grained micaceous quartzites and sparse lenses of carbonate rocks are common also.

In his diary, Paul Stern says that in the same area (Snehorn) in which the quartzitic banks occur, a remarkably large number of blocks of Scolithus quartzite lie spread about, but that no connection between the two types of quartzite could be established. This statement is, in so far, of particular interest, as we are here concerned with the southernmost known occurrence of Scolithus quartzite at the edge of the inland ice in East Greenland. In spite of zealous search, no such erratics were found in the lake district of Gaaseland, while they are widely distributed in the northern parts of Scoresby Sund (Nordvestfjord).

A complication of great genetic significance, but disturbing the stratigraphic relations, is formed by the distinctly increasing metamorphism, from below upward, within the huge group of pelitic sediments. While—as was already ascertained in the section reduced to 150 m at Gnejssø—the deepest members (0—50 m) are still developed as sericite-phyllite, the next-highest already carry garnet and biotite. With the decrease in sericite and the formation of plagioclase, coarse-scaly mica and garnet-porphyroblasts, the phyllites within the flat-bedded series pass upwards into micaschists. In the upper part of the series, characterized by intercalated quartzite beds, the minerals oligoclase, staurolite, and cyanite are generally met with in addition to garnet and mica. According to their fabric and paragenesis, these rocks are indistinguishable from the mesothermal micaschists and paragneisses in the Caledonian crystallines at Faxa Sø. The *inverted succession of the metamorphic zones* at Vestfjord Gletscher represents an intricate problem which may only be solved through a detailed mapping of the rather inaccessible eastern part of Paul Stern Land: Either heat-supplying Caledonian granite masses, conditioning the zonal inversion below their lower limb, were included in the *overthrust of the Caledonides on to the crystalline basement*, and its sedimentary cover. Or the phyllite-micaschist zone of Paul Stern Land is tectonically composed of low-grade metamorphic autochthonous and medium-grade metamorphic allochthonous Caledonian members. The overthrust Caledonian gneiss masses, interfolded with pegmatites in the beds overlying series (c) at Gnejssø, and the constant increase of the metamorphic grade ascertainable already in the lowermost 100 m of the phyllites, speak in favour of the former solution. *The westward thrust of the Caledonian over the pre-Groenlandian basement should then be regarded as an action accompanying and continuing beyond the Caledonian folding activity, but not as separate from this main phase.*

The problem of the inverted zonal succession might be solved through a precise elucidation of the stratigraphy of our phyllite-micaschist series mentioned in the text under (c), but on the geological map divided into an upper and a lower part. This division is clearly visible in the landscape, and had been recognized already during the reconnaissance flights: the upper part is distinctly banded and weathers olive-brown; the lower part is compact, exhibits no structure, and weathers ochreous to rusty-brown. This lower part, consisting of sericite-chlorite-phyllite, garnet-biotite-phyllite, micaschists, and amphibolite, corresponds petrographically and stratigraphically to the 1250 m thick phyllitic series of the Petermann region (WENK and HALLER 1953, p. 19). If it should be established by future investigations that the upper part, which is composed of garnet-cyanite-staurolite-micaschists with intercalated quartzites, should be regarded as equivalent to the ca. 1400 m thick Layered Quartzite-Slate-Dolomite sequence of the Petermann Series, our problem would be answered in accordance with the former solution (prev. page). This question of the stratigraphic correlation will be treated in the succeeding chapter.

Stratigraphical correlation of the Gnejssø section with the sequence of the Eleonore Bay Group.

Observations in the field showed that the sequence in question comprises sediments deposited transgressively and with angular unconformity on a substratum of bedrock after an effective erosion period. It is true that the shearing, folding, and metamorphism associated with the Caledonian orogeny render interpretation more difficult; but relics prove the actual state of affairs.

That we are here concerned with Groenlandian sediments and with equivalents of the Lower Eleonore Bay Group, cannot be proved, but only rendered probable. As fossiliferous beds are absent, and as the sediments of the Gnejssø region show no relationship, either, to the type sections of the Groenlandian, certainty in this respect may only be obtained by an absolute determination of the age. As long as we lack a dating, we have to rely on comparative stratigraphic-lithological studies. Rarer rock sequences of serial significance must be of special importance for the correlation, while the generally distributed types—in the case of the East Greenland Late pre-Cambrian the monotonous sandy and sandy-clayey alternating sequences—furnish few clues. Considering the gigantic extension of the geosynclinal space, we should not be too much impressed by differences in the thickness of widely separated standard sections.

In the sedimentary sequence in southwestern Scoresby Sund dealt with here, the basal psephitic series is succeeded upwards by the very characteristic association of metamorphic limestones and chlorite-phyllites, which in their turn, with the psammitic basal band, are overlain by a thick uniformly pelitic series with intercalated amphibolite lenses. Thick clayey sequences are rather rare in the classical Groenlandian sections.

Let us consider first the classification of the limestones: In the whole succession of pre-Cambrian beds in East Greenland investigated so far, rocks rich in carbonate occur in only three stratigraphic positions.

In the first place, carbonate rocks occur in the upper part of the Upper Eleonore Bay Group, in the so-called Limestone-Dolomite Series. This series is much thicker (2000 m) than the marble-chlorite-phyllite series in Scoresby Sund; it is overlain by the Tillite Group and underlain by the dolomitic-argillaceous-arenaceous "Multicoloured Series" and the huge "Quartzite Series". Thus, the rhythm of the whole succession is entirely different, and a correlation is out of the question. This inference may be made all the more so since wherever the Upper Eleonore Bay Group occurs, it exhibits regionally the same stereotyped fine-bedded structure, regular sequence, and thickness, so the geologist will never be in doubt as to which group he has before him. A distinct lateral variation in facies, however, has been ascertained in the Lower Eleonore Bay Group.

Secondly, a horizon of carbonates of inconsiderable thickness and not thoroughly traced by field geologists occurs in the upper part of the Lower Eleonore Bay Group, at the base of the so-called Eremitdal Series. At Alpefjord the beds underlying it again consist of clayey-sandy deposits of a thickness of more than 3500 m. Accompanying rocks, which in a metamorphic form might correspond to greenschists, are absent in this type locality. Therefore, the whole series excludes a correlation.

A narrow marble zone, which probably corresponds stratigraphically to the above-mentioned zone, is also present in the "Layered Series" of the Petermann Series in Knækdalen above the Portgletscher.

Thirdly, metamorphic carbonates *and* greenschists are found in the lowermost known part of the Petermann Series: the Marble-Chlorite-schist Series of WENK and HALLER 1953, pl. I, and in the lowermost known part of the Eleonore Bay Group in Kejser Franz Josephs Fjord, at Maalebjerg, Gerard de Geer Gletscher (HALLER 1953).

These marble horizons were erroneously correlated by WENK and HALLER (1953, fig. 13) and by HALLER (1953 and 1956a, pl. I) with the marble zone mentioned above (second stratigraphic position). This error is due to the different delimination of the "Eremitdal Series" made by FRÄNKL (1953) and HALLER (1953) in the various localities. The metamorphic sediments at Maalebjerg mapped as "Eremitdal Series" include stratigraphically much deeper-lying members than merely the type series of Eremitdal or the groups of beds corresponding to these latter at the mouth of Alpefjord. This error fortunately does not affect the remaining part of the correlation then made between the Petermann Series and the Eleonore Bay Group; for it is based on the coordination of the very characteristic border horizons between the Upper and the Lower Eleonore Bay Group (horizontal line in fig. 15, WENK and HALLER 1953), which has afterwards been repeatedly confirmed.

This third and stratigraphically deepest carbonate horizon may be equivalent to the marble blocks found by J. Ecklund at Alpefjord south of Schaffhauserdalen and mentioned by FRÄNKL (1951, p. 8), which have not hitherto been found in situ. The two best exposed sections through the Lower Eleonore Bay Group, viz. those of Alpefjord and Maalebjerg, are in need of a revision.

The carbonate series of Gnejssø should be correlated with this third and deepest level. The peculiar and, within the Groenlandian, unique association of marble with carbonate-chlorite-amphibole-schists is always met with in the deepest-lying part of the Eleonore Bay Group, as is also the case in the Petermann-sections. Another significant feature pointing to the correctness of this correlation is presented, as shown by figure 9, by the *agreement between the huge clayey sequences overlying the limestones.* The Gnejssø series (b) corresponds to the Marble-chlorite-schist Series of the Petermann sections, and series (d) to the Petermann Phyllite Series.

On looking at fig. 9, one will easily be convinced that our correlation will be of consequence to the northern area: If the correlation is correct, the basal psephitic series and the "Archaean" must be ascertainable in the base of the Petermann Series (= Eleonore Bay Group) at the hitherto

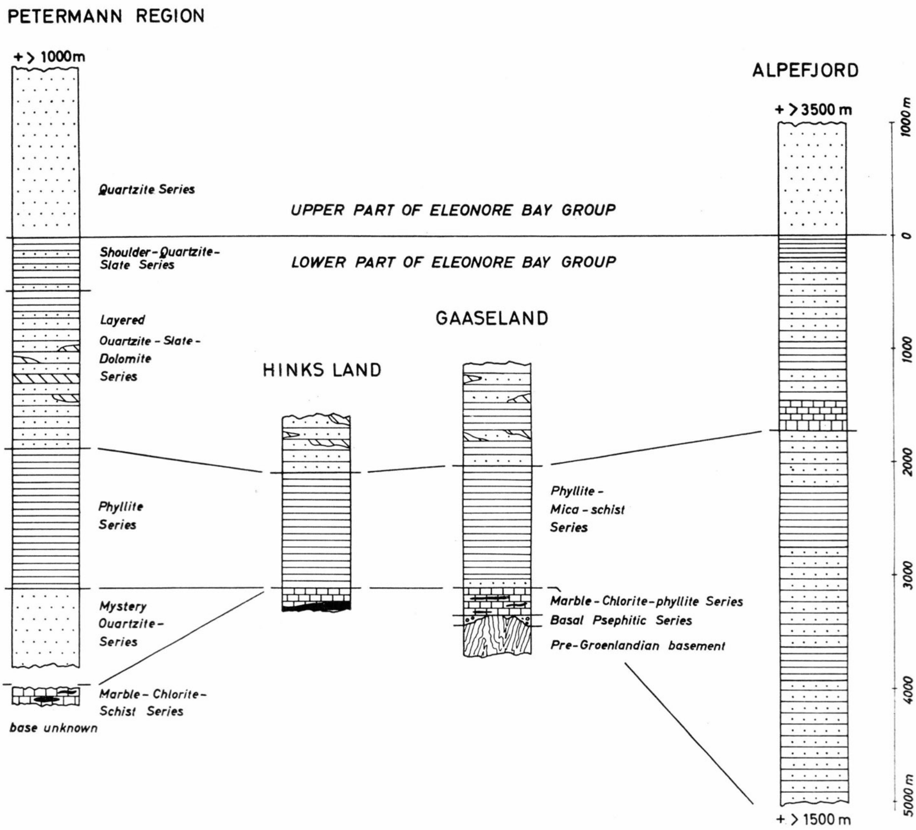

Fig. 9. Stratigraphical correlation of Groenlandian sections.

unexplored Jættegletscher in Louise A. Boyds Land and at Gerard de Geer Gletscher-Maalebjerg in Andrées Land in the base of the marbles. The exploration of these key localities, which are difficult of access but may be reached with modern means of communication, is highly recommendable.

Furthermore, it is remarkable that a correlation between Gnejssø and Alpefjord (distance 260 km) is impossible, as thick, uniformly pelitic series with carbonatic zones and green-schists in their substratum occur neither at Alpefjord nor in other sections of the fjord zone, but that a comparison to the sequence of the 320 km distant Petermanns Bjerg permits a clear correlation. *Along the western margin of the "Central Metamorphic Complex" of the Caledonian mountain chain the character of the late pre-Cambrian sediments, in fact, varies very little in a N-S direction.* The conspicuous sections located between the Petermann region and western Gaaseland, in the interior of Nordvestfjord and in Hinks Land, afford possibilities for a study of the stratigraphy of the lowermost Petermann Series, with a regionally distributed marble-amphibolite series (Marble-Chlorite-schist Series Petermann) below a thick mica-schist series (Phyllite Series Petermann), which latter series is covered by a well-banded, predominantly quartzitic series with characteristic brown carbonate lenses and bands (Layered Quartzite-Slate-Dolomite Series Petermann). The observations made in the summers of 1954 and 1957, which were recorded in the aerial photographs of these areas and are of significance also for the structural interpretation of the northwestern corner of Scoresby Sund, will be published as soon as a topographical map of the region is available.

Very likely the Eleonore Sø Series and the greenstone complex described by KATZ (1952 p. 46) from Arnold Eschers Land correspond to the Marble-Chlorite-schist Series of the lowermost part of the Lower Eleonore Bay Group. This possibly also applies to the Britannia Sø Series in Dronning Louise Land (PEACOCK 1956, HALLER 1958).

KATZ correctly recognized the ophiolitic character of the rocks of Eleonore Sø, but he correlated the series with the uppermost part of the Upper Eleonore Bay Group and with the Tillite Group, the author thus developing the auxiliary hypothesis of a tuffitic character ("tuffogenes Aussehen") of the matrix of the tillites. On studying the basal psephitic series of Gnejssø, the author of the present paper examined also microscopically the matrix of the rocks of those upper tillites from Ella Ø and from the working area of FRÄNKL for comparison, but found no clues whatever for the existence of pyroclastic material. No particles with a negative relief, no glass and no mineral clastics of volcanic origin were found as constituents, but a very fine-grained calcareous-argillaceous matrix with crystalline clastics of a metamorphic origin.

The following general views have been arrived at: The development of the Lower Eleonore Bay Group along the *western* border of the Caledonian mountain range in East Greenland corresponds to a typical eugeosynclinal sequence, even the analogy with the Permian-Triassic-Jurassic succession in the Pennine region of the alpine geosyncline is unmistakable. However, this applies in no way to the Alpefjord facies of the Lower Eleonore Bay Group met with at the *eastern* border of the Central Metamorphic Complex. It is remarkable, also, that the thickness of the Lower Eleonore Bay Group to the west, in the nunatak zone and the inner fjord zone, is much smaller (4.5 km) than to the east (7 km in Alpefjord). If we compare the sedimentary sequence to the west with the predominantly arenaceous development at Alpefjord, we must conclude that an erosional area occurred not very far to the east. As regards the facies development in the sediments of the Groenlandian, the Central Metamorphic Complex has a distinctly asymmetrical position.

3. The Caledonian Crystalline Complex.

This chapter does not deal with the Caledonian metamorphosed and folded parautochthonous sediments covering the crystalline basement in the western foreland of the Caledonian mountain chain, but exclusively with the crystalline rocks of this chain, irrespectively whether they have been overthrust or are rooted in the depth.

Rock types.

Three rock groups are indicated on the map:

(a) *Leucocratic gneisses*, forming anticlinal cores; near Faxa Sø very rich in quartz and grading into tabular quartzites; oligoclase is their principal feldspar; muscovite and biotite occur in subordinate amount, chlorite is missing. In other occurrences the rocks, with a variable, often considerable content of potash feldspar, attain an eugranitic composition and show an irregular layered or flaser-like structure.

(b) *Mesocratic mica-schists and plagioclase-gneisses*, mantling the gneiss-domes and occurring in synclinal structures. The typical dark constituents are, apart from biotite, the minerals garnet, cyanite, and staurolite.

(c) *Amphibolites*, *hornblende-schists*, *hornblende-gabbros*, and related metamorphic basic rocks of magmatic origin. They form thick zones between (a) and (b) and, on the other hand, large stocks and lenses within (a). The minerals oligoclase to andesine, hornblende, and epidote characterize the metamorphic facies, garnet being an accessory constituent. Thin lenses of marble were on two occasions found associated with this group (c).

Evidently the regional Caledonian metamorphism is of a medium-grade. The granulite-like rocks found between Renland and Rypefjord, and Milne Land are not represented in the lake district of western Gaaseland. Therefore, the crucial problems concerning the relationship between the granular garnet rocks and the garnet-micaschists, ubiquitous in the Central Metamorphic Complex, must await the exploration of Hjørnedalen (valley draining Faxa Sø into Føhn Fjord) and the fjord sections of Vestfjord and Føhn Fjord.

Tectonics.

The seemingly simple structure of the Caledonian between Faxa Sø and Gaasegletscher, with granitic cores and mantles formed by metamorphic sediments and basic rocks, are easily read from the map (pl. XII). The facts assembled there demonstrate convincingly *that the trend of the Caledonian mountain chain is directed southeast in this part of Gaaseland.* Observations in the adjacent part of Gaaseland to the east are restricted

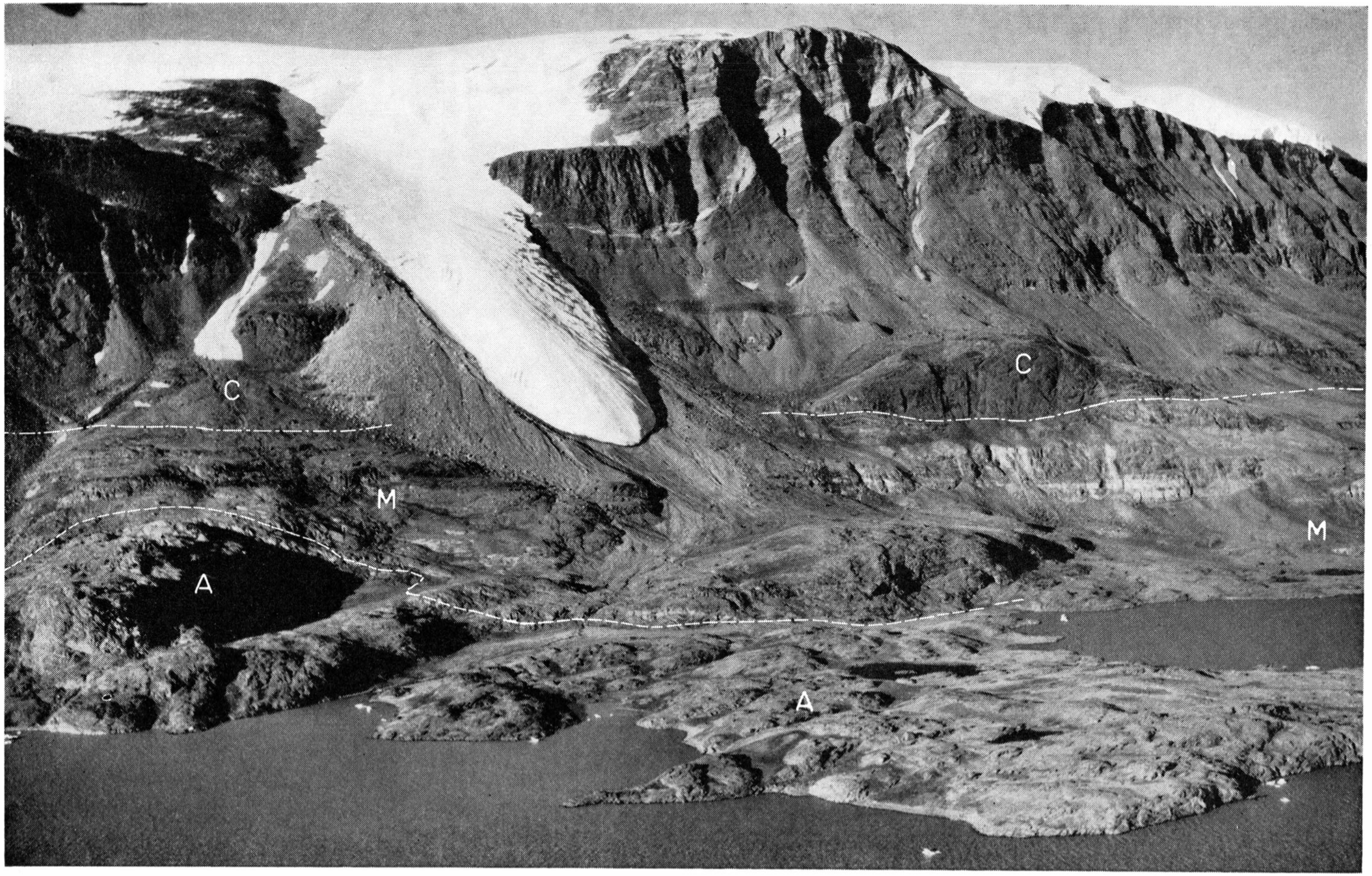

Fig. 10. Caledonian overthrust mass south of Gnejssø. For symbols see figure 3. Photograph by W. DIEHL.

Fig. 11. Folded Caledonian gneisses southeast of Faxa-sø. Photograph by O. WACKERNAGEL.

to two areas, viz. a section southeast of the mouth of Hjørnedalen at the Føhn Fjord and another one west-southwest of Gaasepynt, the easternmost point of Gaaseland. At both localities the direction of strike of the steeply inclined zones is west-east and may indicate that the trend of the mountain chain swings outwards in an eastward direction.

The tectonics of the lake district is highly complicated through the fold structures with inclined axes and the interference of two obliquely-crossing axial directions, especially well-developed in the northwestern corner of Faxa Sø. This structure was carefully analyzed in the summer of 1958. During this analysis it turned out that neither of the two patterns of lineation is of pre-Caledonian age, but that they are associated with the change of the direction of movement between the stage of the paracrystalline vortex- and recumbent flow-fold-formation, and the late- to post-crystalline overthrust structure.

This westward thrust, with a width of transport of at least 20 km, cannot be interpreted solely through the mechanism of a "traineau

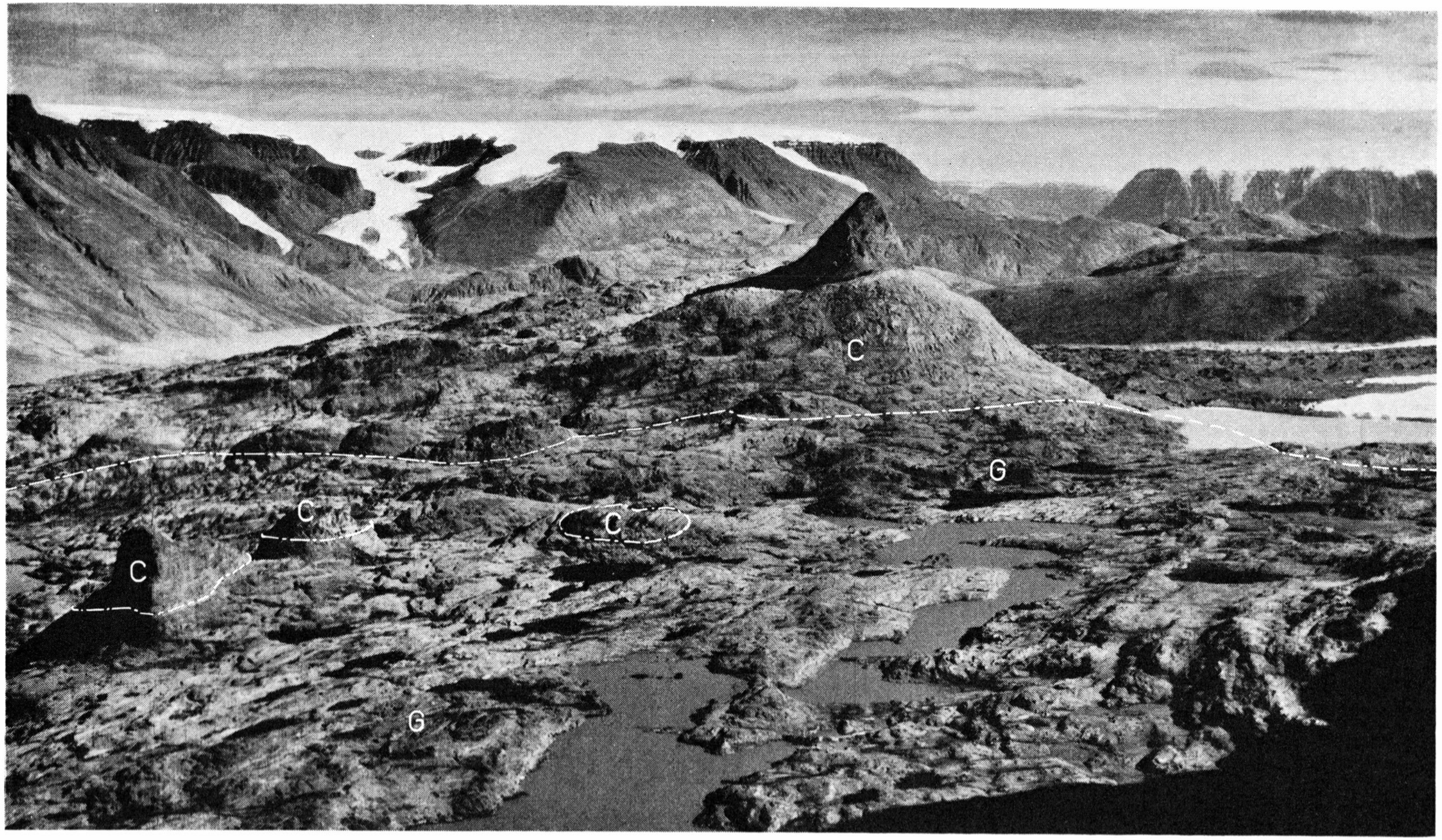

Fig. 12. Munatius Plancus Tinde and country between Gnejssø and Kaskadesø, seen from Point 1166, looking east. Outliers of the Mythen in the foreground on the left (compare figures 13 and 14). C = Caledonian overthrust mass, G = parautochthonous Groenlandian sediments. Photograph by O. Wackernagel.

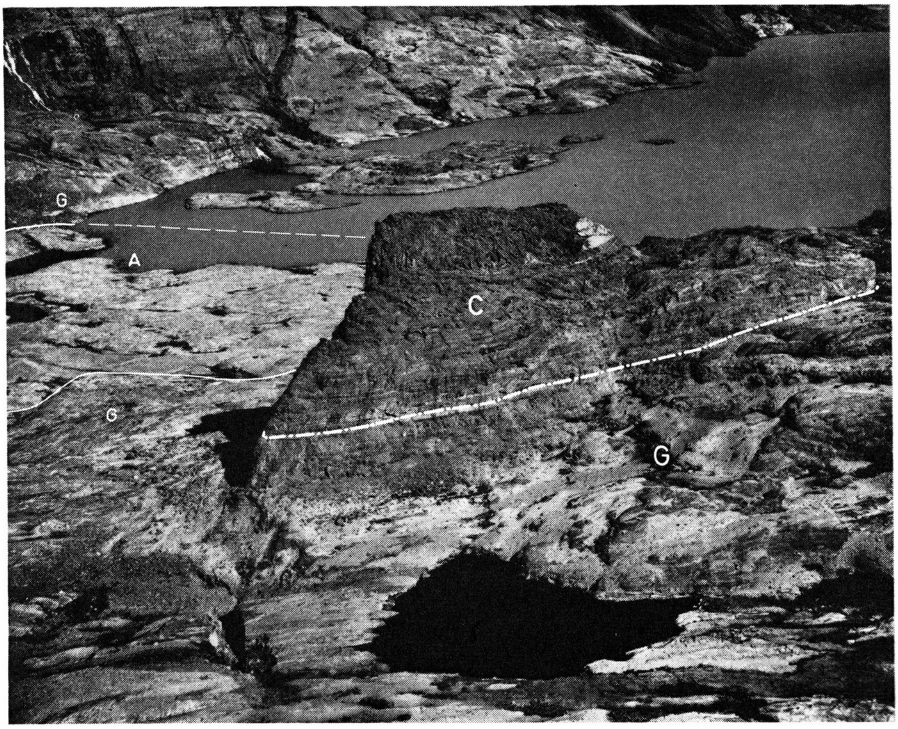

Fig. 13. Mythen, outliers of the Caledonian overthrust mass (C), resting upon parautochthonous Groenlandian (G) and pre-Groenlandian basement (A). Kaskadesø seen from southwest. Aerial photograph by W. DIEHL.

écraseur" (TERMIER), even though the latest thrust movements outlasted the crystallization. The paracrystalline structures in the interior of the overthrust crystallines (figs 10 and 11 as well as plate X) and in the critical transitional zone between the cover and the root prove even more definitely that the thrustplane developed from the underlying limb of a plastic zone of inverted folds. The above-mentioned inversion of the mineral zones would then be synkinematic in regard to the paracrystalline main folding, that is to say, pre-kinematic as far as the latest thrust and shearing movements are concerned. Inverted migmatitic folds of a similar extent are known from the innermost part of Nordvestfjord.

As shown by the map, the thrust-plane at the base of the Caledonian crystallines strikes N-S within the investigated area. In its upper part it dips slightly eastward, to plunge, subsequently, steeply downwards. A peculiarity of the magnificent landscape of the area of the Hellas Strømhvirvler (rapids) south of Kaskadesø (plate I) is formed by the imbricate zone with blastomylonites, fine-grained banded gneisses, marbles, and quartzites, showing an ideal preferred mineral orientation. The prominent peaks called "Mythen" along the southern bank of the lake form cliffs of Caledonian gneiss with folded pegmatites and with enclosed basic rocks resting on the imbricate zone (figs. 12 and 13).

To the north, the zone of overthrust is traceable as far as Rolige Bræ; the further course cannot be ascertained photo-geologically owing to the heavy glaciation.

A similar overthrust zone was observed in 1957 at the western border of the Caledonides in Hinks Land along the southern edge of Daugaard-Jensens Gletscher. Quite possibly the two lines crossing the nunatak region west of Scoresby Sund are associated.

4. Upper Cretaceous-Tertiary Plateau Basalts.

Our studies of the basalt sheet which rests unconformably on the Caledonian bed-rock as a subhorizontal cover, deal only with the deeper portion of the exposed basalt pile and the basal plane of contact with the underlying crystallines. The results of the investigations in the field, which were limited to some few days, and the petrographic and geochemical studies now in progress will be discussed in detail in a paper to be published later. The geological conditions, in so far as they are of interest for our understanding of the geology of Gaaseland, can be briefly outlined as follows:

1. The plateau basalts present in southwestern Scoresby Sund belong to the basalt occurrence, covering roughly one million square kilometres and 4,000 to 7,000 m thick, of Central East Greenland between 69° and 70° N. lat.; thus they form part of the large Upper Cretaceous and Lower Tertiary Brito-Arctic province. The basalts, however, in accordance with the view put forward by WAGER (1934, 1947) as regards the plateau mountains of Blosseville Kyst—though in contrast to the theory advanced by BACKLUND (1944) as to the region of Scoresby Sund—represent typical flood basalts in the sense of TYRRELL (1937). As is particularly well revealed by the very distinct outcrops at the north coast of Gaasefjord, where the base of the basalts is well exposed along a distance of hundred kilometres, thin-flowing basalt lavas have spread across a furrowed, peneplaned land surface, filling the valleys and finally flooding the whole country. Each of the sheets of the layered basalt pile, with an average thickness of 30 m, always consists of a columnar, compact, basic effusive rock in its basal and central parts, with or without phenocrysts and with no horizontal banding at all. In the upper part of the sheet the rock always looses its columnar structure, turning amygdaloidal (zeolite-, calcite-, and opal-amygdales) or vesicular, decomposing into irregular polyhedra or ellipsoidal bodies, and sometimes showing a fluidal structure, to pass finally, near the overlying rock, into a slaggy

porous lava with an irregular surface. The depressions between the lava ridges and knolls are filled with loose agglomeratic material and the lower surface of the subsequent lava is flat. The grains of these clastic formations grow finer towards the overlying bed, and in places the rocks contain abundant alluvial coaly leaf or wood remains. Morphologically these readily decomposing beds form the horizontal stretches between the steep cliffs of compact columnar basalt.

The microscopic examination shows that these intercalated, easily crumbling clastic rocks, at any rate in the lowermost 200 m of the basalt profile, that is, in eastern Gaaseland up to the seventh sheet counted from below, in addition to volcanic material (zonal, highly twinned plagioclase, pyroxene, glass, and in places olivine) often contain numerous minerals of metamorphic origin (quartz, faintly inversely zonal oligoclase, biotite, and garnet). These foreign components are derived from the mountain ridges and outliers of Caledonian crystalline rocks which during the first stages of flooding still rose above the basalt sea. Together with the organic remains[1]) they show that erosion and sedimentation processes were going on between the various phases of effusion, and that these phenomena were repeated rhythmically. The tuff-like, loose clastic rocks are accordingly not the products of an explosive volcanism, as was first assumed, but products of disintegration and a subsequent exogenetic re-deposition.

The picture may vary greatly from one intercalated bed to the other. Thus, intercalated agate beds with silicified tree-trunks occur along the north coast of Gaasefjord, and nut- to head-sized opal druses are widely distributed. Frequently the sedimentary beds in between the basalt sheets have become much reduced, or they consist exclusively of red Bolus—erosion remnants—as is especially the case in the upper part of the investigated basalt profile.

From the description it will be seen that disintegration and sedimentation have always brought about a leveling of the slightly crumpled surface of the lava sheets, so that the succeeding lava flow struck a level plane. This explains the very conspicuous regularity with which the basalt cover is built up of parallel sheets, though the surface of the individual lavas may be altogether irregular in detail. The volcanic activity, eruption, solidification, and subsequent weathering, was a rhythmically repeated process.

[1]) The readily disintegrating coaly beds are easily overlooked in the rocks in situ. In places, however, coal remains are abundantly washed up by the present-day rivulets, so that they will not escape the eye of a close observer, and then it is not difficult to find their place of deposition. Animal remains have not yet been observed in Gaaseland, but may be present. The beds may perhaps be dated by pollen-analytical studies.

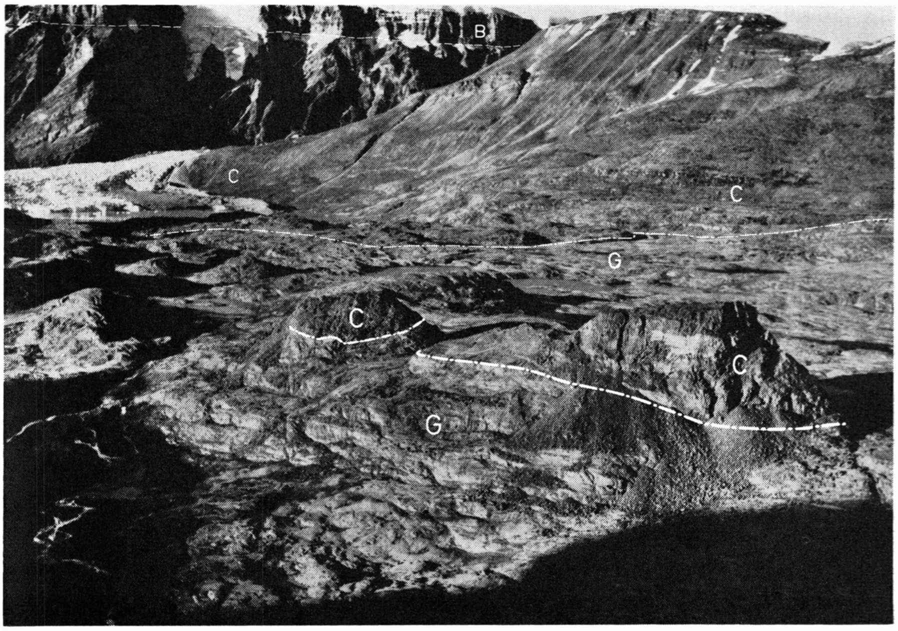

Fig. 14. Outliers of the Mythen seen from the north. B = plateau basalts, compare with plate 1. Photograph by W. Diehl.

2. We suppose that sills played a very subordinate role in the building up of the basalt piles; in 1958 no kind of connection between basalt sills and dykes was observed.

3. Dykes of olivine-dolerite, more rarely olivine-free dolerite, are widely distributed in the area investigated and occur in swarms (fig. 15). Along the section Vestfjord Gletscher—Gnejssø-Faxa Sø-Gaasefjord 30 dykes with thicknesses ranging between 2 and 30 m, although generally between 5 and 12 m, were counted in the crystalline belt and, no doubt many dykes escaped observation. They belong to two regional swarm systems. One system extends south-southwest—north-northeast and is traceable from the Gnejssø region along a distance of 220 km to the northernmost part of Scoresby Sund, where further three thick wall-like-weathering olivine-dolerite dykes extend northward, traversing the line Daugaard-Jensens Gletscher—innermost Nordvestfjord. The second system extends from Faxa Sø northeast- to east-northeastward along a distance of 150 km in the direction Rødeø—Milne Land—Hall Inlet. The southern prolongations of the two directions cut into the unexplored basalt area around the upper reaches of Gaasegletscher, and a centre of intrusion may be assumed to be located in this region, as is the case with the similar dyke systems of Werner Bjerge and of Scotland. It should be added that these dolerite dykes are absent from the central part of the

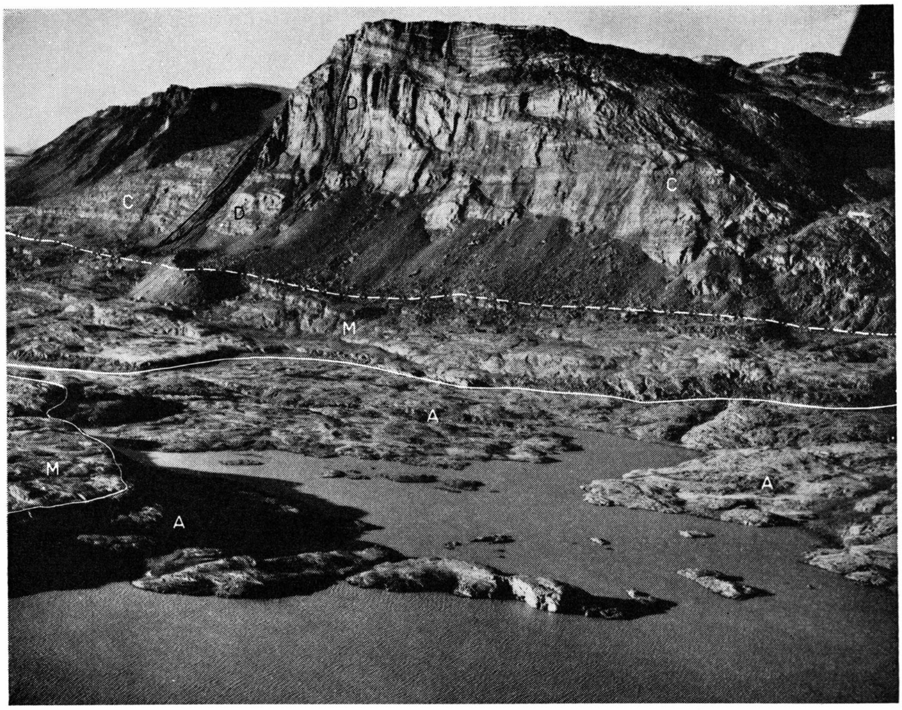

Fig. 15. Dolerite dykes (D) cutting Caledonian gneisses (C) of Point 1166, southeast of Gnejssø. M = Marble-Chlorite-phyllite Series, parautochthonous. A = Autochthonous migmatitic basement, (Archaean). Photograph by W. DIEHL

Caledonian crystalline complex, occurring only in the marginal zones on either side. Thus, for instance, no dolerite was observed in the 150 km long section through Nordvestfjord from Backlund Bjerg to immediately north of Sydkap.

In the crystalline beds of Gaaseland many dykes were observed which do not penetrate the overlying basalt sheet, that is to say, they are older than this latter. North of the lower Gaasegletscher, however, a dyke was observed which could be traced over a great distance, cutting the whole exposed series of plateau basalts without any horizontal branching; thus it is undoubtedly younger than the deep-seated basalt beds. By means of the field glasses such dykes were also observed northwest of Faxa Sø and in the former Knud Rasmussen Land[1]) south of the eastern tip of Gaaseland. But they are rare. No feeders of the plateau basalts were ascertained; in the world literature only very few undoubted examples of such feeding channels are described. But there can be no doubt

[1]) *Knud Rasmussen Land* is now the northern part of Greenland from Melvillebugt to Danmark Fjord.

that the basalt sheets and dolerite dykes in Gaaseland belong to the same magma cycle.

4. All the highest elevations of Gaaseland are built up of basalt, but the whole coast line consists of metamorphic rocks, which form the basement of the basalt sheet. The basalts, however, form no continuous cover to-day, but are cut up by erosion valleys, in which the crystalline basement outcrops, into five isolated areas. The contact between the Caledonian crystallines and the lava pile varies as follows in respect to altitude: In the mountain massif north of Vestfjordgletscher (northwest of

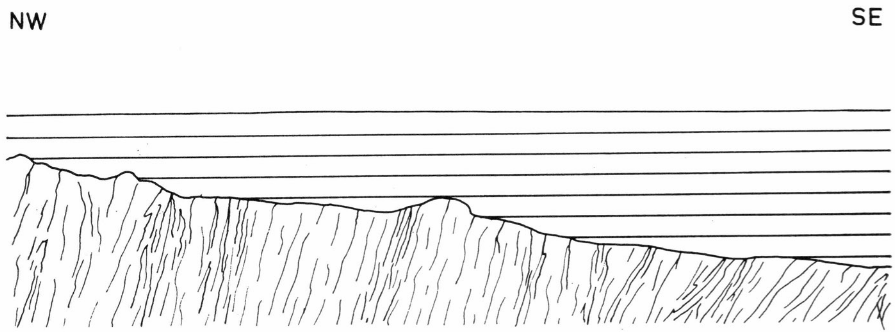

Fig. 16. Schematic section showing the base of the plateau basalts (ruled) and the crystalline basement.

the innermost part of Vestfjord) it lies above the peak rising to an altitude of 2'500 m. Immediately south of Vestfjord Gletscher, at Gnejssø in Gaaseland, the pre-basaltic peneplain occurs at an altitude of 1,600 m, but descends towards the southeast, occurring at 1,300 m at the southeastern end of Faxa Sø, at 1,150 m at the northern shore of the inner Gaasefjord, and at 800 m at the southern shore. Thirty kilometres east-southeastward it reaches sea-level in the southernmost bay of Gaasefjord. Thus it is evident that in this 50 km long section the pre-basaltic peneplain dips toward the southeast. In the 120 km long west-east section Gnejssø—east cape of Gaaseland the peneplain is less inclined, dipping from 1600 m to 500 m. Similarly, smaller dips are ascertainable in the north-south sections than in a south-eastern direction.

An additional criterion is furnished by the course of the line of intersection between the pre-basaltic peneplain and the mountain plateau of the present day which cut each other at an acute angle. It extends from the southern upper reaches of Vestfjord Gletscher to the north coast of Milne Land at Øfjord, thus striking north 50° east and likewise pointing to a south-eastward inclination of the plane of separation. An isohypsic chart of the photo-geologically easily recognizable Upper Cretaceous peneplain may be drawn as soon as the new topographic map of Scoresby Sund is available.

While this ancient peneplain, visible in the base of the plateau basalts and also distinguishable in the map, dips towards the southeast to south-southeast, no corresponding inclination of the basalt flows can be discerned with the naked eye. Only a triangulation of stratigraphically corresponding points of the basalt profile may elucidate the, in any case, rather slight inclination of the subhorizontal table. This contradiction is explained, at least in part, by the photograph of plate XI and by the diagram in fig. 16, which is based on many separate observations: The deepest-lying basalt lavas remained in the southeast, while successively more elevated lavas overflowed the crystalline land surface, rising in flat steps towards the northwest. The basal beds resting on the bedrock are accordingly not the same regionally, and the thickness of the basalt pile in Scoresby Sund decreases towards the north-northwest. These indications might show that a mapping of the marked basalt horizones as well as of the pre-basaltic peneplain would yield highly interresting geological results.

5. All the geological observations tell against the supposition that the valleys of Gaasefjord and the 900 m deep, respectively 3,000 m deepened, Føhnfjord existed or even originated before the feeding activity of the plateau basalts set in. The basalt mantles on either side of this fjord are combinable horizontally one with another, and nowhere descend to the valley bottoms. The rifts recognizable in the pre-basaltic peneplain at the northern shore of Gaasefjord and in Milne Land north of Danmarks Ø run from north to south. Nor do the two large east-west striking fjord valleys follow Lower Tertiary tension fissures; for if so, they would be accompanied by parallel swarms of dolerite dykes. In the whole of Scoresby Sund the fjords nowhere follow the zones of the dyke systems, but run obliquely or at right angles to them. These fjords are *post-basaltic erosion valleys.*

Acknowledgments.

It is a pleasant duty to me to express my thanks to the leader of the expedition, Dr. Lauge Koch, for entrusting me with the interesting Gnejssø campaign, as well as for his active participation in the planning and carrying out of the work and his excellent organisational support.

My co-workers, above all Mr. Paul Stern, but also Mr. J. Papageorgakis, Dr. O. Wackernagel, Mr. B. Moser, and Mr. P. Blattner contributed effectively to the success of the task.

In 1958 we spent together a splendid summer in Gaaseland, full of exciting work, and I thank my companions most cordially. Unfortunately

one of them is no longer among us. To the memory of PAUL STERN, who on July 20th, 1959, died of an accident at the Winterstock in the Urner Alps, I dedicate this paper.

The text was completed in the autumn of 1959, and the reader may notice the spontaneity of the report. For several reasons the editing was delayed, and I am obliged to all those who contributed to bring it into the final form: Mr. W. DIEHL for his air-photographs, Dr. O. WACKERNAGEL for terrestrial photographs Dr. J. HALLER for his advice and help in getting the text-figures and plates ready for print, Miss E. GLEERUP for the translation, and Miss L. AEGERTER as well as Mr. A. G. MILNES for critical reading and corrections.

Basle, November 13th, 1960. E. WENK

POSTSCRIPT

An age determination of the mica from a biotite-albite-microcline-granite (sample Gaa. 135 St.) taken at the southern promontory of Paul Stern Land was recently made by Dr. J. L. Kulp and is of greatest value; it serves as a check for the conclusions reached in this paper. In his diary the collector, Paul Stern, stated that the sample derives from the local moraine but that identical granites form the bedrock along Vestfjord Gletscher.

Dr. Kulp's K^{40}–Ar^{40} measurements give an apparent isotopic age of the biotite of 1890 m.y. (6.74 % K; 6.98×10^{-4} scc/g Ar^{40*}). In connection with further determinations made on materials collected by the Danish East Greenland Expeditions that are to be published in "Nature" and in "Meddelelser om Grønland", this result proves that at least one type of our "autochthonous crystalline basement of pre-Groenlandian age" ("Archaean") indicates the highest age so far determined in East Greenland. The values of rocks from the Central Metamorphic Complex of the Caledonian mountain chain range between 402 and 425 m.y.

In his letter of December 16th 1960 to Dr. Lauge Koch, Dr. Kulp commented on sample Gaa. 135 St. as follows:

"...The determination was an excellent one and gives an apparent isotopic age of 1890 m.y. This is probably the most exciting determination of the four since it establishes beyond any reasonable question that the basement rocks, at least in the "window" in the inner part of Scoresby Sound are at least 1890 m.y. old. Vast orogenic events in the area of the Baltic Shield about 1800 m.y. ago are evident as determined by concordant zircon ages and Rb-Sr determinations on microcline. On the other hand, the micas which were also formed in the Karelian Province in Finland at 1800 m.y. ago and the micas of the other older rocks in the Baltic Shield area which were strongly reheated at 1800 m.y. ago all show lower apparent isotopic ages, namely, 1650 to 1750. The explanation for these lower ages is quite clearly the fact that these metamorphic rocks which were recrystallized or strongly affected at 1800 remained buried rather deeply for 100 to 200 m.y. following the metamorphic event. During this time the elevated temperature, 150–200°C(?), caused argon loss resulting in the lower apparent ages. My point here is that the 1890 date for Sample GAA-135ST is clearly older than the micas from the Karelian Province of the Baltic Shield area, and therefore is probably unrelated.

We may conclude, therefore, that in the area of Scoresby Sound, the basement rocks have not been affected by a North American counterpart to the Karelian event, the Rapakivi intrusive event, the Grenville or Caledonian orogenies. It is entirely possible, of course, that the time of metamorphism of these basement rocks is very much older than 1890 and that this date merely reflects argon loss. This matter can only be determined by analyzing different samples preferably by different methods ..."

APPENDIX: TERMS

It is a prerequisite for all regional-geological discussions that the reader should in some measure be familiar with the generally applied formation names and collective terms. If this prerequisite is not complied with, the following explanation may facilitate the understanding.

Of *stratigraphic* concepts, only the terms denoting the huge conformable sequences of pre-Cambrian sediments will have to be introduced.

The collective term "*Groenlandian*", introduced by LAUGE KOCH in 1930, comprises all the pre-Cambrian sediments of North and East Greenland which rest unconformably on the "Archaean" bedrock (shield) and are generally conformably overlain by the Cambro-Ordovician. Their upper boundary is formed by the small sedimentation gap in the beds immediately below the deepest-seated fossiliferous Cambrian (Olonellus Thompsoni). The following well-known groups (formerly called formations or series) belong to the Groenlandian:

1. The *Tillite Group*, thickness some hundred to more than thousand metres. The group, including the sediments immediately below the Cambrian which were deposited during an ice age, occurs in the central part of East Greenland.

2. The *Eleonore Bay Group* of East Greenland, underlaying the Tillites, thickness 10 to 12 km. It comprises multicoloured and well-bedded calcareous-dolomitic, arenaceous, and arenaceous-argillaceous sediments. Type locality: Eleonore Bay in Kejser Franz Josephs Fjord.

3. The *Thule Group*, thickness 600 to more than 3,000 m. Compared with the much thicker and cyclically stratified Eleonore Bay Group, this group presents a rather monotonous psammitic-psephitic sequence of a predominantly red colour, and is chiefly made up of quartzitic sandstones, arkoses, and conglomerates, subordinately of dolomite and shales, and is rich in basic eruptives. Type locality: Thule in Northwest Greenland, it has its main distribution in North Greenland and extends along the east coast southward to 76° N. lat., but has not yet been observed in Central East Greenland.

The age relations of groups 2 and 3 have not yet been established: Only group 3 occurs in Northwest Greenland, in Central East Greenland only group 2 (and 1). The key localities are probably to be found in the northeastern corner of Greenland; they still await a field-geological elucidation.

The Groenlandian, being the upper sedimentary division of the pre-Cambrian, corresponds to the not very fortunate term "Proterozoic" generally applied in the Canadian shield, while the pre-Groenlandian basement corresponds to the "Archaean".

The term to be introduced below is not of a stratigraphic, but of a *petrogenetic-tectonic* character and will need some comments.

In the area of distribution of the Groenlandian in East Greenland, whole mountain masses occur which cannot be denoted by stratigraphic terms. They form petrogenetic-tectonic units. Their integral components originated in the course of a post-Groenlandian orogeny from rock material of different age and origin. One part of the material belonged to the external crust of the earth. The other part, however, is derived from more deep-seated regions, and it was not till the setting in of the various processes of the orogeny, characterized essentially by the rise of temperature and the mobilization of matter, and not by tangential thrusting, that it began to rise, sometimes diffusely penetrating and deforming the crust, sometimes swarming through it in coherent intrusive masses. The boundary planes of the *new* rocks, heterogeneous but intimately connected so as to form a geological unit, correspond to thermal and metasomatic fronts which intersect the sequences of the original sediments sometimes at high, sometimes at low angles. An accurate and differentiated stratigraphic dating of the endogenetic rock formation that extended over a long space of time, is excluded, the new-formed rocks being nowhere in contact with contemporaneous exogenetic deposits. As long as an absolute dating is lacking, the endogenetic rock formation can only be dated indirectly relative to the folding, as well as by the denudation period following upon the orogeny. This way can give only an approximate dating, for the folding as well as the endogenetic processes represent complex events comprising several phases and of an intensity varying from place to place. Moreover, it has long been recognized that the transfer of matter, intrusions and effusions, may begin already in the geosynclinal stage, and extend, in part, beyond the denudation period following upon the orogeny. Their genetic connection with the orogeny, however, is beyond doubt.

The classical East Greenland example is characterized by crystallization processes which for the main part took place during the post-Ordovician and pre-Upper Devonian orogeny termed Caledonian s. l.[1]). All these rock masses which came into existence during the orogeny through processes of crystallization, transformation, dissolution, intrusion, and

[1]) When the term Caledonian is employed, it is always applied in this wide sense.

exchange of matter, may therefore consistently be termed *Caledonian crystalline.* This term comprises metamorphic and ultrametamorphic sediments of the Groenlandian[1]), metamorphic and mobilized portions of the pre-Groenlandian basement, and the most varied, in the widest sense of the word "Plutonic", rocks (Kennedy, Read) of the Caledonian cycle.

However, the petrogenetic-tectonic term cannot be applied to the Caledonian folded but non-metamorphic sediments. The term "Caledonian sediments" should be dropped as unrequired and misleading, for the formation names are fully satisfactory and should, if anything, be supplemented by the comprehensive term the "Caledonian geosynclinal sequence" (Eleonore Bay Group + Tillite Formation + Cambro-Ordovician).

[1]) Metamorphic Lower Palaeozoic sediments have not yet been met with.

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Færdig fra trykkeriet den 7. december 1961.

PLATES

Plate I.

Inlier-like outcrop of the pre-Groenlandian basement (A = Archaean) west of Kaskadesø, surrounded by parautochthonous Groenlandian sediments (G) and covered by the Caledonian overthrust mass (C), which forms the outliers Mythen in the middle-ground of the picture on the left and the mountains in the background. Note the parallel swarm of Tertiary dolerite dykes cutting across the older rocks in south-southwestern direction. In the background, on the right, Gnejssø. Photograph by O. WACKERNAGEL taken from Point 1010, southwest of Kaskadesø, looking south-westward. Photo-montage by Messrs. R. & W. EIDENBENZ.

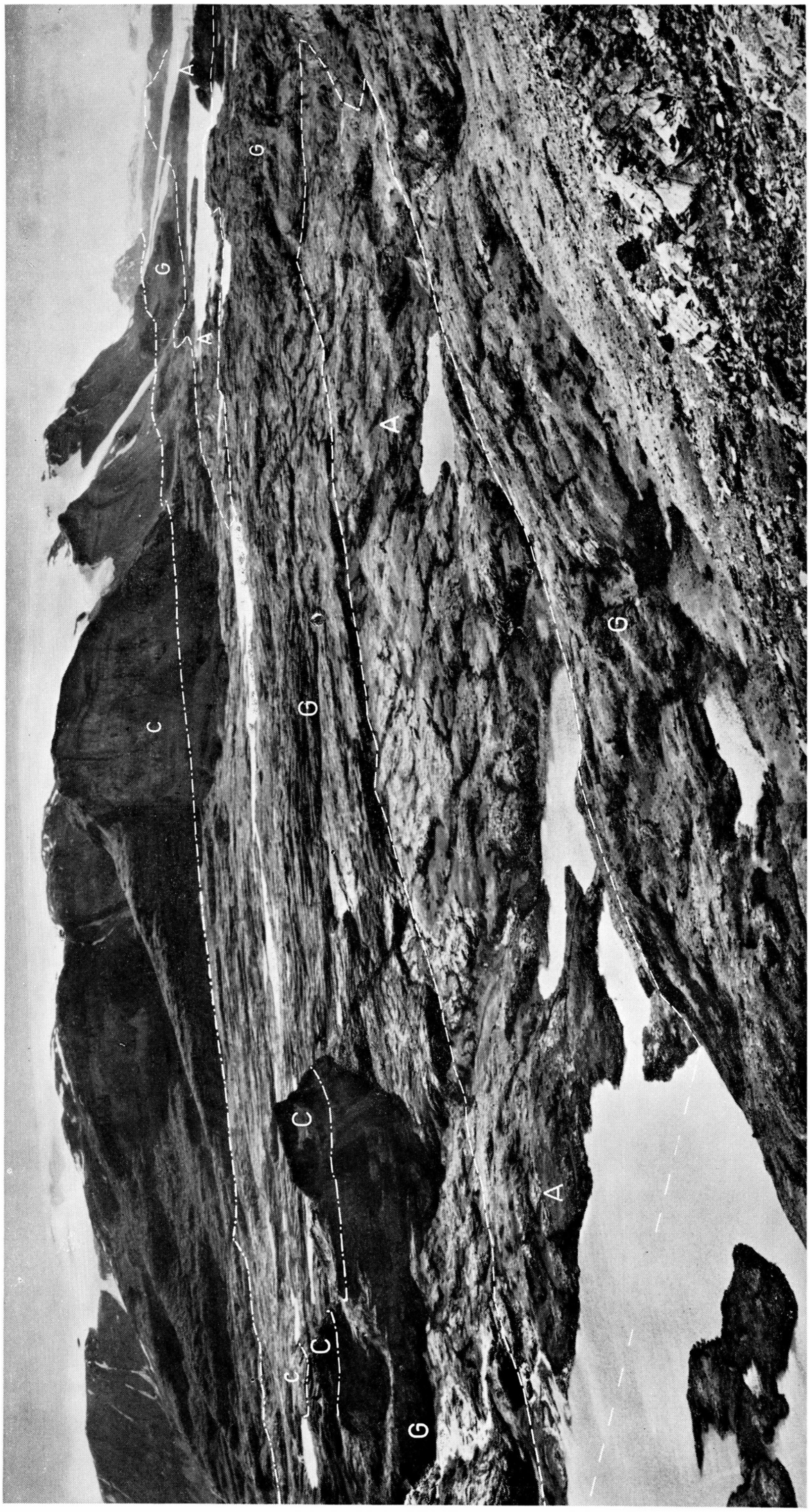

A
G
G
A
A
C
G
G
C
C
C
A
G

Plate II.

View of Gnejssø area seen from Point 1166, towering 650 m above the lake plateau. Pre-Groenlandian basement (A) surrounded by metamorphic Groenlandian sediments (G). Vestfjord Gletscher in the background. Photograph by O. WACKERNAGEL.

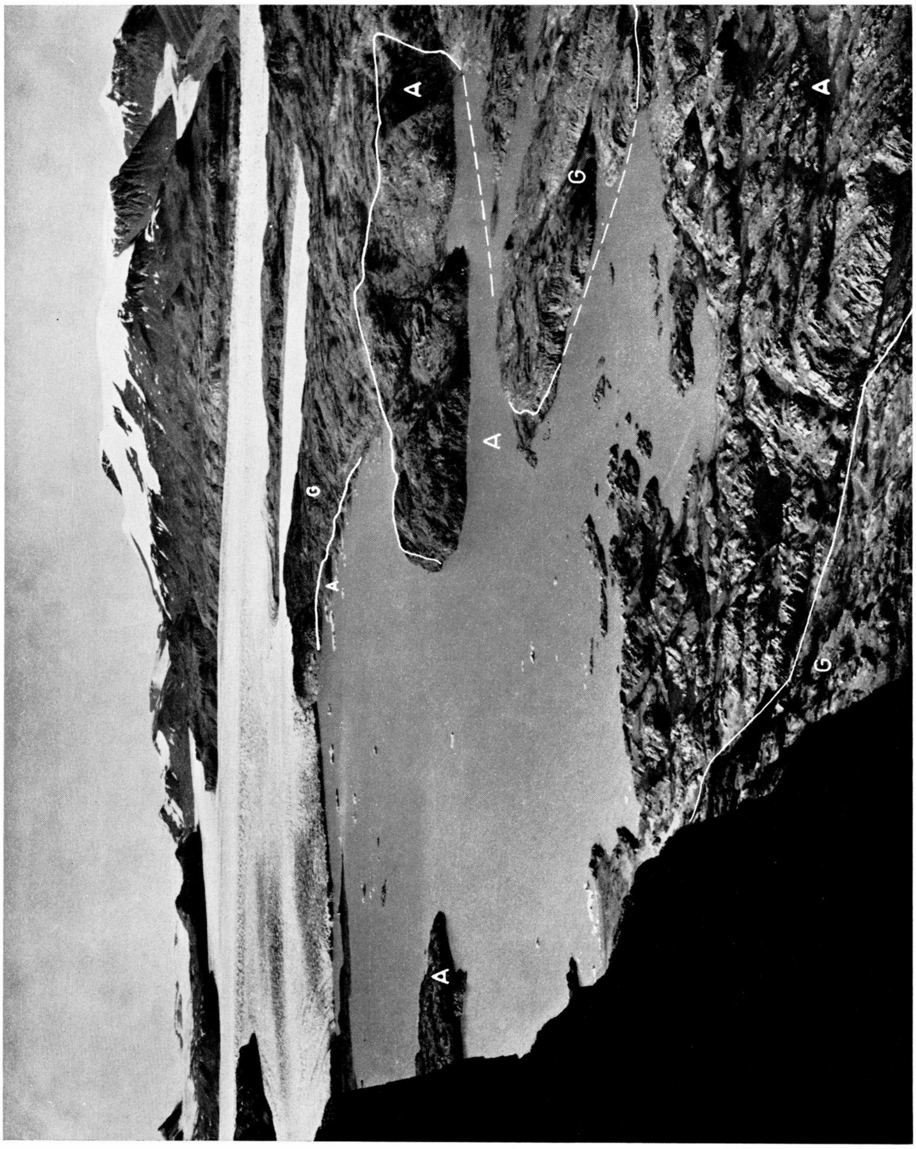


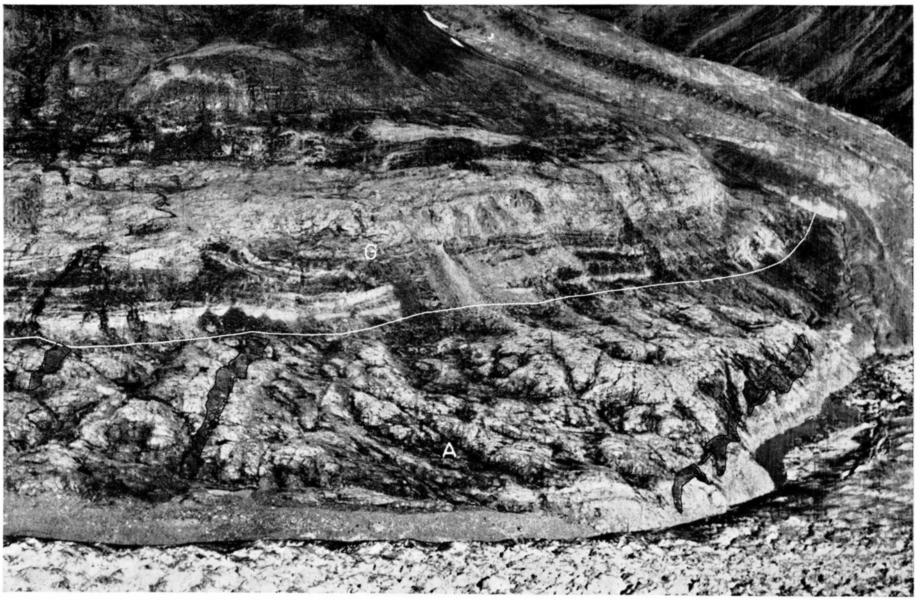
Plate III.

Exposure of pre-Groenlandian migmatite on the peninsula projecting from the southern bank of Gnejssø. Photograph by E. WENK.

Plate IV.

a. Pre-Groenlandian basement (A) with amphibolite dykes covered by Groenlandian sediments (G) northwest of Vestfjord Gletscher. Photograph by W. Diehl.

b. Outcrop of the Basal Psephitic Series (type-locality) on the peninsula north of Gnejssø. Photograph by O. Wackernagel.



IV a

IV b

Plate V.

Panorama of Paul Stern Land along Vestfjord Gletscher. Photograph by M. BRENNEISEN. A = pre-Groenlandian. Plate IVa refers to the locality in the centre of the picture. Photo-montage by Messrs. R. & W. EIDENBENZ.


A
A
A
A

Plate VI.

Aerial view of Paul Stern Land and Vestfjord Gletscher taken in eastward direction towards Vestfjord (left) and Gaaseland with Gneiss-sø, Faxasø, and Gaasefjord in the background on the right. The granite sample of the pre-Groenlandian basement (A) on which was based Dr. J. L. Kulp's age-determination, giving an apparent age of 1890 million years, derives from the southern promontory of Paul Stern Land, seen in the centre of the plate. Ph = Phyllite-Mica Series, M = Marble-Chlorite-phyllite Series, Ps = Basal Psephitic Series of the Groenlandian. Photograph 651 J-12084 by Geodætisk Institut, Eneret.


A
M
Ph
A
M
A

Plate VII.

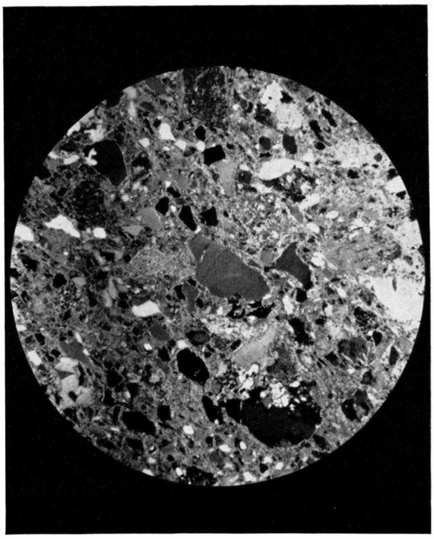
a and b. Varve-structured boulder clay and tillite of the Basal Psephitic Series of the Groenlandian from Paul Stern Land, exposures along Vestfjord Gletscher. Photographs by P. STERN.

VII a

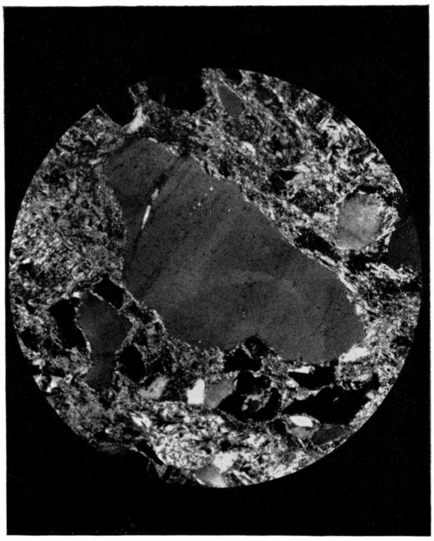
VII b

Plate VIII.

Microphotographs of the matrix of tillites from Paul Stern Land. Crossed Nicols. Pictures a (× 10) and b (× 32) = sample Gaa. 140, c (× 10) = Gaa. 119, and d (× 10) = Gaa. 123 (chemical analysis). Note the unsorted character of the matrix, the highly differing roundness of the fragments, and the concave contours of microcline and quartz grains.



a



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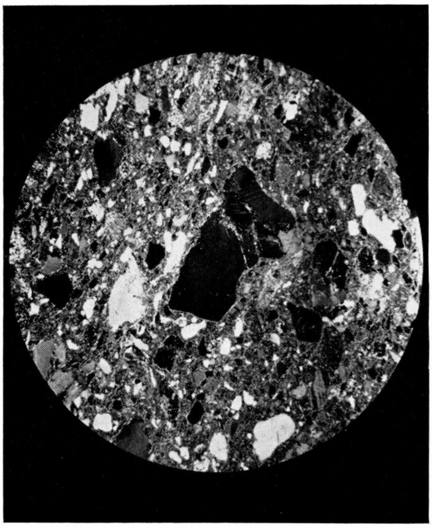
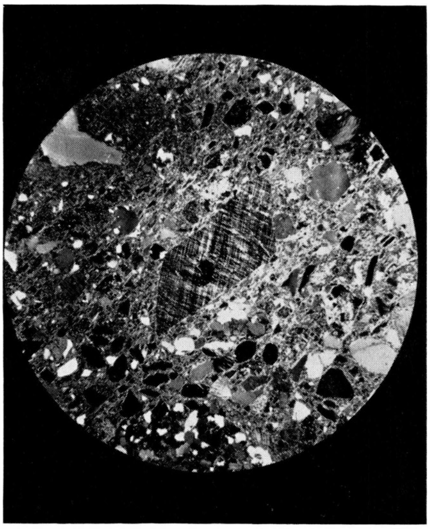


c



d

Plate IX.

Aerial view of Vestfjord Gletscher towards northeast, in the direction of Paul Stern Land and of Vestfjord (right). Gnejssø near the margin, on the right. A = pre-Groenlandian basement. Photograph 660 M-NØ 14011 by Geodætisk Institut, Eneret.

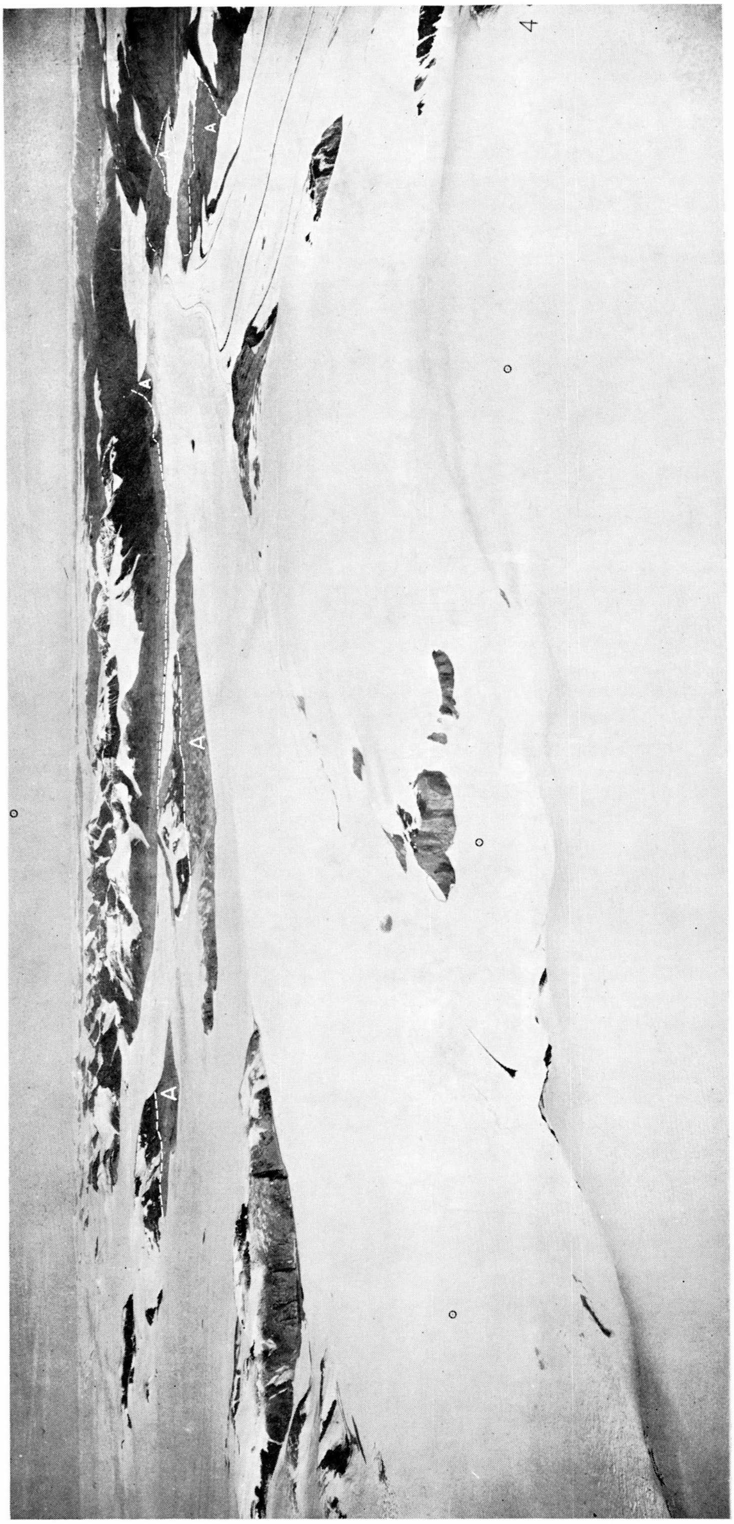


Plate X.

Folded gneisses and amphibolites of the Caledonian overthrust mass north of the Gnejssø cut obliquely to the fold axis. Vestfjord in the background. Photograph by W. Diehl. Photo-montage by Messrs. R. & W. Eidenbenz.

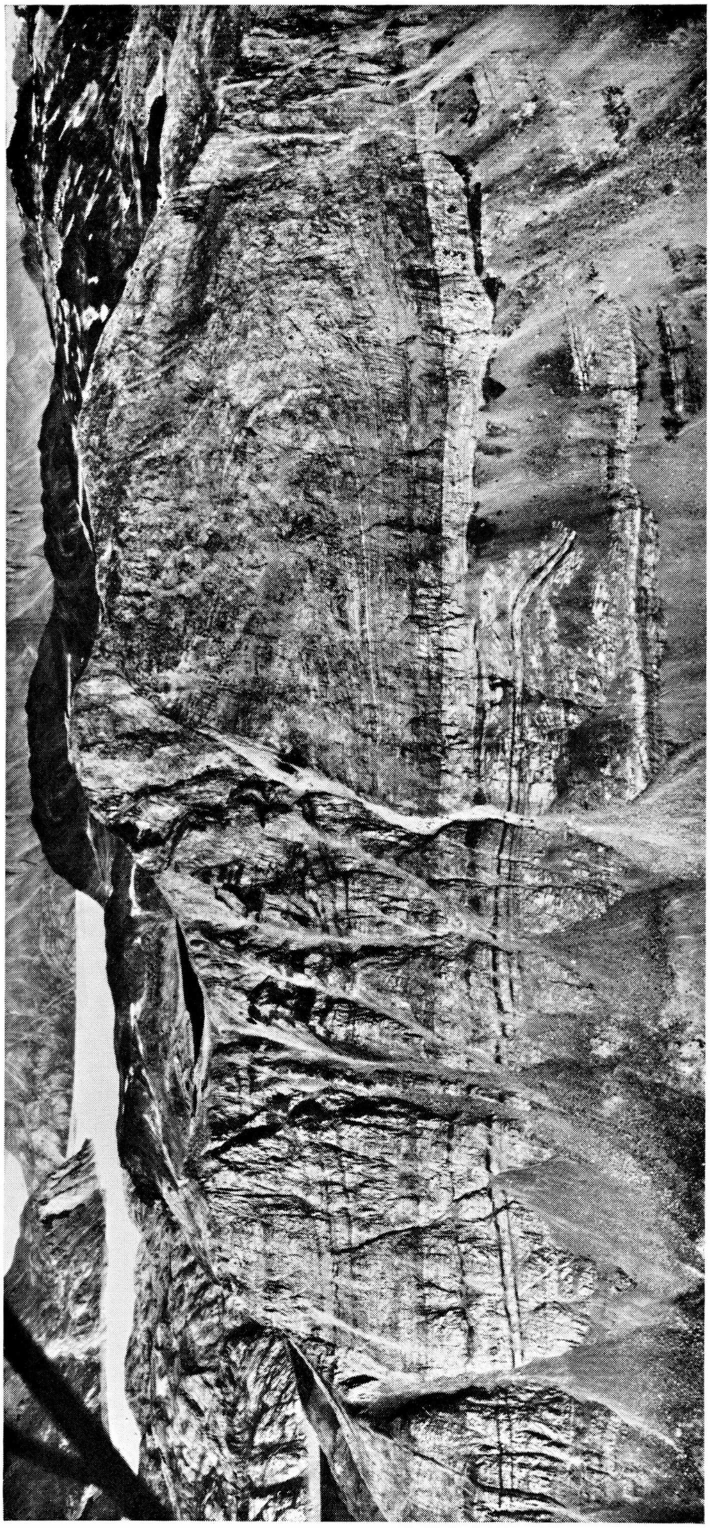


Plate XI.

Caledonian rocks, mainly kyanite-garnet-micaschists and amphibolites, northeast of Faxasø covered by Tertiary plateau basalts. Note the clear unconformity between the Caledonian and Tertiary rocks and the slight angular disconformity between the sheet-structure of the basalts and their basal erosion-plane. Photograph by W. Diehl.

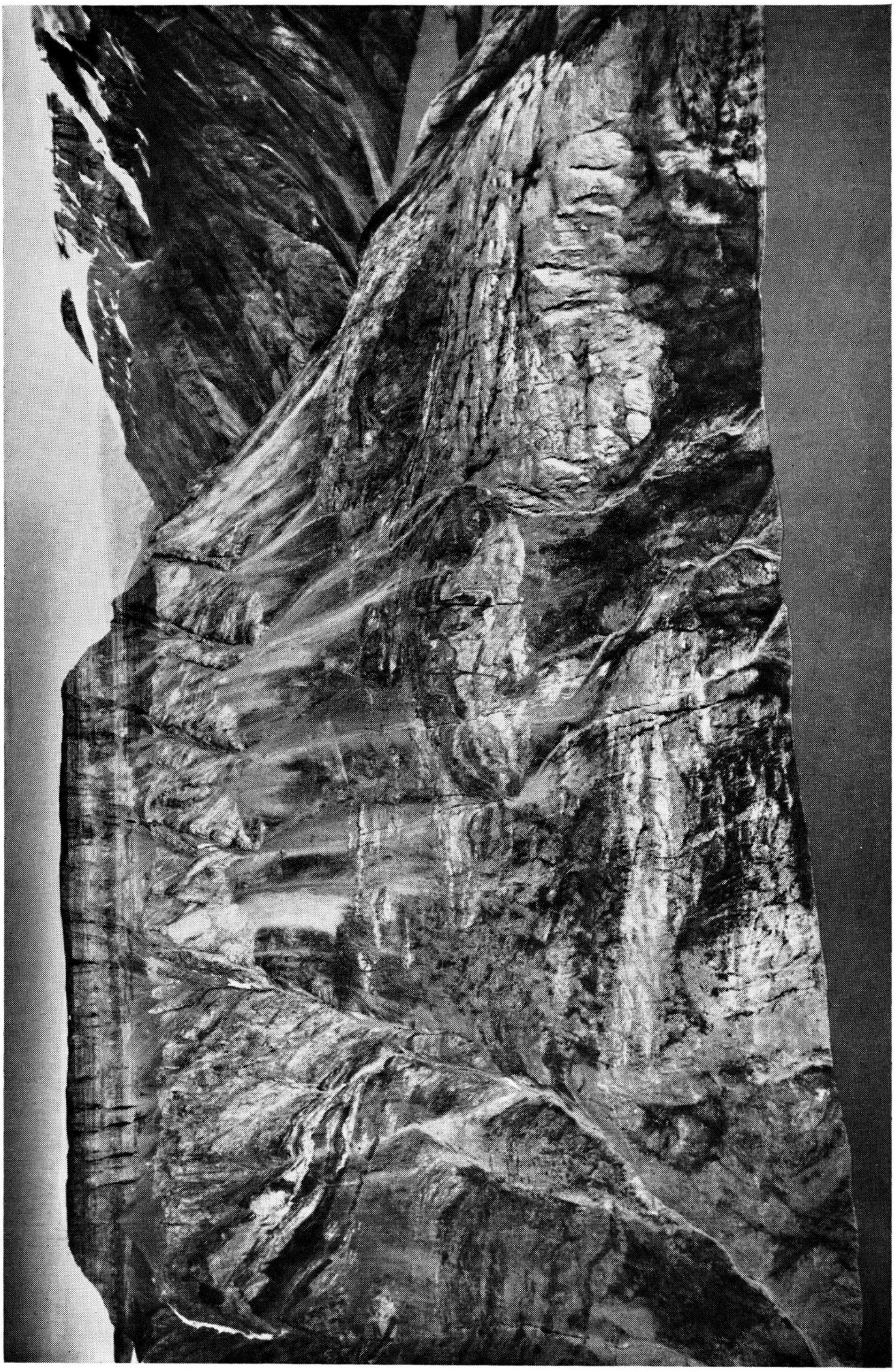


Plate XII.

Geological map of Gaase Land, western part, scale of 1:150.000, by E. Wenk, P. Stern, and J. Papageorgakis.

Topography according to preliminary map of the Geodætisk Institut, København, dated May 1959.

GEOLOGICAL MAP

OF THE WESTERN PART OF

GAASELAND

by
E. WENK P. STERN
and
J. PAPAGEORGAKIS

1:150 000

0 5 10 km

LEGEND

QUATERNARY deposits.

TERTIARY-UPPER CRETACEOUS

Plateau-basalts and dolerite dykes.

Sub-basaltic sediments.

Hydrothermal alteration-zones with ore-impregnation.

CALEDONIAN CRYSTALLINE COMPLEX

Leucocratic gneisses and migmatites.

Mica-schists ± garnet, cyanite and staurolite and mesocratic plagioclase-gneisses (metamorphic Groenlandian sediments).

Marbles

Amphibolites and related metamorphic basic rocks of magmatic origin (refers also to the similar rocks of the Pre-Groenlandian basement).

PARAUTOCHTHONOUS GROENLANDIAN

Phyllite-mica-schist series.

Marble-chlorite-schist series.

Basal psephitic series (tillites).

PRE-GROENLANDIAN BASEMENT

Microcline-granites and migmatites with discordant sheets of amphibolite.

Thrust-plane and faults.

Fold structure

HEIGHTS IN METERS
CONTOUR INTERVAL 500 METERS

Reproduceret ved Geodætisk Institut. København 1962

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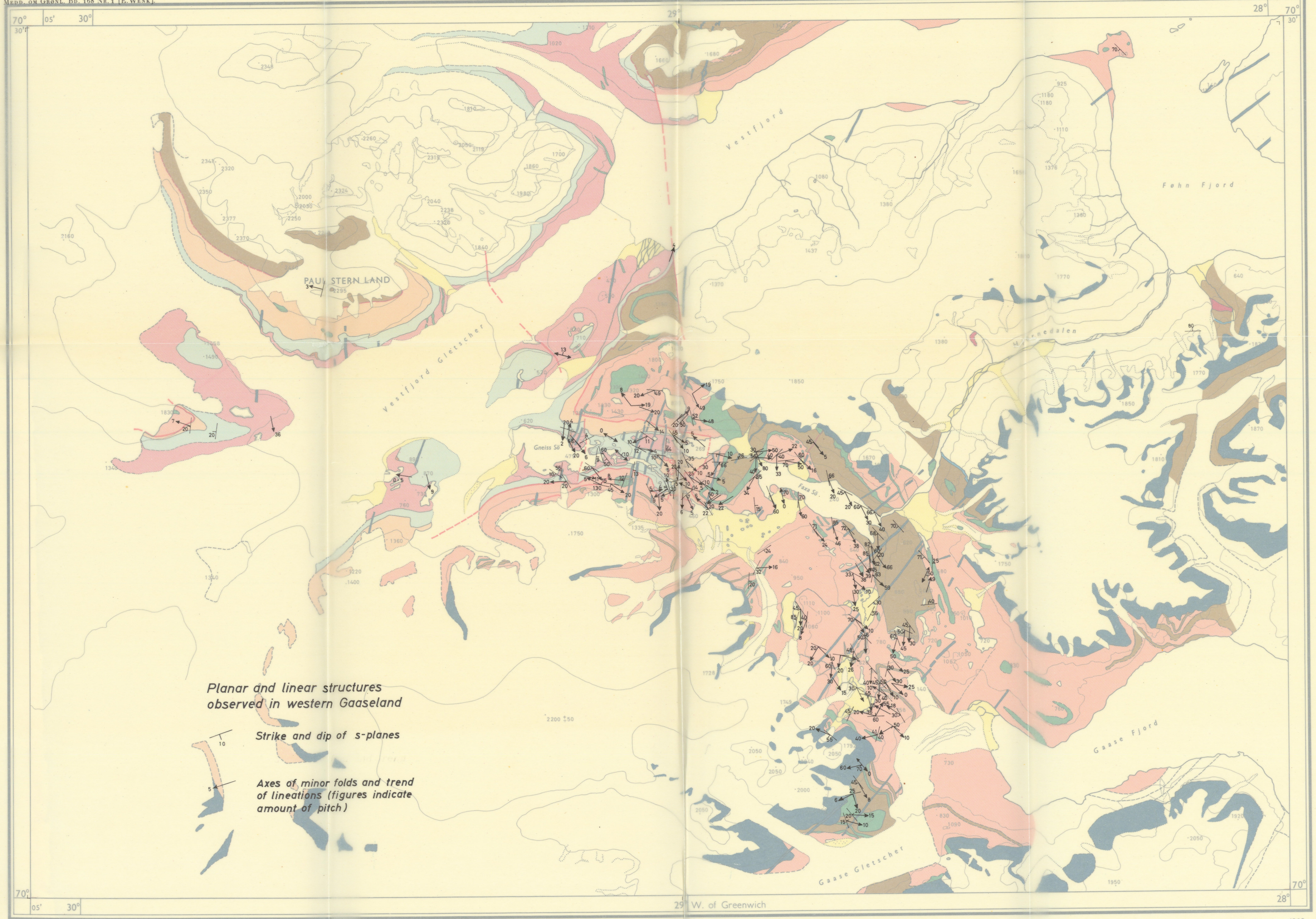
Medd. om Grønl. Bd. 168, Nr. 1. [E. Wenk].



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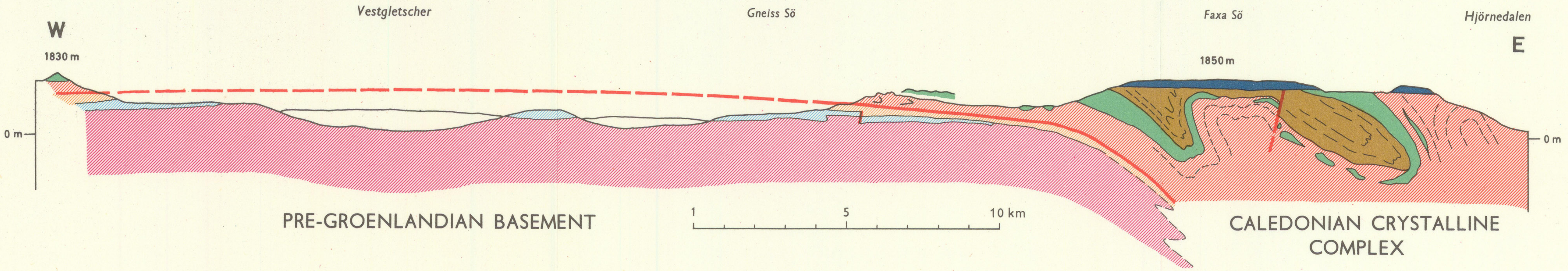
Reproduceret ved Geodætisk Institut. København 1962

Plate XIII.

Geological section across Gaase Land and Vestfjord Gletscher (for legend, see Plate 12).



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